Is the Share of Agricultural Maintenance Research Rising? Implications for Future Productivity Growth in U.S. Agriculture.

John Adam Sparger

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Agricultural and Applied Economics

George W. Norton, Chair
Jeffrey R. Alwang
Christopher F. Parmeter
Paul W. Heisey

March 2, 2009
Blacksburg, VA

Keywords: maintenance research, research depreciation, agricultural research, total factor productivity

Is the Share of Agricultural Maintenance Research Rising? Implications for Future Productivity Growth in U.S. Agriculture.

John Adam Sparger

ABSTRACT

Agricultural research is susceptible to research deterioration due to biological, climatic, and economic forces. Research deteriorates as the base conditions it addresses change which leaves the resulting information or technology less effective, efficient, productive, and/or relevant. Maintenance research targets deterioration in an attempt to prevent any loss of previous gains. Maintenance research is in contrast to productivity enhancing research which attempts to increase efficiency or productivity beyond previously attained thresholds.

In 1986, Adusei and Norton conducted a survey of agricultural scientists across the United States to measure the amount of commodity based agricultural research devoted to maintenance research (1990). They discovered roughly 35% of all agricultural research related to commodities was spent on maintenance research. A follow-up survey was conducted in 2008 to see if the proportion of maintenance research engaged in agricultural research had risen. In this survey, the amount of maintenance research in non-commodity based agricultural research was also measured. The percentage of agricultural commodity research engaged in maintenance research was found to have risen to roughly 41%. In contrast, the percentage of maintenance research in agricultural non-commodity research was found to be roughly 29%.

An empirical model was developed to explain maintenance research expenditures. Agricultural research funding, climatic conditions, land degradation, pest and pathogen control, and agricultural production were thought to influence maintenance research expenditures. From these five categories, seven representative variables were included in the model. The model found each category except land degradation to have a statistically significant impact on maintenance research expenditures.

Acknowledgements

My accomplishments and good fortune cannot be credited to any single source. Instead, they are the result of all the past and ongoing influences on my life which have shaped its direction, interests, and values. Similarly, this thesis is a culmination of each teacher's guidance and dedication to my education from the day I first set foot in Kindergarten. They kindled a passion for learning, an appreciation of the larger world around me, and, most importantly, why I should care about it.

Several people have been invaluable throughout the duration of this research to whom I would like to extend a heartfelt thanks. Foremost, I would like to thank my major advisor and committee chair Dr. George Norton. I feel my education and understanding of economics have benefited greatly through working with him directly. Dr. Norton may be the busiest person I know, yet he always gives time to his students. I am particularly grateful for his patience during which he has explained concepts and provided directions to me more than once. I am also grateful for his inexhaustible good humor throughout the project.

I am grateful to Dr. Paul Heisey at the Economic Research Service of the USDA. In addition to providing valuable insight and direction throughout this research, Dr. Heisey was a gracious mentor and sponsor during my time spent working at the Economic Research Service.

I would like to thank Drs. Jeffrey Alwang and Christopher Parmeter for serving on my committee and helping me get through the trickier aspects of the conceptual and empirical models.

I would like to thank Dr. Dan Taylor for being a great teacher, for his warm inclusion of the graduate students, and for bringing a sense of family to the world of academia.

A special thanks is due to Allen Moore and Carolyn Deckers at the Cooperative State Research, Education, and Extension Service of the USDA. They kindly agreed to help with this research project and were instrumental in collecting critical data from the Current Research Information System.

My gratitude goes out to my parents who have always encouraged me in my education and as a person. They have always been a great source of strength to me. I do not know where I would be without them.

Lastly, I want to thank my lovely wife Fatima for her support, her strength of character, and her love. She is my inspiration in all that I do.

I would also like to acknowledge the USDA and the Ralph G. Kline Fellowship at Virginia Tech for providing me with the opportunities and funding to perform this research while earning my degree.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1. Research and Agricultural Productivity

Public investments in agricultural research have historically been a decisive component of productivity growth in U.S. agriculture (Ball 2005). However, past achievements in agricultural productivity cannot be taken for granted. The deterioration of past agricultural research results may cause productivity and output to decline. Research deteriorates as the base conditions it addresses change, leaving the resulting information or technology less productive (Swallow et al. 1985). Deterioration of research is unique to fields concerned with subjects of a protean nature such as socio-economic or biological forces. Whereas socio-economic forces affect research deterioration in many sectors of the economy, biological forces are an additional burden to the agricultural scientist. Gains in agricultural research cannot be thought of with the same permanence as, for example, gains in the computer and chemical industries. Whereas knowledge acquired in the computer and chemical industries is not especially susceptible to deterioration, agricultural research is vulnerable to changes in its physical and biological environment. A computer engineer is fortunate that silicone is not constantly adapting a resistance to conductivity. Similarly, a chemical engineer is fortunate that oxidants do not develop immunity to the laws of thermodynamics.

However, the agricultural scientist is not so fortunate. A new disease resistant crop variety will only last a few years until the disease adapts. A new pesticide may only be effective against several generations of a pest until those pests with immunity breed the population back to its previous level. This is compounded by economically induced deterioration which affects agricultural research through changes in agricultural policy. Policy changes can cause existing economic research and/or agricultural techniques to no longer reflect current price relationships or economically efficient outcomes.

In addition to deterioration, research results depreciate for another reason – obsolescence (Swallow et al. 1985). Obsolescence is less of a concern than deterioration. American farmers gradually replaced horses and oxen with tractors to carry out the same work. It was not that horses or oxen simply refused to pull plows after doing so for the previous 4,500 years or that American soil in the 1940s became increasingly sticky. Rather, new technology was developed that rendered the still effective yet antiquated technology obsolete. Obsolescence is the depreciation of past research due to newer research which addresses the same base conditions but that is in some way more productive, economically efficient, and/or otherwise improved upon previous research.

The aim of agricultural research is to improve productivity for a variety of reasons including: to meet the increasing demand for food and energy from a growing population, to keep a country's agricultural sector competitive, and to find more efficient methods of utilizing resources. New productivity enhancing research is itself a cause of research depreciation through the by-product of obsolescence. Lack of obsolescence would indicate that no research is being conducted towards finding better methods and technologies. In this way, obsolescence can be viewed positively as the growth pangs of progress or as a part of Schumpeter's "creative destruction." Even if all productivity enhancing research were to cease, some agricultural research would still be needed to combat the effects of depreciation due to deterioration from biological and other factors. This research, known as maintenance research, is undertaken to replace existing research results that have deteriorated due to changes in the base conditions which result in a loss of productivity, economic efficiency, or other realized past gains (Swallow et al. 1985).

Since 1950, humanity has nearly tripled its presence on the planet which has required feeding an additional 4 billion people. Even as total agricultural inputs decreased during this period, U.S. agricultural output in 2004 was 2.66 times the amount it was in 1948 (Fuglie and Heisey 2007). The source of sustained agricultural productivity will increasingly have to rely on research as the amount of arable land has limited prospects for expansion, resources are becoming depleted or contaminated, the use of agricultural products to meet energy needs is growing, and the population continues to grow. By 2050, there will likely be an additional three billion more people (USDC 2008a) who will need to be fed.

1.2. Problem Statement

Rising agricultural research budgets and productivity over the past 20 years (Fuglie and Heisey 2007) imply that the total research dollars spent on maintenance research have risen relative to Adusei and Norton's previous estimate in 1986. Adusei and Norton (1990) found that roughly one third of all U.S. agricultural research could be classified as maintenance research although this differed by commodity and region. Ruttan (2002) fears the proportion of the total research budget spent on maintenance research has already risen to a level where agricultural research is experiencing diminishing returns. He notes, for example, falling yields from incremental fertilizer applications, declining labor input reductions from more powerful mechanical equipment, and physiological limits to increasing the efficiency of animal feed in producing animal products. His fear indicates productivity enhancing research is reaching the boundaries of the possible and is experiencing diminishing returns in its attempts. Were this true, funding would be directed away from productivity enhancing research, as this is a lost cause, and would, instead, go towards maintenance research. This would be evident through a relative rise in maintenance research to productivity enhancing research funding. However, a relative rise in maintenance research funding on its own does not necessarily indicate diminishing returns to agricultural research. It may simply be an indication of funding constraints.

As productivity grows, a growing proportion of research relative to the entire research budget must be devoted to maintenance research so that the productivity gains realized will not be lost to deterioration (Plucknett and Smith 1986). To illustrate why the relative proportion spent on maintenance research would rise over time, a hypothetical country with a fixed agricultural research budget over time is used. In the first year of research, all the funds would be directed towards productivity enhancing research as there would be no previous research that needs maintenance. But over time as productivity enhancing research has cumulatively pushed back the boundaries of the possible, a growing proportion of those fixed research funds would be needed to maintain the productivity enhancing research and keep those boundaries from receding. Given enough time, in theory, it could take the entire amount of the fixed agricultural research budget devoted towards maintaining past gains. This hypothetical country has not experienced diminishing returns to research, but, rather, it has exhausted its ability to increase productivity given the level of funding available to it. Therefore, in order to sustain productivity growth, the agricultural research budget must increase over time in order to provide adequate funding for both increasing productivity and maintaining past productivity increases.

A rising proportion of maintenance research could also mean that, for whatever reason, recent research has been less effective compared to research conducted 20 years ago. Less effective research would deteriorate faster than more effective research requiring maintenance research, comparatively, much sooner. Perhaps recent research is less effective due to exogenous factors such as increased susceptibility from climatic conditions and pests, or it is due to endogenous factors related to how the research is being conducted. For example, if research conducted prior to 1986 dealt with changing, say, four genes on average to develop pest resistance as opposed to more recent research which changed, say, two genes on average, then it is expected the latter research would require more maintenance research as pests can overcome two gene modifications easier than four (Plucknett and Smith 1986). One additional consideration about the proportion of agricultural research engaged in maintenance research is that there simply may be inadequate funding going towards productivity enhancing research as discussed in the preceding paragraph. In this case, the proportion of maintenance and productivity enhancing research expenditures are thought to be independent of the actual demand for them and based, instead, on some federal or state formula or the directives of private research donors.

On the other hand, the proportion of agricultural research that is maintenance research does not have to be higher than it was 20 years ago despite evidence suggesting otherwise. It could have stayed approximately the same over the past 20 years or even be less now. This would suggest either recent agricultural research is more effective than it was 20 years ago or maintenance research areas have simply been ignored by funding despite being needed.

If agricultural research truly is experiencing diminishing returns, this has dramatic consequences for society. For instance, if increasing agricultural productivity is becoming prohibitively expensive at the margin, then some combination of the following four scenarios will happen. The first scenario is that some scientific advancement on the horizon will somehow offset and/or delay diminishing returns to productivity. The second is that productivity growth will effectively cease and that output growth will rely on the growth of inputs such as new farmland, capital, labor, and intermediate inputs. The third is that a growing population will have to accept a different diet based on productivity and/or output growth constraints in order to feed itself. For example, the production of beef cattle might decrease as pastureland is converted to grain production for human consumption. The fourth scenario is that population growth responds to a fixed amount of the food supply.

The need for adequate maintenance research and the conditions driving this need are not unique to agriculture in the United States. It is applicable to any country engaged in agriculture. Alston and Pardey (1996) note that in the absence of continued applied research, agricultural productivity in a country does not stay constant but, rather, decreases. This does not seem to be widely understood by either scientists or policy makers. Many past methods of assessing the benefits and costs of agricultural research weighted the determining criteria inappropriately (Alson, Norton, and Pardey 1998). When considering the benefits and costs of agricultural research, the benefits should be measured against a "without" scenario that takes into consideration the effects of deterioration. Methods that do not account for this "without" scenario are likely to bias the rate of return to agricultural research with a large maintenance component downwards.

In spite of its importance, few studies have attempted to quantify the proportion of agricultural research devoted solely towards maintaining agricultural productivity against decline or to quantify how this proportion has changed over time. Furthermore, few studies have analyzed the underlying factors which affect the need for maintenance research expenditures. If science hopes to improve the accuracy of rates of return to agriculture, research depreciation must be better understood as it is one of three major factors affecting the temporal distribution of research benefits (Swallow et al. 1985).

1.3. Objectives

The objectives of this study are to:

1.) Determine the proportion of public agricultural research engaged in maintenance research in U.S. agriculture.

2.) Compare the current proportion of maintenance research to the proportion from 20 years ago.

3.) Determine and compare the proportion of maintenance research in non-commodity public agricultural research with that in commodity public agricultural research.

4.) Develop and apply a model to explain maintenance research expenditures.

5.) Develop testable hypotheses about the impact of maintenance research on agricultural productivity.

1.4. Conceptual Framework

Factors that necessitate maintenance research, in biological terms, are best conceptualized through making a distinction between the actual and the theoretical agricultural yield. Swallow et al. (1985) describe theoretical yield progress as being estimated using quantitative genetics principles based on parameters from the breeding trials. Actual yield progress, on the other hand, is measured with yield data from those experiments. Thus, a gap arises due to factors inhibiting the actual yield from approaching the theoretical yield.

Advances in molecular biology and genetic engineering can close this gap by removing some of the scientific and technical constraints limiting agricultural production (Ruttan 2002). For example, advances are currently being made in the areas of plant protection and animal health which have lessened the need for chemical pesticides in cotton varieties which have a genetically incorporated resistance to cotton bollworm (Ruttan 2002). The result is production yields closer to their genetically determined biological maximum. However, the biological maximum yield remains fixed at a point reached previously by researchers using Mendelian genetics (Ruttan 1999).

On one hand, research intended to increase theoretical yields is productivity enhancing research. On the other hand, whatsoever factors preclude the actual agricultural yield from equaling the theoretical production yield are addressed by maintenance research. In some instances, this may constitute an entirely new problem area such as mitigating production losses due to a newly introduced invasive species or adapting crops to climatic and/or environmental stressors such as prolonged drought. In other instances, such as pesticides that have lost their efficacy or that have been outlawed due to chemical restrictions, maintenance research replaces previous research within the same problem areas which has since deteriorated.

However, not all agricultural research is biological in nature and, accordingly, cannot be grouped into maintenance or productivity enhancing research using the above distinctions. Much of the non-biological agricultural research is related to economics. As prices, demand, production, and elasticities are in a constant state of change, research regarding them deteriorates over time and must be replaced through maintenance research. One could hardly expect farmers to base production decisions on relative prices, consumer demands, and governmental farm support practices from 5 years ago much less 50 years ago. Similarly, marketing and trade related agricultural research deteriorates over time and relies on maintenance research to stay current.

The factors affecting maintenance research fall under six broad categories which are: agricultural research funding, climatic conditions, land degradation, pest and pathogen control, agricultural production, and economics. Only the first five categories were used to develop a model that explains maintenance research expenditures. This is because changes in governmental policies, trade dynamics, and price ratios that affect economic conditions and incentives are thought to occur more at the national or international level and as a result would not vary significantly across individual states. Furthermore, collecting such data would prove to be prohibitive for the scope of this research study.

Two variables were chosen to be tested from the agricultural research funding category. The first variable is the overall agricultural research budget. Maintenance research is a subset of total agricultural research which makes it a function of the agricultural research budget under the following assumption. A state with an agricultural research budget larger than that of another state, *ceteris paribus*, spends the same amount on maintenance research but more on productivity enhancing research. This is because the amount needed for maintenance is fixed whereas the amount needed for productivity enhancing research is a function of political, economic, and social factors. Maintenance research can be thought of as a necessity good, as such, a state should not spend any more on maintenance research than is necessary. In contrast, productivity enhancing research is comparatively a luxury good which a state would want to fund as much as it could. By indexing the agricultural research budget to the value of agricultural sector production for each state, it is included as the first explanatory variable. It is indexed to eliminate scaling problems such that arise from differences between a Texas sized budget and a

Rhode Island sized budget. The hypothesis is that as the ratio of agricultural research increases relative to the value of agricultural sector production, the proportion of agricultural research that is maintenance research should decrease due to the amount of maintenance research needed being fixed.[1]

The second variable to be tested from agricultural research funding is the source of research funding. Individual states are the most likely to fund research that is responsive to the holistic wellbeing of agriculture because they have an incentive to serve the public. Contrarily, private agricultural industries are motivated by turning profits and will likely fund agricultural research to that end. A state is also more likely to be aware of and responsive to agricultural conditions unique to itself as opposed to the federal government. Due to these reasons, a state that receives a higher proportion of its funds from federal and private sources is more likely to have its hands tied in terms of maintenance research than a state that funds its own research, *ceteris paribus*. The variable to be tested is the ratio of federal and private research funding to state research funding.

Two variables were chosen from the climatic conditions category. The effects of climate change are ambiguous for agricultural conditions overall. A warmer climate could extend growing seasons in some areas, be responsible for a positive fertility effect for certain crops through higher greenhouse gas concentration, destroy coastal farmlands through flood, and/or result in changes to rainfall, sunlight, and temperature (Ruttan 2002). Yet, climate change appears to have unambiguous effects on maintenance research through temperature, the first variable to be tested. Warmer temperatures are likely to reduce the number of frosts and shorten

[1] The placement of total agricultural research as both the denominator of the dependent variable and the numerator of the independent variable leads to endogeneity between these variables within the structural form of the model. However, total agricultural research itself is exogenous to this structural form and is assumed not to cause significant bias.

cold seasons leading to a higher level of susceptibility to pests and pathogens. Their reduction could increase the rate of pest and pathogen adaptation to control measures as well as extend the geographical ranges of pest and pathogen habitats beyond their current areas. Consequently, *ceteris paribus*, states with higher temperatures spend more on maintenance research. This should already be evident through a cross section of states, for example states in the Mississippi delta versus states in the northeast, whereby states with warmer average temperatures spend more on maintenance research. In addition, as temperatures increase on average for all of the U.S., states should spend more on maintenance research over time due to rising global temperatures. Thus, temperature has both a cross sectional and time series effect on maintenance research expenditures.

The second variable to test climatic conditions is precipitation. Unlike temperature, there is no reason why differences in precipitation across states would be correlated with maintenance research expenditures. Instead, correlation between maintenance research expenditures and precipitation is thought to happen only over time as precipitation levels change within a state. If precipitation is taken as a constant for individual states, then they should have agricultural practices, crops, and livestock best suited for that level of precipitation. However, as global weather patterns change, some areas become drier that had traditionally been wet, some become wetter that had traditionally been dry, and some stay the same. States that are experiencing more dramatic changes in precipitation from an established norm, either becoming drier or wetter over time, are likely to spend higher amounts on maintenance research, *ceteris paribus*, to adapt moisture sensitive crops, livestock, irrigation practices, and/or farming techniques to either the wetter or drier environment. Conversely, a wet and a dry state that do not experience a change in their precipitation should not exhibit increases in maintenance research, *ceteris paribus*.

Soil erosion is the only variable under the land degradation category. Wiebe (2003) reviews many studies from around the world that find negative correlations between land degradation and agricultural productivity. He finds that productivity increases through technology, increased inputs, and other sources have historically masked the productivity losses related to land degradation. Land degradation is the result of forces which inhibit the land's ability to produce goods of value to humans. Some contributors to this are soil erosion, salinization, pollution, and nutrient depletion. The variable to be tested from this category is the ratio of acres of cropland with highly erodible soil to acres of cropland with non-highly erodible soil. The hypothesis is that states with a higher proportion of cropland in highly erodible soil, *ceteris paribus*, spend more on maintenance research in order to mitigate productivity losses associated with land degradation. Highly erodible soil is defined by the USDA's Natural Resources Conservation Service as having an Erodibility Index of at least 8 (USDA 2003). This index is based upon a soil's propensity to erode considering many factors such as physical and chemical properties of the soil as well as climatic factors. Higher index numbers indicate soils more likely to erode. Consequently, higher index numbers also indicate a greater investment needed to maintain soil resources if intensively cropped (USDA 2003).

Pesticide resistance is the only variable under pest and pathogen control. Ruttan (1999) estimates that pest and pathogen control will contribute most dramatically to the rising budget proportion spent on maintenance research. Whereas precipitation and soil degradation could play a major role in certain fragile areas, pest and pathogen control will affect all of agriculture. Technologies and chemicals that target specific pests and pathogens favor the emergence of resistant pests which, in turn, leads to the need for maintenance research – a vicious cycle. As pests adapt and gain increased resistance to pesticides, maintenance research is increased, *ceteris* *paribus*, in the attempt to develop more effective pesticides. Pesticide resistance is proxied in the model by indexing state agricultural expenses on pesticides per acre of farmland within that state. The hypothesis behind this approach is that if pesticide resistance is not occurring, then expenditures should remain constant per acre over time, excluding normal year to year deviations. However, when pesticides lose their efficacy, farmers respond by increasing the amount of pesticides used per acre. Thus, higher expenditures per acre over time are correlated with pesticide resistance. Pesticide resistance necessitates maintenance research to develop new pesticides or augment older ones that have lost their efficacy.

The ratio of livestock production to crop production within a state is the variable chosen to represent the agricultural production category. This is proxied by the value of livestock production to the value of crop production. Adusei and Norton (1990) found that maintenance research efforts differed among commodities with livestock being on the low end and barley and vegetables being on the high end. Based on their findings, the hypothesis is that states with a higher proportion of livestock and poultry production to crop production, *ceteris paribus*, will spend less on maintenance research. Ideally, there would be a test for each individual commodity and combination thereof. However, this would use up many degrees of freedom and present conceptual difficulties in modeling. This ratio admittedly does not capture differences arising between different livestock and crop commodities. For example, the production of broilers and dairy cattle should require different amounts of maintenance research as should the production of soybeans and potatoes. Furthermore, it does not capture differences within commodities such as crops genetically modified to resist pests and those varieties which are not.

1.5. Hypotheses

The null hypotheses to be tested concerning maintenance research are:

1.) The proportional amount of agricultural research engaged in maintenance research is unchanged from 20 years ago.

2.) The real dollar amount of agricultural research engaged in maintenance research is unchanged from 20 years ago.

3.) Maintenance research comprises equal proportions of the total commodity public agricultural research and total non-commodity public agricultural research.

4.) Maintenance research expenditures as a share of the overall agricultural research budget

    - decrease as a state's agricultural research budget indexed to the value of agricultural production increases,
    - increase with pesticide resistance,
    - increase with soil erosion, deviations in precipitation, and temperature,
    - decrease as a higher proportion of research funds originate privately or federally relative to at the state level,
    - decrease with higher proportions of animal to plant production within a state.

1.6. Thesis Structure

The remainder of this thesis is organized into three additional chapters. Chapter 2 begins with a literature review providing a context for the role of maintenance research in assessing rates of return to agricultural research. The model to explain maintenance research expenditures is developed and the data is described. Additionally, the survey used to determine the proportion of agricultural research engaged in maintenance research is presented. Chapter 3 provides the results of the survey and of the empirical model testing the determinants of maintenance research expenditures. Chapter 4 contains a summary of the study, testable hypotheses about the influence of maintenance research on agricultural productivity for use in further research, and conclusions.

Chapter 2: Scientist Survey and Developing the Applied Model

2.1. Literature Review

Between 1948 and 2006, U.S. agricultural output grew 1.59 percent per year (Ball 2009). Ball (2009) reports that a contraction of labor and capital inputs contributed -0.54 and -0.06 annual average percentage point per year, respectively, to output growth. In contrast, material inputs contributed a modest 0.69 annual average percentage point per year to output growth. The remaining 1.5 annual average percentage point per year of agricultural output growth is attributed to total factor productivity (TFP). Several studies have examined the causes of growth in the agricultural sector (Kendrick and Grossman 1980; Ball 1985; Jorgenson, Gollop, and Fraumeni 1987; Jorgenson and Gollop 1992; Ball et al. 1997). They unanimously have found that growth in TFP has been the singular driving force of growth for U.S. agriculture following World War II. Between 1960 and 2004, growth in TFP explained a dramatic 117 percent of the growth in agricultural output (Fuglie, MacDonald, and Ball 2007). This is in contrast to the U.S. industrial sector in which TFP growth only accounted for 13 percent of all industrial output growth during this same time period (Fuglie, MacDonald, and Ball 2007).

Individual economists' study of the agricultural productivity phenomenon began with Barton and Cooper (1948) who developed the first set of national annual estimates for total factor productivity (TFP) in U.S. agriculture. Total factor productivity is a ratio of total output to total inputs. On the surface, these national statistics seemed to indicate U.S. agriculture was enjoying a "free lunch" – inputs were falling and output was rising. Griliches (1961, p. 446) incisively remarked that what researchers' were calling productivity was the discrepancy between their "total input" index and their output index. Productivity, according to Griliches (1961, p. 446), "is a measure of our ignorance, of the unknown, and of the magnitude of the task that is still ahead of us." Economists began looking into the nature of this "free lunch" with the studies of Schultz (1953), Loomis and Barton (1961), Kendrick (1961), Denison (1962), and the seminal work done by Griliches (1963a, b, 1964). They show that it is not just the quantities of inputs used that count; it is also their quality. This fact is illustrated by farmers' input purchases during the last century. At the beginning of the twentieth century, farmers were purchasing only 14 percent of their inputs from off-farm, but at the end of the century, they were purchasing over 45 percent of their inputs from off-farm (Huffman and Evenson 2006).

Investment in productivity-increasing activities through public and private research has yielded high returns in terms of input quality. Thanks to advances made through research and development, the farmers of today have at their disposal an arsenal of sophisticated technologies that would have been unimaginable to farmers just 100 years ago. Genetically modified seeds produce higher yields and resist pests. Pesticides, herbicides, and fungicides combat hosts of other potential pests. Technological miracles on wheels dominate where horses once trod, and animals, themselves, are being selectively bred for increased yields in terms of meat and milk production. These are but a few illustrations of how research and development projects have changed the face of agriculture in the last century.

In addition to public and private research, previous econometric studies have identified extension, farmers' education, and infrastructure as primary sources of productivity growth. Agricultural extension interprets scientific and market information and transmits key information to farmers. It distributes relevant information about management, production, and technical practices to farmers while informing researchers of farmers' issues. Extension can aid the speed of new technology adoption (Huffman 2000) and has an almost immediate effect on productivity.

Alston, Norton, and Pardey (1998) explain that current knowledge is a capital stock created by past investment. This knowledge pool is susceptible to depreciation but can be maintained and increased through continued research. Knowledge, on its own, has limited value in affecting output. However, knowledge utilized is a service flow that is an input into agricultural production. Therefore, the returns to knowledge are highest when its adoption is greatest, and adoption comes through education. Educated farmers have more direct exposure to the knowledge pool and, similarly, will develop the skill set to utilize new knowledge as it becomes available. Thus, education increases a farmer's productivity through exposure and access to the knowledge capital stock making the average farmer of today more educated and more productive than his counterpart from 100 years ago.

Modern, adequate communications and transportation are necessary for the development and support of the U.S. economy, and the agricultural sector is no different. Such investments in infrastructure lower costs, aid in production and distribution, and in numerous other ways allow farmers to be more productive. Previous work by Antle (1983) found communications and transportation infrastructure to contribute positively to agricultural productivity for a cross-section of 66 countries. Gopinath and Roe (1997) also found a positive correlation between infrastructure and agricultural productivity for the aggregate U.S. Yee et al. (2002) were the first to measure infrastructure's impact on agricultural productivity at the state level. Their infrastructure variable only included data on highways, but, expectedly, infrastructure still had a positive impact on state level agricultural productivity.

Although the weather is not a source of productivity growth, per se, it can affect productivity through year to year fluctuations in humidity, temperature, and precipitation. Therefore, yearly fluctuations in productivity due to weather have often been controlled for through econometric modeling using some form of a weather index – Stallings (1958), Oury (1965), Doll (1967), or Thornthwaite (1948). A review of the literature revealed no standard practice among economists as to which weather index to employ, although, many articles tend to favor the indices popularized by Oury (Zhang and Carter 1997; Barnes 2002). Nonetheless, the consensus is that an index is preferred over original temperature and precipitation data due to saving degrees of freedom through fewer variables and mitigating high multicollinearity (Barnes 2002). Other approaches in controlling for weather have used the Palmer Drought Index (Ball, Butault, and Nehring 2002) and dummy variables based on the United States Department of Agriculture's (USDA) precipitation data to indicate years of less than normal and above normal rainfall (Yee et al. 2002).

With many identifiable sources of productivity, estimating and isolating research's impact on productivity is an important yet tricky procedure. Economists have used three categories of methods to estimate the impact of research on productivity. The following definitions of the three estimation methods are summarized from Huffman and Evenson (2006) below.

The first are the imputation-accounting methods. These methods attribute productivity to such sources as research and development projects based on experimental evidence and professional opinion. The benefits from adoption of a new technology are the additional producer and consumer surplus. Griliches' (1958) influential study on hybrid corn is an example of this method. However, in many instances, the interaction of effects when more than one technology is adopted, the slow accrual of benefits over time not captured directly in consumer or producer surplus, and the arbitrariness of this method make statistical approaches preferred.

The second are the statistical meta-function methods. These methods include variables such as research and development, extension, and education directly into a production or profit function. Thus a conventional function becomes a meta-function. The impact of research on output is then estimated directly through statistical means. A major advantage of the meta-function methods is that profit-maximizing conditions are not required to establish the relationship between growth in output to growth in inputs.

The third are the statistical productivity decomposition methods. These methods estimate TFP without input or output variables; instead, they use variables not included in a conventional production function. TFP is statistically decomposed into its component sources such as research, extension, and education to determine their impacts on productivity. This method is preferred over meta-functions in that functional forms of production functions do not need to be specified, and, furthermore, this method allows production coefficients to vary by observation allowing different states to have different production technologies.

The comprehensive meta-analysis compiled by Alston et al. (2000a, b) obviates the need for improvement in estimating the rate of return to research. They analyze 294 studies that provide 1,886 different annual rates of return to agricultural research and development which range from slightly negative to an extreme outlier of 724,323%. Dropping the lowest 5% and highest 5% of the estimates narrows the range of rate of return from 8.2 to 430%. Only 21% of the analyzed estimates actually fall within the range of the prevailing conventional wisdom which espouses the rate of return to be between 40 and 60% annually. They report that many of these estimates are positively skewed with extremely high returns, and variation of estimates from within similar groups, such as basic versus applied research, is so large that determining a meaningful estimate is difficult. They find on average the annual rate of return to agricultural research to be 81.3%.

One important consideration is the fact that there is no single rate of return for agricultural research (Alston and Pardey 2001). Interpreting national aggregated estimates of the rate of return as if they are representative of any agricultural research undertaking is misleading. These aggregated estimates include many failures and successes across different regions for different sectors of agriculture. Individual research projects have their own true rates of return with some being very high and others being zero, but no single rate of return exists. Attempting to find this one true rate is fruitless. Similarly, attempting to find the true rate of return for every single research project would be a monumental undertaking. Therefore, researchers must be content with some level of aggregation such as basic and applied research, field crop and livestock research, and state level research.

Economists have identified several areas in which to improve efforts of estimating the returns to agricultural research. Alston and Pardey's (2001) assessment of rates of return for agricultural research is that they are generally biased upwards. Their reasoning is that the costs of doing research are usually underestimated and the benefits are usually overestimated. Cost underestimation occurs from both omission of overhead costs and from omission of certain underlying research activities such as development and extension which culminate in a specific research outcome. Benefits are overestimated by inadequate consideration of the effects of research spillovers into a state or region, the spill-ins. Spillovers occur between private and public research, among states, across country boundaries, and among agricultural sectors such as between different field crops or different livestock commodities. However, spillover effects can also lead to an underestimation of benefits if the spill-outs from a state or region are not considered when measured only from that specific state's or region's point of view.

A small but emerging trend is to account for the non-market externalities of both agricultural research and production on the environment and to society (Byerlee and Murgai 2001; Ball et al. 2001). These have not historically been taken into account and can have both positive and negative externality effects. For example, traditional measures of productivity growth that do not consider if a certain component of growth is due to faster usage of an exhaustible resource will tend to overestimate productivity growth or attribute this wrongly to the effects of research. Furthermore, research leading to a technology that increases agricultural output but that adversely affects air or water quality or that increases soil degradation will have a higher rate of return under conventional estimates. In contrast, the benefits from the role of farmland in preserving open spaces from more environmentally and socially degrading forms of development may also be underestimated using traditional measures.

One other important component of estimating the rate of return to agricultural research involves the lag representing the adoption and disadoption process of technology resulting from research. Estimated rates of return are sensitive to assumptions made about the lag length and shape. Arbitrarily changing a research lag's length by only a few years can result in widely different rates of return. Estimating the shape and length of a lag is the most difficult empirical aspect regarding research evaluation according to Alston and Pardey (2001). They suggest that past studies have arbitrarily chosen lags that are too short due to ease of use as longer lags place a heavy burden upon the data. They suggest, instead, that a flexible, infinite lag which allows for some obsolescence would be the best candidate as some research effects may persist indefinitely.

Indeed, Chavas and Cox (1992) use a nonparametric approach and find that at least a 30 year lag is necessary to capture the effects from public research.

Justifying government support of agricultural research was easier in the past when agriculture comprised a much larger proportion of the U.S. economy. However, as the economy has become increasingly diverse, agriculture has become relatively less important in the minds of policy makers who perceive such subjects as energy, bio-terrorism, and defense to be more important candidates for research dollars. Still, agriculture is largely food, without which nothing else can take precedence. Ensuring adequate supplies of food in the future requires present action to stay ahead of the changing nature of the planet. This makes economists' burden of providing accurate and credible rates of return to agricultural research more important than ever. These estimated rates of return are used to justify past agricultural research investments and to justify current appropriations of government tax dollars to affect productivity in the future. But as the comprehensive meta-analysis by Alston et al. (2000a, b) shows, all that any policy maker need do is choose one of the 1,886 estimated rates of return to agricultural research that supports his argument either for or against funding public agricultural research.

Finally, the last area of improvement in estimating research's impact on productivity, and the focus of this study, involves estimating the importance of maintenance research. In contrast to the areas mentioned above which attempt to correct for overestimation, failure to make the distinction between productivity enhancing and maintenance research can lead to an understatement of research benefits (Alston and Pardey 2001). Blakeslee (1987) equates the relationship between research and productivity to the Red Queen's admonition to Alice in Lewis Carroll's Through the Looking Glass. The Red Queen proclaims to Alice that just to stay in place, a person must run as fast as he can; to move forward, a person must run even faster.

Similarly, just to keep agricultural productivity at its current level, maintenance research is required; to increase productivity further, productivity enhancing research is required.

Research benefits cannot be measured purely in terms of output gains, but also in terms of losses avoided. Failure to account for losses avoided through maintenance research will bias the rate of return to agricultural research downwards (Plucknett and Smith 1986; Aduesei and Norton 1990; Townsend and Thirtle 2001; Marasas, Smale, and Singh 2003). For example, Townsend and Thirtle (2001) analyzed research funding for livestock in South Africa by separating research into productivity enhancing research and maintenance research, which addressed animal health. They found that the rate of return to livestock research investments were undervalued at a minimum of 50% by not accounting for the benefits from avoiding disease related livestock deaths.

Blakeslee (1987) says one reason legislators and other non-agricultural interests may have for cutting public support for agricultural research is based on the perception that doing so would merely slow or reduce agricultural productivity growth. In reality, productivity may decline without continued research. With the private sector funding an increasing amount of agricultural research, it becomes easier for legislators to justify reducing the amount of public expenditures on agricultural research. However, this scenario will leave maintenance research underfunded. By using conventional measures for the returns to agricultural research, the private sector will fund research projects perceived to have the highest rate of return which would not be projects classified as maintenance research. For example, a study by White and Araji (1990) measured the returns to investments in agricultural research as part of an explanation of how state agricultural experiment stations' decide to allocate resources. Their model did not take into account a "without" research scenario where productivity losses are avoided by maintenance research. Instead, returns to research were measured from a constant level of productivity, and benefits were based on productivity increases past this constant level. In turn, they found maintenance research to yield the lowest return on investment in which the marginal product of a dollar invested returned $8.49 in benefits compared to $33.60 in benefits for basic research and $53.80 in benefits for applied research. In contrast, a study by Araji (1990) did account for a "without" scenario in which productivity declined annually by 3% to 5% after 5 years of no maintenance research. Based on this estimate, the internal rate of return to investments in maintenance research was 57.6% compared to 16.4% for basic research and 26.3% to applied research.

Townsend and Thirtle (2001) question the conventional assumption in which rate of return estimates for research and development only explain positive growth. They argue that this is an indefensible assumption due to a lack of data to estimate the counterfactual case: one in which productivity actually declines because no research has taken place. A study by Araji, Sim, and Gardner (1978) estimates that the elimination of maintenance research could result in as much as a 25% reduction in productivity in as little as five years and anywhere from 15% to 40% over fifteen years depending on the commodity.

Morris and Heisey (2003) evaluated the returns to plant breeding research and suggest any methodology that does not account for the "without" research scenarios is flawed. For example, studies that measure the impact of plant breeding research on plant performance sometimes assume performance will remain constant if research is not undertaken. In reality, they must take account of the counterfactual scenario whereby plant performance deteriorates. Marasas, Smale, and Singh (2003) did take into account the "without" scenario and found that the International Maize and Wheat Improvement Center's maintenance research program to develop leaf rust resistant wheat yielded a 41% rate of return on maintenance research expenditures.

Very few economic estimates of maintenance research have been conducted. An early study by Evenson (1968) estimated that 30% to 50% of agricultural research expenditures on crops, poultry, and livestock were devoted to maintenance research in 1967. Araji, Sim, and Gardner (1978) estimated between 10% and 35% of a research scientist's time, depending on the commodity, was spent on maintenance research in the western region of the U.S. Blakeslee (1987) estimated that 70% to 80% of each year's research and extension expenditures after 1973 were needed just to maintain the prior year's productivity. He hypothesized that increased research funding needed to occur for each subsequent year to account for the prior year's productivity gains. Accounting for this, he concluded as much as 90 percent of research and extension expenditures could be needed just to maintain productivity from the previous year. Araji (1990) found that 40.3% of Idaho agricultural experiment stations' resources were used just to maintain the level of production achieved from past research. Adusei and Norton's (1990) estimate is generally more accepted. They conducted a national survey of agricultural scientists and based their estimates upon these scientists' own estimates. Overall, they found that 34.8% of agricultural research was devoted to maintenance research. The specific estimate for livestock was 21.4% compared to crops, fruits, and vegetables which ranged from peanuts on the low end at 27.6% up to barley at 42.2%.

2.2. Methods

Fulfilling the first four objectives is a two step process. In the first step, a survey nearly identical to the one used by Adusei and Norton (1990) is sent to agricultural scientists across the United

States (appendices A and B). The results of this survey are used to fulfill the first three objectives: to determine the proportion of agricultural research engaged in maintenance research, compare this proportion to that from 20 years ago, and compare the proportion between commodities and non-commodities. The second step involves analyzing data within the USDA's Current Research Information System (CRIS) based upon the survey results. CRIS data are used to fulfill the fourth objective of developing and applying a model to explain maintenance research expenditures.

An email containing a link to an online survey was electronically mailed to approximately 4,000 agricultural scientists across the United States in March of 2008. The USDA provided a list of agricultural scientists and their e-mail addresses. However, this list was not up to date and contained over 9,000 names, many of which were duplicates. This list was later revised to approximately 4,000 correct and unique entries.

The email contained a letter providing definitions and examples of maintenance research similar to Adusei and Norton's original letter (appendices A and B). Measurement errors arising from scientist interpretation of different survey formats, definitions, and examples were kept to a minimum by ensuring the content of the letters, survey questions, and maintenance examples were as identical as relevantly possible. However, only one of the original maintenance research examples was used while three more recent ones were added for scientists not familiar with the original examples and also to provide a broader spectrum of maintenance research that included non-commodity examples as well. The survey questions are the same as Adusei and Norton's questionnaire which ask about research objectives, research subject areas, estimates of the proportion of a scientist's own research devoted to maintenance research, and observed examples of research depreciation. These responses were used to evaluate the scientists' understanding of maintenance research, determine the commodity and/or non-commodity focus of their research, determine their research discipline, and provide examples of maintenance research. Commodity research areas are grouped as vegetables, livestock, fruits, cotton, wheat, corn, barley, potatoes and so forth pursuant to the classifications used in Adusei and Norton's research. Additionally, there are categories for new commodity areas such as: oil crops; sugar crops; treenuts; and aquatic animals and for non-commodity areas such as: soil, air, and water; other natural resources; and human resources, organizations, and institutions. The complete list of commodity and non-commodity categories is contained in table 2.

The percentage of total research that is maintenance research is estimated as the mean of individual scientist responses within each commodity or non-commodity category (table 2). t-tests were conducted to determine whether means between categories are significantly different at the 5% level (appendix C). The means in each category were compared to their counterpart from Adusei and Norton's research to see how maintenance research expenditures have changed in the past 20 years (table 3). Categories were grouped together as being either commodity or non-commodity and contrasted. Significant differences in means between commodities and non-commodities, as a group, were tested with a t-test (appendix C).

The second step involved using CRIS data as classified by the Manual of Classification for Agricultural and Forestry Research, Education, and Extension administered by the Cooperative State Research, Education, and Extension Service (CSREES). CSREES is the USDA agency which maintains the CRIS database. CSREES categorizes research projects by knowledge areas (KA) such as "plant management systems," (KA205), or "animal diseases," (KA311). Based on scientist responses to the nature of their research discipline, certain knowledge areas were picked from the CRIS database that could essentially be classified as maintenance research (appendix D). One example is animal diseases which, by the nature of the research involved, deals almost exclusively with maintenance research by updating old vaccines and medicines to remain effective or combating new disease threats to current productivity.

All CRIS knowledge areas were divided among four categories: plants, animals, natural resources, or other. CSREES already makes a distinction for the plant, animal, and natural resource categories. All the remaining categories such as markets, policies, education, safety, and economic issues were arbitrarily grouped under the category of other. The expenditures of the maintenance research knowledge areas within each of the four categories were compared against the total expenditures of all the knowledge areas within that category. Through this derivation, the percentage of maintenance research within each category was derived from the CRIS data. These figures were then compared to those obtained using the survey data in order to verify that the knowledge areas chosen as maintenance research in CRIS did not lead to outcomes grossly incompatible with the survey results.

Using the knowledge areas selected as maintenance research, total maintenance research expenditures were obtained for each of the 48 continental states from 1976 through 2006. The classifications changed three times during this time period: Research Problem Areas (RPAs) from the Manual V classifications were used from 1976 through 1997, RPAs from the Manual VI classifications were used from 1998 through 2004, and Knowledge Areas from the Manual VI classifications were used for 2005 and 2006. However, care was made so that KAs and RPAs matched among all time periods. In all but a few cases, this meant CSREES renumbered RPAs or renamed RPAs to KAs so that recategorization was a straightforward process.

Accordingly, the dependent variable was derived for 48 states over 31 years from the CRIS data. To use these figures in developing an explanatory model, maintenance research expenditures were divided by total agricultural research expenditures to give proportions of agricultural research that are maintenance research for each state. In this way, the model would be testing the determinants of the proportion of agricultural research engaged in maintenance research versus actual dollars of maintenance research. This eliminates scaling problems arising from absolute dollar differences between states like Texas, with a large agricultural research budget, and Rhode Island, with a small agricultural budget.

2.3. Data Descprition

Overall agricultural research budget data were obtained simultaneously with the maintenance research expenditures from the CRIS database. The value of agricultural production for each state is available through the Economic Research Service website of the USDA, Farm Income: Data Files (USDA 2008a).

The source of research funding is available through the CRIS database. CRIS reports the source of research funding for each research project by its dollar amount. This variable was constructed as the ratio between the amount of research dollars attributed to USDA, CSRS, other federal, industrial, and other to the amount of research dollars attributed to state and the sale of products from state universities for years prior to 1993. For the years 1993 on, this variable was constructed as the ratio between research dollars attributed to USDA, CSREES, other USDA, other federal, and other non-federal to the amount of research dollars attributed to state.

State area averaged annual temperatures in degrees Fahrenheit and state area averaged annual precipitation data are available through the Department of Commerce's National Oceanic and Atmospheric Administration website (USDC 2008b). Annual precipitation data were collected for the years 1935 through 2006 to establish a long run 72 year norm. The average annual precipitation in inches for each state was calculated for this time period. The absolute values of the yearly deviations from the 72 year norm were recorded for each year from 1976 through 2006. These were used in the model to check for correlation between maintenance research expenditures and relatively recent changes in precipitation levels during the past 31 years from the 72 year norm.

Acres of state cropland classified according to the Erodibility Index are available through the USDA's Natural Resources Conservation Service website, National Resources Inventory data (USDA 2008b). The National Resources Inventory began in 1982 and was conducted in five year intervals thereafter. There are no data included in the model for years prior to 1982. Likewise, data for years not corresponding to a survey year are included in the model as the data from the preceding survey year.

Pesticide expenses were adjusted for inflation using the USDA's agricultural chemical price index where 1910-1914 are the base years (USDA 2007). Pesticide expenses, farmland data, livestock production values, and crop production values are available through the Economic Research Service website of the USDA, Farm Income: Data Files (USDA 2008a).

Table 1: Summary Statistics: Observations for the 48 Contiguous States from 1976 to 2006

	Variation	Obs.	Mean	Std. Dev.	Mininum	Maximum
Dependent Variable						
Maintenance Research Expenditures / Total Research Expenditures	Total	1488	0.3677	0.0980	0.0537	0.8978
	Between	48		0.0643	0.2522	0.5976
	Within	31		0.0745	0.1062	0.8006
Independent Variables						
Total Research Expenditures / Value of Agricultural Production	Total	1488	0.0162	0.0141	0.0017	0.1462
	Between	48		0.0106	0.0037	0.0507
	Within	31		0.0095	-0.0195	0.1262
Federal and Private Expenditures / State Expenditures	Total	1488	1.6827	2.6092	0.2610	54.2869
	Between	48		1.3219	0.6899	7.9319
	Within	31		2.2574	-5.8869	52.2103
State Area Averaged Annual Temperature	Total	1488	52.2070	7.6732	36.5179	72.5948
	Between	48		7.6511	40.8520	70.7320
	Within	31		1.2329	47.8729	56.3193
Abs(Deviations from Precipitation Norm)*	Total	1488	4.1627	3.5621	0.0093	22.5341
	Between	48		1.3897	1.6154	6.8609
	Within	31		3.2857	-2.3180	20.2181
Acres of Highly Erodible Cropland / Acres of Non-highly Erodible Cropland	Total	1200	0.7850	1.4287	0	8.9842
	Between	48		1.4251	0.0401	8.4076
	Within	25		0.2261	-0.1391	4.1023
Pesticide Expenditures / Acres of Cropland	Total	1488	1.3901	1.0942	0.0208	5.9051
	Between	48		1.0061	0.0403	3.5999
	Within	31		0.4533	-0.8581	3.6953
Value of Livestock Production / Value of Crop Production	Total	1488	1.6295	1.5544	0.1619	16.6911
	Between	48		1.3997	0.2749	8.3391
	Within	31		0.7045	-2.4864	9.9814

* Abs( ) indicates the Absolute Value, Norm is established between 1935 and 2006

2.4. Developing the Empirical Model of Maintenance Research Expenditures

The relationship of the dependent variable to the seven explanatory variables is hypothesized to take a linear form,

$$\left(\frac{MaintR}{TotalR}\right)_{it} = \beta_{0i} + \beta_1\left(\frac{TotalR}{AgP}\right)_{it} + \beta_2\left(\frac{Fed + Other}{State}\right)_{it} + \beta_3\left(\frac{Fed + Other}{State}\right)^2_{it} + \beta_4 Temperature +$$

$$\beta_5 Precipitation_{it} + \beta_6 Erosion_{it} + \beta_7 PesticideResistance_{it} + \beta_8\left(\frac{Livestock}{Crop}\right)_{it} + \mu_i + \lambda_t + \upsilon_{it} \qquad (1)$$

which is estimated in a panel regression model. Each *i* observation is for the 48 continental states, and each *t* observation is for the years 1976 through 2006. *MaintR* is the dollar amount of agricultural maintenance research; *TotalR* is the dollar amount of total agricultural research. *AgP* is the dollar value from production in the agricultural sector. *Fed* is the dollar amount of research contributed by the federal government; *Other* is the dollar amount of research contributed by private industry and other nonfederal sources; and *State* is the dollar amount of research contributed by the state government. *Temperature* is the state area averaged annual mean temperature in degrees Fahrenheit. *Precipitation* is the absolute value of year *y*'s deviation from the 1935 through 2006 state area averaged mean precipitation in inches. *Erosion* is the ratio of highly erodible acres of cropland to non-highly erodible acres of cropland. *PesticideResistance* is the inflation adjusted expenditure of pesticides per acre of farmland. *Livestock* is the value of livestock production; *Crop* is the value of crop production. μ is a state specific term, λ is a time specific term, and υ is the normal random error term.

A quadratic term for the ratio of outside funding to state funding is included in the model to test for nonlinear effects. The hypothesized reasoning is that, in general, outside funding should diminish the proportion of a state's budget spent on maintenance research due to the profit driven motives of private corporations or objective driven motives of grant funded federal research which reduce a state's ability to conduct maintenance research. However, there could be private or federal objectives that target research which is maintenance research specific. In these cases, a state may be focusing more exclusively on maintenance research projects than it would otherwise. An example is a private corporation that has given research dollars to study a specific invasive pest or federal grants that require research to relate agricultural practices with climate change.

One conceptual aspect that is difficult to model relates to research spill-ins and spill-outs among states. When research conducted in one state is used by other states, this spillover effect would not be captured by this model. Conceivably, a state's proportion of agricultural research spent on maintenance research would be lower than normal if a bordering state with similar agro-climatic parameters conducts maintenance research that is easily and cheaply adopted by the first state. Similarly, a state may conduct more maintenance research relative to neighboring states if a relationship evolves in which the neighboring states' *de facto* policy is to adopt the first state's research. This problem becomes magnified when one state receives funding to conduct research on a problem in another state or even another country. A state in this situation would show high amounts spent on maintenance research even if this research were not related to or being conducted within that state. Due to the difficulty in measuring spill-ins and spill-outs among states and the very tedious nature of separating the point of research conducted from the origin of research expenditures, spillovers are not included in this model. This will likely affect the individual estimates, but should not change any fundamental results drawn from them.

Lags also pose a modeling difficulty. Some variables should have very immediate impacts on the proportion of the agricultural research budget spent on maintenance research. Variables such as the ratio of outside funding to state funding, the availability of funding due to the size of the overall research budget, and commodity choices such as the ratio of livestock to crop production should affect the proportion spent on maintenance research in the short run. On the contrary, variables such as erosion, temperature, precipitation, and pesticide resistance should affect maintenance research expenditures over the long run. Year to year changes in these variables are too insignificant to impact research deterioration or policy responses regarding maintenance research very quickly. On an annual basis, they would be unnoticed. However, with sufficient time, their cumulative effect should have a significant impact on maintenance research expenditures. The difficulty lies in determining the appropriate lag length between each yearly observation of the long run variables and the subsequent impact on maintenance research expenditures. Threshold values for certain variables such as temperature or erosion would also be difficult to incorporate. For example, annual temperature increases may have no bearing on maintenance research until temperatures increase past a threshold value which triggers factors leading to maintenance research expenditures. Furthermore, using temperature as an example, the lag length may be much shorter in areas such as Florida where the growing season is year round versus Maine where temperature increases only extend the growing season by a few days.

In addition to estimating equation (1) in level form, all of the variables are standardized and estimated to obtain beta coefficients. Like a constant elasticity model, beta coefficients are useful for interpreting variables on different scales with different measurement units by using standard deviations. Beta coefficients determine how the standard deviation of the dependent variable changes if the independent variable increases by one standard deviation. However, standardization has the added advantage of not being dependent upon the range of a variable's variation. For example, a 1% change in temperature may represent a much larger absolute change than a 1% change in the ratio of the agricultural budget to agricultural output as the latter has a much narrower band of variation. Therefore, it may not be reasonable to expect all variables to change by the same percentages.

Ordinary least squares regression on panel data is biased unless the influence of omitted variables is uncorrelated with the explanatory variables. All data are from observations taken at the state level, and it is likely that heterogeneity at the state level influences the proportion of agricultural research spent on maintenance research. For example, one state might have a very developed and renowned pest management program which would lead to a larger proportion of funds being spent on maintenance research than ordinarily would be, *ceteris paribus*. Conversely, a state might be a national leader for plant breeding trials in terms of yield enhancement which would distort the productivity enhancing to maintenance research ratio. Furthermore, there are explanatory variables which have been omitted either through difficulty in data collection such as those related to economic and policy issues or through a limited understanding of just what is affecting maintenance research expenditures. The omission of these explanatory variables will produce a biased OLS estimate.

Fixed effects estimation corrects for omitted variables. Unobserved state specific effects are eliminated by implicitly including dummy variables for each state. Below is a generalized model of equation (1) for only one variable.

$$y_{it} = \beta_0 + \beta_1 x_{it} + \varepsilon_{it} \tag{2}$$

The mean value of all observations for variable *x* of state *i* over all years is calculated.

$$\bar{y}_i = \beta_0 + \beta_1 \bar{x}_i + \bar{\varepsilon}_i \tag{3}$$

Subtracting equation (3) from equation (2) results in the fixed effects model whereby the intercept has been eliminated and individual states now have their own intercept.

$$y_{it} - \bar{y}_i = \beta_1 (x_{it} - \bar{x}_i) + (\varepsilon_{it} - \bar{\varepsilon}_i) \tag{4}$$

where $\varepsilon_{it} = \mu_i + \lambda_t + \upsilon_{it}$.

In theory, a random effects estimator is preferred for its efficiency over a fixed effects estimator if the random error component of the composite error term is uncorrelated with the explanatory variables. However, the units of observation for this study are U.S. states. States are not a random draw from a larger population. It is logical to conclude that the observed effects, the μ_i, are state specific effects and not random error. Therefore, there should be correlation between the explanatory variables and the state specific effects. For this reason, a fixed effects estimator is chosen over a random effects estimator. Additionally, time effects, λ_t, are included in this model to capture anticipated yearly shocks affecting maintenance research expenditures that could arise from, for example, changes in research policy related to the passage of a new Farm Bill.

Chapter 3: Results

3.1. Survey Results

There were 491 surveys returned, roughly 12% of the estimated 4,000 emails sent. The actual number of scientists who received the survey is unknown due to e-mail server capacity, spam filters, out-of-date email addresses, and other electronic issues. Several scientists responded through e-mail but did not take the survey either because they had retired or because they felt maintenance research did not apply to their fields of research. This latter group could be evidence of selection bias. Out of the 491 returned surveys, 457 were used. The remaining 34 respondents either did not fully complete the questionnaire or clearly did not understand the concept of maintenance research as defined in the survey. One respondent commented that research depreciation and maintenance research are not easy concepts to communicate even to a research audience. In contrast, Adusei and Norton mailed surveys to 2,426 agricultural scientists in 1986 and received 905 responses, using only 744 for similar reasons. Adusei and Norton’s response rate was roughly 37%, higher than the current 12%. People’s likelihood to respond to emailed surveys versus stamped and mailed surveys, email spam filters, and an outdated USDA list of agricultural scientists were all thought to contribute to the lower response rate.

Adusei and Norton (1990) also found evidence of possible selection bias by receiving a higher percentage of responses from crop than from animal sciences. They suggested the possibility of respondents being more likely to be heavily involved in maintenance research than non-respondents, leading to an overestimation of maintenance research. Similarly, due to scientist email responses admittedly not taking the survey because they felt maintenance research did not apply to their work, the estimation of maintenance research from the current survey is likely to be biased upwards as well. However, as both surveys are likely to suffer from the same upward bias, comparing the two becomes simpler if the following assumption is made: the size of the bias has not changed over time. Therefore, the bias is eliminated from comparing the change in the proportion of maintenance research between the two surveys.

The overall percentage of research devoted to maintenance research averaged 39.4% across all commodities and non-commodities. The percentage of research devoted to maintenance research by individual commodity and non-commodity area are presented in table 2. In general, grains and sugar crops tend to require the highest proportion of maintenance research, human resources requires the lowest, and most commodity and non-commodity areas fall between 25% and 50%.

The percentage of research devoted to maintenance research is 40.8% for commodities. In contrast, Adusei and Norton estimated the percentage of research devoted to maintenance research in 1986 to be 34.8% across all commodities. The proportion of commodity oriented maintenance research could be different from Adusei and Norton's finding solely from the inclusion of new commodity categories not on the original survey: tree nuts, sugar crops, oil crops, ornamentals, and aquatic animals. A t-test was used to determine if there was a significant difference between all commodities including the new categories and all commodities excluding the new categories. However, the difference in means with and without the new categories is not statistically significant at the 5% level. By excluding the new commodity categories, the maintenance research percentage is 40.6%. Whereas, including the new categories only raises it slightly to 40.8%.

Table 2: 2008 Survey Results of Commodities and Non-Commodites

Commodities	% Maintenance Research	Range in Responses %	Standard Deviation	Median Response	Sample Size
Barley	46.9	90	29.8	50.0	11
Vegetables	34.7	100	33.2	22.5	102
Wheat	52.9	100	30.9	60.0	73
Sorghum	50.0	100	29.8	50.0	18
Cotton	40.6	100	32.9	40.0	25
Potato	35.2	100	34	25.0	21
Oats	62.3	90	31.4	66.0	7
Fruits	40.4	100	29.8	50.0	89
Corn	34.6	100	28.1	30.0	51
Rice	41.3	100	40.8	25.0	8
Poultry	27.5	80	22.2	25.0	17
Pasture and Forage Crops (Hay)	25.7	80	30.4	5.0	27
Tobacco	25.0	50	35.4	25.0	2
Soybeans	49.2	100	32.6	45.0	49
Peanuts	47.4	100	45.2	67.0	5
Livestock	39.7	100	34.3	35.0	92
Tree Nuts	46.9	75	27.1	55.0	8
Oil crops (except soy and peanut)	37.8	100	32.2	25.0	18
Sugar Crops	52.0	100	40.3	80.0	15
Ornamental and Turf	35.2	100	32.7	20.0	33
Cultured Aquatic Animals	28.1	80	30.8	22.5	8
Other (Misc.) Crops	41.1	60	17.5	50.0	19
All Commodities (old and new categories)	40.8	100	32.3	40.0	731
All Commodities (without new categories)	40.6	100	32.2	40.0	632
Non-Commodities					
Soil, Air, Water	29.2	90	24.2	25.0	47
Other Natural Resources (trees, forests, range and grasslands, wildlife habitat)	35.2	100	38.5	25.0	24
Food and Manufacturing Resources	32.5	75	36.2	27.5	4
Human Resources, Organizations, and Institutions	21.1	80	29.2	5.0	14
Other (Misc.) Non-commodities	10.8	25	12.0	10.0	6
All Noncommodities	28.5	100	29.3	20.0	95
Plant	41.4	100	32.3	40.0	599
Animal	38.3	100	32.6	30.0	132
Natural Resources	31.2	100	29.7	25.0	71
Other	20.4	80	27.1	7.5	24
Total	39.4	100	32.2	30.0	826

The percentage of research devoted to maintenance research for all non-commodities is much lower at 28.5%. t-tests were used to test for significant differences at the 5% level between groups of commodities and non-commodities. All commodities and all non-commodities were tested against each other as well as differences between the plant, animal, natural resources, and other group. Plant is highest at 41.4% followed by animal at 38.3%, natural resources at 31.2%, and other at 20.4%. This is consistent with Adusei and Norton's findings in which they found livestock to require the lowest percentage of maintenance research and crops to require the highest percentage. The results of these tests are presented in table 2.

The hypothesis that the proportion of research devoted to maintenance research differed by individual commodity and non-commodity area was tested at the 5% significance level using a series of two-sided t-tests. Under the null hypothesis, the means are equal. Under the alternative, they are not.

H_O: $M_i = M_j \quad i \neq j$

H_A: $M_i \neq M_j \quad i \neq j$

M is the mean percentage of total research devoted to maintenance research for commodity or non-commodity area i and j. The results of these tests are also presented in appendix C. The most notable differences occur between other commodities and non-commodities with wheat; oats; pasture and forage crops; soil, air, and water; soybeans; and human resources, organization, and institutions. The proportion of research engaged in maintenance research increased in twelve of Adusei and Norton's original categories between 1986 and 2008, and it decreased in five. However, the general trend is that the proportion of research devoted to maintenance research has increased since 1986. The current survey results in table 2 can be compared to

Adusei and Norton's findings in table 3 to see how the proportion of maintenance research has changed for individual commodities over time.

Table 3: Adusei and Norton's 1986 Survey Results of Commodities

Commodities	% Maintenance Research	Range in Responses %	Standard Deviation
Barley	42.2	100	28.4
Vegetables	41.5	100	32.2
Wheat	41.1	100	28.2
Sorghum	40.6	100	27.7
Cotton	39.3	100	29.1
Potato	39.3	100	30.5
Oats	35.4	100	27.8
Fruits	35.1	100	30.1
Corn	34.2	100	29.8
Rice	33.6	100	46.0
Poultry	33.4	100	30.3
Pasture and Forage Crops (Hay)	33.1	100	30.1
Tobacco	30.2	90	30.8
Soybeans	27.9	100	26.2
Peanuts	27.6	60	19.1
Livestock	21.4	100	26.5
Other (Misc.) Crops	32.8	100	28.7
All Commodities	34.8	100	29.4

3.2. Survey Responses

Roughly 40% of the usable surveys provided examples of research depreciation and maintenance research. Instead of listing all the responses, selected examples are presented as they relate to specific research disciplines. From these examples, a pattern emerges from which knowledge areas representing maintenance research in the CRIS database will be based upon.

Natural Resources

Research regarding water consumptive use for certain crops has depreciated over time as dynamics have changed. Maintenance research is being conducted to update these references which are often 40 to 50 years old.

The overall ability to maintain agriculture in the US requires a balance between regulatory expectations for water quality and agricultural economic viability. Present maintenance research efforts are focused on the quantification and compensation for environmental services provided on agricultural lands. This will ensure adequate monetary streams offset the elimination of certain practices that are detrimental to water quality.

Human burdens on natural resources in south Florida outpaced a relevant understanding of natural resources. Maintenance research is underway regarding current water use and soil conservation work with respect to agricultural practices.

Global concern over climate change has lead to restrictions of air emissions for regulatory or nuisance purposes. The amount of emissions to restrict requires knowing the environmental impacts of air emissions (odor, gas, particulate matter) from animal agriculture on people and the surrounding environment. Maintenance research on air emission from animal agricultural has been initiated to counter regulatory and nuisance concerns, allowing animal production to continue and hopefully expand.

Research conducted in the past has documented a 5 to15% yield loss for ozone sensitive crops such as cotton, peanut, soybean, and wheat. The potential impact of ozone pollution has not been generally recognized by growers because of seasonal and regional variation in pollution and the lack of "clean air" controls under field conditions. Maintenance research is currently identifying ozone tolerance mechanisms and sources of ozone tolerance genes in soybean.

Economics

Changes in government policy continually impact farm income. Maintenance research is needed to develop new economic models and simulations to provide accurate evaluation of decision processes. Doing business according to old policy, institutional, and market conditions can result in business failure for producers.

Previous economic thresholds for aphids depreciate with the advent and increase of vectored viruses. Maintenance research is needed to develop new methods of sampling and decision making to determine the new threshold level.

Most research that incorporates economics or the value of any input or practice depreciates. Markets have changed greatly in the past few years, and they are always in a state of change. Climate change predictions will depreciate much of the research based on old stable weather patterns. Many chemical inputs are being dropped from the market due to safety and environmental concerns or from reduced effectiveness. The gains in productivity that these inputs had brought are depreciating. Maintenance research is needed to develop models and cost/benefit ratios that can respond to changes easier by being more easily manipulated and site-specific.

Soil and Nutrient Relationships

Cattle feeding on endophyte-infected tall fescue progress toward copper deficiency faster than cattle on non-infected forages. With the current emphasis on using high-value sires through artificial insemination or embryo transfer, animals with less tolerance to fescue toxicosis are selected over those that are naturally resistant. Maintenance research was conducted and found that adding copper to cattle diets helps reduce the compounding of fescue toxicosis with copper deficiency. Additionally, maintenance research is being used to determine genetic markers for resistance to tall fescue toxicosis. Selection indices for cattle that are more tolerant to tall fescue toxicosis give producers the opportunity to maintain or improve the tolerance of their herd to fescue toxicosis.

Tall fescue was quickly adopted by farmers and proved to be the best cool-season grass for the transition zone of the United States. However, animal performance was lower than predicted. Researchers discovered that an endophyte in tall fescue was responsible. Maintenance research was conducted to mitigate the negative impact of the endophyte. This research included removal of the endophyte from tall fescue, incorporation of legumes into pastures, and eventually the development of a novel endophyte cultivar.

Increasing fertilizer prices have caused significant depreciation in the rate, source, timing, and placement efficiency research that was done previously on row crops. In Louisiana, the introduced pasture plants in the region are highly dependent on nitrogen fertilization for profitable production, and the cost of the required fertilizer has increased to the extent that profit potential has greatly declined. Maintenance research has involved finding methods to increase the efficiency of nitrogen fertilization and the utilization of legumes for biological nitrogen fixation.

Changes in corn hybrids over the past few decades have resulted in a crop that is more fertilizer efficient than in the past. Fertilizer recommendations have thus depreciated requiring maintenance research. New nitrogen rate research trials have been conducted to update the nitrogen recommendations in the Corn Belt.

Inactivity in evaluating fertilizer application rates for sugarcane led to over fertilization of the leading varieties. Maintenance research into the appropriate fertilizer rates was conducted over the last few years to determine optimal application rates.

Farm safety issues have reduced ammonium nitrate availability and led to the need for revised fertilizer recommendations. Maintenance research is ongoing on the influence of urea ammonium sulfate, a locally available replacement, on soil pH and tomato crop production.

Production Practices

As the concept of sustainable agriculture has changed, crop and animal production practice databases have depreciated which do not incorporate the science of the new understanding. Maintenance research was conducted which updated the databases through surveys to reflect the latest developments in sustainable agriculture.

Changes in tillage practices alter the importance of insects affecting legumes. Maintenance research is needed to study how grower practices should respond.

The increased adoption of reduced tillage has resulted in the appearance and/or increase in new wheat diseases such as tan spot, Stagonospora leaf blotch, Fusarium head blight, and Cephalosporium stripe. Maintenance research is focused on producing wheat cultivars with increased resistance to these diseases. Additionally, there has been research on cultural practices that can mitigate the impacts of these diseases.

No-till corn and sorghum production resulted in reduced nitrogen use efficiency and the need to increase nitrogen application rates. Maintenance research was undertaken to develop alternative application methods through modifications of fertilizer application equipment which enhanced efficiency, reduced needed application rates, and reduced costs.

"Roundup Ready" soybeans depreciated previous research related to optimal soybean plant populations. Maintenance research revealed that lower populations provide excellent yield. Yield remained the same, but efficiency increased.

Animal Disease

Flies are known to mechanically or biologically carry many pathogens. Increased animal densities have resulted in increased opportunities for fly contact with pathogenic bacteria and viruses in recent years. With the increased use of antibiotics, antibiotic resistant bacteria have spread. Both of these factors have contributed to depreciated research regarding pest, animal, and disease interaction. Maintenance research is being conducted to study the spread of antibiotic resistant pathogens and the role of flies in this.

Welfare-related changes in animal housing and the organic food movement have created new scenarios for pest management in animal systems leading to a depreciation of the old research. Conventional pesticides used earlier are unavailable or no longer appropriate. Maintenance research is being done to develop less toxic control materials. Additional maintenance research is needed to address new housing as it affects pest complexes.

Genetics

The incorporation of transgenic traits into major field crops resulted in a yield and quality reduction. Maintenance research has improved the genetics of transgenic crops by incorporating valuable genes into adapted germplasm to preserve yield gains.

Fertility is declining in poultry and dairy cows. A number of researchers are trying methods of hormone treatment and genetic selection to restore dairy cow fertility. Survival of purebred dairy cattle has also declined, leading to crossbreeding as an alternative breeding system.

Pest Management

The Food Quality Protection Act of 1996 eliminated major insecticides which have no alternatives. Additionally, the implementation of GMO crops has changed pest complexes. Both of these factors have contributed to the depreciation of pest management related research. Maintenance research is being undertaken to replace eliminated insecticides and develop new ones to address the new pest make-up, but known biology and ecology have important gaps that are major barriers to short run remediation.

In Adusei and Norton's original survey, Russian wheat aphid attacked wheat lines in the plains states in the 1980s and required maintenance research to incorporate resistance into wheat. However, in 2003, the appearance of new Russian wheat aphid biotypes threatened wheat production in the High Plains region of the US Great Plains making the previously resistant cultivars ineffective. Maintenance research was needed to identify resistant germplasm and breed resistant cultivars. Resistant cultivars will likely be released within three years.

Rice varieties were released that were highly susceptible to kernel smut (*Tilletia barclayana)* and false smut (*Ustilaginoidea virens).* Maintenance research was needed to screen rice germplasm in order to improve selection of resistant breeding lines and to increase testing on fungicides to prevent both diseases.

Honey bees are affected by pesticides used in agricultural production. Any pesticides which harm honey bees indirectly reduce the production capabilities of agriculture. Maintenance research is underway to develop alternatives to harmful insecticides such as using cultural practices like mulching with straw, row covers, and beneficial insects.

Florida 47 used to be the tomato of choice. However, without resistance to tomato spotted wilt virus, it is slowly losing favor. Evaluations of newer spotted wilt resistant varieties occurred between 2003 and 2006, leading to new recommendations and adoption by growers.

Fungicides become ineffective for managing apple scab and post-harvest diseases in apples after pathogen populations develop resistance to the fungicides (sometimes only after 10 to 20 years of successful use). Growers using these fungicides against resistant pathogens can suffer very high crop loss. Populations of resistant pathogens are monitored in commercial orchards and packinghouses, and data is used to warn fruit growers about current trends in resistance development. New fungicides and programs are evaluated to replace failing fungicides. Sanitation and biological controls are being studied as replacements for failing fungicides.

The phase-out of methyl bromide and regulatory restrictions to reduce volatile organic compounds in ambient air will bring an end to soil fumigation in California. Fruit and nut production will experience a dramatic increase in replant problems, reducing crop production by 10 to 30% over the lifetime of the orchard. Maintenance research has been focusing on other soil fumigants (1,3D + Chloropicrin and/or metam sodium).

In the Midwest, corn rootworm developed two mechanisms for overcoming control by crop rotation with soybean: extended diapause and the ability to feed on soybean roots. By understanding the corn rootworm adaptations, entomologists have identified Integrated Pest Management scouting methods and variants of crop rotation for rootworm control.

Soybean aphid began to invade the Midwest in 2000. Without IPM methods to manage it, farmers initially increased insecticide use radically to avoid yield loss estimated to be 11 bushels per acre. Entomologists with IPM economic threshold experience from prior research rapidly developed effective thresholds for soy aphid by 2004.

Rising summer temperatures in Tennessee have increased the incidence and severity of charcoal rot on soybeans and ashy stem blight on snap beans. These diseases are caused by Macrophomina phaseolina, a soil borne pathogen that is more common in hot, moderately dry soils. Maintenance research is underway to test the effects of new chemical seed treatments, biological agents, and cultural practices on Macrophomina.

Weed Management

New wheat and canola varieties are developed but the information related to Sencor® tolerance is for the older varieties. As these older varieties become unimportant, maintenance research is needed to screen newer varieties for Sencor® tolerance.

In some areas, Roundup was used as the sole herbicide for the past 15 years. This lead to Roundup resistant weeds in those areas. Maintenance research is underway to evaluate other herbicides to control Roundup resistant weeds.

In the Southeast, invasive weeds such as benghal dayflower (*Commelina benghalensis* L.), tropical soda apple (*Solanum viarum* Dunal), and cogongrass (*Imperata Cylindrica*) are threatening pastureland, cattle production, and crop production. Intensive efforts are underway to find control techniques using existing technology.

3.3. Agricultural Research Funding

Another commonality of the survey responses was funding. Close to 26% of the survey respondents mentioned agricultural research funding as a barrier to maintenance research. As it is not a source of research depreciation or an example of maintenance research, it cannot be classified as one of the categories above. However, as it relates to maintenance research expenditures, one of the categories under investigation in the empirical model, it is worthy of special mention here. Some of the more illustrative examples taken from the additional comments portion of the survey are presented below.

One scientist mentions that the biggest barrier to conducting maintenance research is financial resources. Funding for maintenance research is almost impossible to obtain unless it is linked to some other trendy research topic. Only topics which have grant support are able to be addressed by maintenance research. This funding structure which emphasizes trendy research topics to ongoing maintenance research topics means that maintenance related problems have to deteriorate to a near crisis level or have political backing before they are addressed.

Another scientist comments that an overriding issue is a shrinking pool of general research funding, especially for very applied forms of research. Extramural funding sources want cutting edge basic research that is hypothesis driven. Very applied projects such as maintenance research suffer from a lack of funding. Funding for applied research has become increasingly competitive and difficult to obtain as commodity funds shrink. Initiatives like biofuels and bioterrorism divert support away from traditional agricultural enterprises. Funding sources dictate what researchers work on which are often not the biggest problems.

Several scientists mentioned other related issues such as: a) the private sector will not sufficiently fund nor conduct research for the public good because it has a bottom line which trumps best practices not contributing to its profits; b) maintenance research is not attractive to articles in refereed journals; c) much of the research that is carried on today is funded by dollars other than those from the state. It keeps states from having to fund wanted programs with their own tax money but often has unintended consequences like a lack of maintenance research; d) research funding is almost totally dependent on competitive grants for "new" projects from programs that do not recognize the need for maintenance type projects; e) erosion of state funds to land grant universities led to grants initiative funding programs whereby research is dictated by federal grant categories that do not recognize maintenance research.

Finally, a scientist notes that the trend of supporting only large extramural grant areas may cause the traditional areas of agricultural research to disappear. Maintenance research is almost impossible to conduct in areas that cannot generate large grants. This is true in states that have huge commodity interests but no mechanism to support experiment station projects through traditional political mandates. Even in states where such support is still available, the pressures on faculty to eschew those lesser supports in favor of larger grant sources (NIH, NRI, NSF, etc.) are excessive.

3.4. CRIS Classification

The major patterns of maintenance research are established by the examples above. Some examples are hard to classify as purely belonging to a single research discipline such as those straddling climate and pest related problems or production practices and animal diseases, yet the major themes of maintenance research are unmistakable. Many more examples were submitted but were not listed above due to the constraint of space. However, their inclusion would only serve to reinforce the established patterns. These survey responses compare consistently with the commodity oriented maintenance research examples obtained by Adusei and Norton which are mainly pest and pathogen related.

In addition, these survey results are consistent with the survey results gathered from Idaho Agricultural Experiment Station researchers by Araji (1990). In his survey, the following classifications of maintenance research were established:

> (a) soil conservation research to maintain present productivity by reducing the loss of top soil due to wind and water erosion; (b) economic research to analyze the impact of new technology and price relationships on the agricultural sector efficiency and to develop agricultural policies compatible with the relationships; (c) pest control research for maintaining present productivity including (1) surveys of insect population and determination of infestation levels, (2) testing of new pesticides and herbicides to replace present ones that have become less effective, (3) finding replacements for chemicals banned or scheduled to be banned by the EPA, and (4) controlling pests on large acreages of rangeland; and (d) research in such areas as (1) cultural practices, (2) pest and disease control during storage, (3) discovery and control of natural toxicants in the food chain, (4) environmental stress research to maintain yield and quality, and (5) information management.

Based upon the survey responses and the patterns of maintenance research contained therein, knowledge area categories were chosen from the CRIS database which corresponded to research disciplines largely involved in maintenance research. These categories, along with all CRIS categories, are presented in appendix D using the respective designations from the Manual V, VI, and VII classifications for research problem areas and knowledge areas. This arbitrary process does oversimplify the notion of maintenance research by drawing distinct boundaries between what constitutes maintenance research and what does not. It is important to note that the maintenance research figures obtained from the CRIS data are used purely to construct a model to test hypotheses as to what is driving maintenance research expenditures. The impossibility of reviewing every single research project over a 31 year period to classify conducted research as either maintenance or not necessitates this method. These figures should not be referred to as the amount of research engaged in maintenance research. Instead, the amount of research engaged in maintenance research should be based upon the survey results whereby the percentages were 41.4% for plants, 38.3% for animals, 31.2% for natural resources, and 20.4% for other.

The expenditures of the maintenance research knowledge areas within natural resources, plants, animals, and other were divided by the total research expenditures within each respective category. Through this derivation, the percentage of maintenance research within each category was derived from the CRIS data (table 4). Compared to the survey percentages, the CRIS percentages were higher with the percentage of maintenance research for plants being 54.2%, 50.4% for animals, 46.3% for natural resources, and 39.2% for other. Although the percentages are higher than those from the survey, the ordinal rankings among groups are preserved.

Additionally, the percentages from the 1986 CRIS data are compared to the plant and animal categories of Adusei and Norton's survey in table 4. Two important points are apparent from this additional information. The first is that the CRIS maintenance research percentages are higher than the survey percentages, but, like the 2006 CRIS data, the ordinal rankings for the plant and animal categories are preserved between the survey and CRIS data. The second is that the percentage of maintenance research in the CRIS data rose in each category except natural resources between 1986 and 2006 using consistent designations for maintenance research knowledge areas and research problem areas. This is supported by the findings from the two surveys in which the percentage of maintenance research also rose. The discrepancy in the 1986 natural resources category is most likely related to the recategorization of research problem areas and knowledge areas between Manual V and Manual VII rather than suggesting maintenance research expenditures on natural resources were much higher in 1986. Manual V has research problem areas under natural resources that were separated and reclassified as plant, animal, and other for Manual VII.

Table 4: Maintenance Research Effort Comparison between CRIS categories and Survey

Category	Research Effort Devoted to Maintenance from CRIS categories (%)	Research Effort Devoted to Maintenance from Survey (%)
	2008	
Natural Resources	46.3	31.2
Plant	54.2	41.4
Animal	50.4	38.3
Other	39.2	20.4
	1986	
Natural Resources	51.0	N/A
Plant	41.3	35
Animal	37.5	27
Other	31.3	N/A

3.5. Model Results

The results from the fixed effects regression of equation (1) with and without time effects are presented below in table 5. The overall R^2 values seem low but are typical for estimates of panel data. This can be attributed in part to the fact that some of the explanatory power of the model is reduced by eliminating the intercepts through the process resulting in equation (4). An F-test for the joint significance of the fixed effects confirmed they should be included in the model.

In the model with only fixed effects, the only variable that appears insignificant according to a two-tailed hypothesis test is the ratio of livestock to crop production. However, in the case of pesticide expenditures, temperature, erosion, and precipiation, a one-tailed test should be performed as the relevant alternative hypothesis for each variable states that the coefficient on each is greater than 0.

H_O: $\beta_i = 0$

H_A: $\beta_i > 0$

By using a one-tailed test, it becomes obvious erosion is not significant within the model. Instead of suggesting erosion does not contribute to expenditures on maintenance research, the erosion variable is most likely suffering from a lack of observations. As noted above, observations for highly erodible land were not available prior to 1982 or during non-survey years. Further data collection for soil erosion, salinization, pollution, nutrient depletion, or some other form of land degradation should be included in future models.

With the addition of time effects to the fixed effects model, temperature and pesticide expenditures appear to lose significance while precipitation becomes significant only at the 10% level. An F-test for the joint significance of the time effects confirmed they should be included in the model. However, this does not indicate temperature or pesticide expenditures are invalid

Table 5: Fixed Effects Model with and without Time Effects and Erosion

Explaining the Share of Maintenance Research Expenditures				
Fixed Effects	**w/ Time Effects**	**w/o Time Effects**	**w/ Time Effects**	**w/o Time Effects**
			Variable Dropped	
Independent Variable	**Coefficient**			
Federal and Private Expenditures / State Expenditures	-0.0294*	-0.0293*	-0.0257*	-0.0258*
	(0.0023)	(0.0023)	(0.0022)	(0.0022)
Federal and Private Expenditures / State Expenditures (^2)	0.0006*	0.0006*	0.0005*	0.0005*
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Total Research Expenditures / Value of Agricultural Production	-0.9970*	-0.5709**	-1.9693	-1.0579*
	(0.3136)	(0.3276)	(0.2841)	(0.2975)
Pesticide Expenditures / Acres of Cropland	-0.0010	0.0261*	-0.0046	0.0305*
	(0.0062)	(0.0052)	(0.0048)	(0.0041)
State Area Averaged Annual Temperature	0.0023	0.0134*	0.0038*	0.0153*
	(0.0020)	(0.0015)	(0.0019)	(0.0014)
Value of Livestock Production / Value of Crop Production	-0.0085*	-0.0043	-0.0121*	-0.0120*
	(0.0030)	(0.0032)	(0.0022)	(0.0024)
Abs(Deviations from Precipitation Norm)	0.0009**	0.0011*	0.0008**	0.0010*
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Acres of Highly Erodible Cropland / Acres of Non-highly Erodible Cropland	-0.0200	-0.0178	Dropped	Dropped
	(0.0072)	(0.0077)		
Number of Observations	1200	1200	1488	1488
F	26.82	68.27	28.57	86.17
Prob > F	0	0	0	0
R^2 Overall	0.1205	0.0236	0.1312	0.0193

Note: (Standard Errors are presented below the Coefficients)
 * indicates significance at the 5% level
** indicates significance at the10% level

explanatory variables of maintenance research expenditures. Rather, this supports the hypothesis that maintenance research expenditures respond to certain variables in the short run and other variables over the long run. The long run variables (pesticide expenditures, temperature, and precipitation) become less significant once time effects are added because time effects prove to be an effective proxy for the long run contributions these variables have on maintenance research expenditures. By including time effects, the within variations of each variable which occur slowly over time are washed out so as to make them appear either less significant or insignificant altogether. The significance of the short run variables is either unchanged or even improved in the case of the commodity ratio when time effects are included.

Erosion can also be thought of as a long run contributor to maintenance research. Year to year erosion should have no drastic effect on maintenance research expenditures; yet, over time, erosion should play a significant role in determining maintenance research expenditures. Nevertheless, the erosion variable remains insignificant in both models due to limited observations and is dropped from the next two models in table 5. A comparison of the four models reveals that dropping erosion improves the significance and explanatory power of the models. In particular, the ratio of livestock to crop production becomes significant in the fixed effects model without time effects.

Further evidence of the long run effects on maintenance research is apparent through the addition of ten year uniformly weighted moving averages applied to the long run variables in table 6. In these regressions, time effects were removed and moving averages were added to pesticide expenditures, temperature, and precipitation. In this case, the long run effects of pesticide expenditures and temperature are being captured by the moving averages instead of by the time effects. In the model including moving averages and time effects, pesticide

Table 6: Fixed Effects with 10 Year Moving Averages on Pesticide Expenditures, Temperature, and Precipitation

Explaining the Share of Maintenance Research Expenditures		
Fixed Effects	**w/ Time Effects**	**w/o Time Effects**
Independent Variable	**Coefficient**	
Federal and Private Expenditures / State Expenditures	-0.0267*	-0.0299*
	(0.0022)	(0.0023)
Federal and Private Expenditures / State Expenditures (^2)	0.0005*	0.0006*
	(0.0001)	(0.0001)
Total Research Expenditures / Value of Agricultural Production	-1.8011*	-1.1980*
	(0.2903)	(0.3095)
Pesticide Expenditures / Acres of Cropland	-0.0019	0.0313*
	(0.0056)	(0.0055)
State Area Averaged Annual Temperature	0.0005	0.0299*
	(0.0060)	(0.0044)
Value of Livestock Production / Value of Crop Production	-0.0112*	-0.0118*
	(0.0023)	(0.0024)
Abs(Deviations from Precipitation Norm)	0.0002	-0.0015
	(0.0016)	(0.0017)
Number of obs	1440	1440
F	28.31	81.44
Prob > F	0	0
R^2 Overall	0.1725	0.0072

Note: (Standard Errors are presented below the Coefficients)
* indicates statistical significance at the 5% level

expenditures, temperature, and precipitation all proved to be highly insignificant as expected. Different moving averages including a 5 and a 15 year moving average were applied to the precipitation variable, but none proved significant or as effective at capturing the long run effect on maintenance research as well as the inclusion of time effects. The closest approximation was by including a one year, two year, and three year lag on precipitation. However, these also were statistically insignificant.

The standardized variables reveal more about the short run and long run effects on maintenance research expenditures as well as confirm hypotheses regarding the other explanatory variables, table 7. The fixed effects model without time effects shows that temperature has the greatest impact on maintenance research expenditures over the long run, followed by the ratio of outside funding to state funding as the second biggest influence and pesticide expenditures as the third biggest. The fixed effects model with time effects shows the ratio of outside to state funding is the largest impact on maintenance research expenditures followed by the size of the agricultural research budget relative to the value of agricultural production as the second largest and temperature as the third largest in the short run. The beta coefficients on both the ratio of funding sources and its quadratic term remain relatively unchanged between the two models.

In table 7, the long run standardized variables lose significance with the inclusion of time effects which effectively account for all the within variation over time. The pesticide expenditures variable loses all significance in the short run, and the precipitation variable becomes significant only at the 10% level. Interestingly, temperature still remains significant at the 5% level in the short run. Fixed effects should account for all the between variation that occurs among observations of different states in the same time frame, for example Florida spends more on maintenance research related to temperature than Maine year to year. However, the total variation of temperature is large enough to make it significant in the short run, albeit less so than in the long run.

Table 7: Standardized Variables with Fixed Effects

Explaining the Share of Maintenance Research Expenditures		
Fixed Effects	**w/o Time Effects**	**w/ Time Effects**
Independent Variable (standardized)	**Beta Coefficient**	
Federal and Private Expenditures / State Expenditures	-0.6869*	-0.6837*
	(0.0589)	(0.0585)
Federal and Private Expenditures / State Expenditures (^2)	0.4423*	0.4489*
	(0.0437)	(0.0429)
Total Research Expenditures / Value of Agricultural Production	-0.1526*	-0.2840*
	(0.0429)	(0.0410)
Pesticide Expenditures / Acres of Cropland	0.3401*	-0.0510
	(0.0457)	(0.0540)
State Area Averaged Annual Temperature	1.2013*	0.3009*
	(0.1113)	(0.1456)
Value of Livestock Production / Value of Crop Production	-0.1897*	-0.1911*
	(0.0374)	(0.0348)
Abs(Deviations from Precipitation Norm)	0.0366*	0.0290**
	(0.0184)	(0.0175)
Number of obs	1488	1488
F	86.17	28.57
Prob > F	0	0
R^2 Overall	0.0193	0.1312

Note: (Standard Errors are presented below the Coefficients)
 * indicates significance at the 5% level
** indicates significance at the10% level

Changes in temperature, pesticide expenditures, and precipitation patterns can occur so slowly over time that most of this variation is included in the time effects, effectively reducing the individual explanatory power of these variables. Similarly, for a variable such as temperature, fixed effects serve as a proxy for most of the between variation of observations across states. One way to determine the contributions of these variables in explaining maintenance research expenditures is to separate them from the other unobserved factors that are collectively grouped into the time effects and fixed effects. In order to do this, equation (1) is rewritten with the long term variables (and erosion) removed.

$$\left(\frac{MaintR}{TotalR}\right)_{it} = \beta_{0i} + \beta_1\left(\frac{TotalR}{AgP}\right)_{it} + \beta_2\left(\frac{Fed + Other}{State}\right)_{it} + \beta_3\left(\frac{Fed + Other}{State}\right)_{it}^2 + \beta_4\left(\frac{Livestock}{Crop}\right)_{it} + \mu_i + \lambda_t + \upsilon_{it} \quad (5)$$

The fitted values for the time effects, $\hat{\lambda}_t$, and fixed effects, $\hat{\mu}_i$, are obtained after estimating equation (5). Then, the excluded variables are regressed on the time effects and fixed effects, respectively, in two separate regressions shown below to determine their contribution to each.

$$\hat{\lambda}_t = \beta_0 + \beta_1 Temperature + \beta_2 Precipitation_{it} + \beta_3 PesticideResistance_{it} + \delta_4 dperiod2 + \delta_5 period3 + \delta_6 period4 + \upsilon_{it} \quad (6)$$

$$\hat{\mu}_i = \beta_0 + \beta_1 Temperature + \beta_2 Precipitation_{it} + \beta_3 PesticideResistance_{it} + \delta_4 Northeast + \delta_5 Pacific + \delta_6 Mountain + \delta_7 Central + \delta_8 Northernplains + \delta_9 Southernplains + \upsilon_{it} \quad (7)$$

Dummy variables are included in the time effects regression to capture any time period specific differences that temperature, precipitation, and pesticide expenditures may have on the time effects. The base time period is 1976-1979.[2] These time periods are not arbitrary. They are based on cyclical peak-to-peak subperiods of the agricultural productivity growth rate (Ball 2009). Dummy variables are included in the fixed effects regression to capture any regional

[2] Period 1: 1976-1979
Period 2: 1980-1989
Period 3: 1990-1999
Period 4: 2000-2006

differences on the fixed effects. The base group of states is the Southeast.[3] The results from equations (5), (6), and (7) are displayed in tables 8 and 9.

Table 8: Estimating Fixed Effects and Time Effects without Long Term Variables

Explaining the Share of Maintenance Research Expenditures without Long Run Variables	
Independent Variable	**Coefficient**
<u>Federal and Private Expenditures</u> **State Expenditures**	-0.0259*
	(0.0022)
<u>Federal and Private Expenditures</u> **(^2)** **State Expenditures**	0.0005*
	(0.0000)
<u>Total Research Expenditures</u> **Value of Agricultural Production**	-1.9181*
	(0.2839)
<u>Value of Livestock Production</u> **Value of Crop Production**	-0.0118*
	(0.0022)
$\hat{\lambda}_t$	0.5128*
$\hat{\mu}_i$	0.0124*
Number of obs	1488
F	30.76
Prob > F	0
R^2 Overall	0.1741

Note: (Standard Errors are presented below the Coefficients)
* indicates significance at the 5% level

[3] Southeast: Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.
Northeast: Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.
Pacific: California, Oregon, and Washington.
Mountain: Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming.
Central: Indiana, Illinois, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin.
Northernplains: Kansas, Nebraska, North Dakota, and South Dakota.
Southernplains: Arkansas, Louisiana, Mississippi, Texas, and Oklahoma.

Table 9: Long Term Contributions to Time Effects and Fixed Effects

Explaining the Share of the Time Effects and Fixed Effects Attributed to the Long Term Variables		
Dependent Variable	Time Effects $\hat{\lambda}_t$	Fixed Effects $\hat{\mu}_i$
Independent Variable	**Coefficient**	
State Area Averaged Annual Temperature	0.0000	0.0007*
	(0.0003)	(0.0003)
Abs(Deviations from Precipitation Norm)	0.0017*	-0.0005
	(0.0006)	(0.0005)
Pesticide Expenditures / Acres of Cropland	-0.0053	-0.0035
	(0.0023)	(0.0019)
Northeast		0.0935*
		(0.0064)
Pacific		0.0087
		(0.0077)
Mountain		0.0593*
		(0.0062)
Northernplains		-0.0525*
		(0.0076)
Central		0.0068
		(0.0067)
Southernplains		-0.0049
		(0.0059)
Period 2 (1980-1989)	-0.1540*	
	(0.0073)	
Period 3 (1990-1999)	-0.1669*	
	(0.0075)	
Period 4 (2000-2006)	-0.2206*	
	(0.0080)	
Number of obs	1488	1488
F	145.84	93.44
Prob > F	0	0
R^2 Overall	0.3714	0.3627

Note: (Standard Errors are presented below the Coefficients)

* indicates significance at the 5% level ** indicates significance at the 10% level

In the time effects regression, only precipitation has positive and significant explanatory power. This supports the hypothesis that changes in precipitation over time contribute to the proportion of agricultural research devoted to maintenance research. However, temperature and pesticide expenditures do not appear to contribute significantly to the time effects. The coefficient on temperature was positive at 6.01×10^{-6} yet very insignificant. The within variation of temperature and pesticide expenditures may be too little to show any positive and significant contributions to the time effects. Nonetheless, based upon the hypotheses developed above and the results in tables 5, 6, and 7, temperature and pesticide expenditures should contribute significantly to maintenance research expenditures over time.

The dummy variables in the time effects regression indicate that time effects play an increasingly smaller role in explaining the proportion of maintenance research expenditures. The coefficients are all significant and decreasing through each consecutive time period. This would support the hypothesis of the long term variables contribution to maintenance research expenditures over time. The more recent time periods have lower intercepts because maintenance research expenditures are being attributed more to the short run variables and less to the long run variables. Whereas, the earlier time periods have higher intercepts because maintenance research expenditures are being attributed relatively more to the long run variables and less to the short run variables.

In the fixed effects regression, only temperature is significant in explaining proportional differences of maintenance research expenditures across states (table 9). This conclusion supports the earlier hypothesis that temperature differences across states are likely to influence maintenance research expenditures. In contrast, differences in precipitation or pesticide expenditures across states should not influence maintenance research expenditures. Rather, these would only influence maintenance research expenditures within a state over time. Deviations in precipitation are insignificant as well as pesticide expenditures, using a one-tailed hypothesis test. The negative coefficient implies that increases in pesticide expenditures result in a lower intercept value for states' level of maintenance research. This is inconsistent with theory and the results from tables 5, 6, and 7.

The dummy variables in the fixed effects regression indicate that, relative to the Southeast region, the Northeast and Mountain regions have a higher intercept and thus have higher proportions of their research budget devoted to maintenance research, *ceteris paribus*, than does the Southeast. This is surprising given that the Southeast, being hotter and more pest prone, should have a higher intercept term. This may indicate that some other explanatory variable or variables are affecting maintenance research expenditures in these regions that have not been included in the model. By being excluded, they would show up in the fixed effects and time effects for these regions. The Northernplains region has a lower intercept relative to the Southeast which is consistent with it being cooler and less prone to pests. The other regions do not vary significantly in their intercepts relative to the Southeast. This is more clearly illustrated in figure 1.

The fixed effects for the majority of states fall within 0.5 standard deviation above or below Alabama's fixed effect. Fourteen states have fixed effects less than 0.5 standard deviation below Alabama's. This includes the states in the Northerplains region as well as other states at higher latitudes. Curiously, the states clustering around Alabama also fall into this category. These states are climatically similar to Alabama. However, production choices or funding decisions may be accounting for these differences. The Mountain region's higher intercept is due solely to Colorado. Colorado is unique in that it is the only state whose fixed effect intercept is greater than 2.5 standard deviations away from Alabama. This suggests a very localized phenomenon behind Colorado's high proportion of maintenance research expenditures. Similarly, Delaware, Connecticut, Massachusetts, Rhode Island, and Vermont are responsible for the higher intercept on the Northeast regional dummy variable.

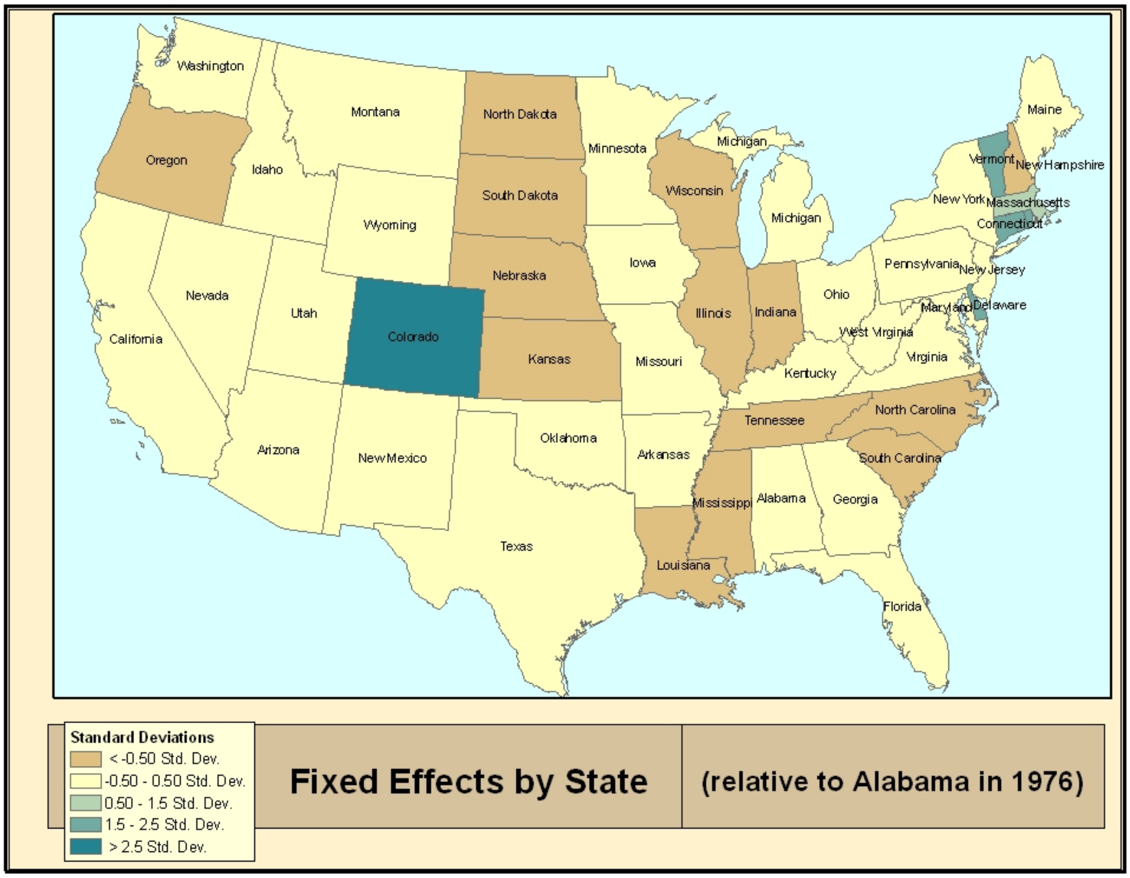

Figure 1: Map of Fixed Effects for Proportion Spent on Maintenance Research by State

Agricultural research funding, climatic conditions, pest and pathogen control, and agricultural production are broadly supported by their representative variables as determinants of maintenance research. All of the hypotheses regarding the explanatory variables were confirmed through the regressions with the exception of erosion. The signs on the coefficients are in agreement with their hypothesized directions and very significant. Several qualitative conclusions can be made based on the information in tables 5, 6, and 7.

1) *The ratio of maintenance research to total research decreases as the ratio of outside funding to state funding within a state increases.* Outside funding has a statistically significant negative impact on the amount of maintenance research a state conducts up to a certain ratio whereby outside funding begins to increase the proportion spent on maintenance research. The positive coefficient and statistical significance of the quadratic term confirms the nonlinearity of this effect. A computation of the coefficients from tables 5 and 6 reveals that the ratio's turning point of outside funding to state funding is somewhere between 24.7 to 26.7. However, only five observations out of 1,488 have a funding ratio higher than 20. Between 1999 and 2003, Maryland's outside funding to state funding ratio fluctuated between 20.1 and 33.3. This may represent a very time and location specific injection of either private or federal capital into agricultural research that had a large maintenance component. Nevertheless, in general, private and federal funding reduce the share of a state's agricultural research budget devoted to maintenance research. The funding ratio has the third largest impact on maintenance research expenditures in both the short run and the long run for a change of one standard deviation. For example, a one standard deviation increase in the ratio of outside funding to state funding decreases the ratio of maintenance research to total research by 0.2348 standard deviation. The nonlinearity of this variable means that a two standard deviation increase of the funding ratio will increase the ratio of maintenance research to total research by 1.1 standard deviations.

2) *The ratio of maintenance research to total research decreases as the ratio of agricultural research to agricultural output increases.* In the short run, the ratio of the agricultural research budget to agricultural output has the second largest impact on the proportion of the research budget spent on maintenance research. As the size of the research budget grows, the proportion of maintenance research within that budget diminishes. This supports the idea that maintenance research is more of a necessity good than productivity enhancing research in terms of funding priorities. For example, a one standard deviation increase in the ratio of the agricultural research budget to agricultural output decreases the ratio of maintenance research to total research by 0.284 standard deviation in the short run.

3) *The ratio of maintenance research to total research increases with expenditures of pesticides per acre.* Pesticide expenditures have a statistically significant positive impact on the amount of maintenance research a state conducts. By assumption, as pests develop resistance to established pesticides, farmers increase their per acre spending on pesticides to counter this resistance. In the short run, increased pesticide usage seems to have no effect on maintenance research expenditures and may even be temporarily effective in dealing with the pests. However, in the long run, this has the second largest impact on maintenance research expenditures by establishing the need for new pesticides and/or pest management strategies. Thus in the long run, for example, a one standard deviation increase in pesticide expenditures per acre is associated with a 0.34 standard deviation increase in the ratio of maintenance research to total agricultural research.

4) *The ratio of maintenance research to total research increases with temperature.* Temperature has a statistically significant positive impact on maintenance research. Temperature variations between states have the largest impact on differences in the proportion of maintenance research expenditures in the short run as indicated by the results in tables 7 and 9. For example, a one standard deviation increase in average state temperature increases the ratio of maintenance research to total research by 0.3 standard deviation. This would represent the higher proportion of maintenance research a state like Georgia with an annual temperature of 63.5F has compared to Virginia with an annual temperature of 55.2F, *ceteris paribus*. In contrast, temperature changes within a state over time have the single largest impact on maintenance research in the long run. For example, a one standard deviation increase in average state temperature is associated with a 1.2 standard deviation increase in the ratio of maintenance research to total agricultural research. This would represent the higher proportion of maintenance research Virginia had, *ceteris paribus*, in the years following 2000 with an average annual temperature of 55.9F compared to the years prior to 1984 with an average annual temperature of 54.4F.

5) *The ratio of maintenance research to total research decreases as the ratio of livestock to crop production increases.* States that have a relatively larger share of livestock production to crop production have a lower proportion of their agricultural research budget devoted to maintenance research. This conclusion is in agreement with Adusei and Norton's (1990) earlier findings. Interestingly, the livestock to crop ratio stays almost the same in both the long and short run models. For example, a one standard deviation increase in the ratio of livestock production to crop production

decreases the ratio of maintenance research to total research by 0.19 standard deviation in both models. This suggests that the fundamental difference between the maintenance component of livestock research and the maintenance component of crop research has not changed over time. Crops are more sensitive to changes in their environments than are livestock.

6) *The ratio of maintenance research to total research increases with the absolute value of deviations in precipitation from the norm.* Deviations in precipitation over time have a statistically significant positive impact on the proportion of maintenance research expenditures. This variable captures any changing trends in precipitation patterns over time both negatively and positively by using the absolute value of the deviations. Deviations in precipitation do have some impact on maintenance research expenditures in the short run model at the 10% significance level. However, deviations in precipitation affect maintenance research expenditures the most over the long run. For example, a one standard deviation increase in the deviation of average state precipitation from the 72 year norm is associated with a 0.0366 standard deviation increase in the ratio of maintenance research to total agricultural research.

Chapter 4: Conclusions

4.1. Summary

The first research objective was met through a survey that was sent to approximately 4,000 agricultural scientists across the United States which was nearly identical to the survey used by Adusei and Norton. The survey provided examples of research depreciation and maintenance research and asked questions about the proportion of maintenance research within each scientist's own research program. An analysis of these responses established that 39.4% of all agricultural research is classified as maintenance research.

Total agricultural research was divided into commodity and non-commodity focused research to meet the second and third research objectives. For commodity research alone, the percentage of total research engaged in maintenance research is 40.8%. In contrast, Adusei and Norton (1990) found that 34.8% of commodity research is maintenance research, showing an increase in the amount of maintenance research over the past 20 years. For non-commodity research, the percentage of research engaged in maintenance research is 28.5%. The differences in commodity and non-commodity percentages provide evidence to the contrary of Hypothesis 3. Commodity research was divided into plant and animal focused research while non-commodity research was divided into natural resources and other. Plant had the highest component of maintenance research at 41.4% followed by animal at 38.3%, natural resources at 31.2%, and other at 20.4%.

Based on scientist responses to the survey, certain research areas were classified as being mainly composed of maintenance research such as plant and animal diseases and economics. To meet the fourth research objective, these research areas were used to choose categories from within the CRIS database that could be used in developing a model to explain maintenance research expenditures. Six broad categories were identified as influences on the amount of maintenance research expenditures: agricultural research funding, climatic conditions, land degradation, pest and pathogen control, agricultural production, and economics. Only the first five were tested in the model due to modeling problems associated with the economics category.

Fixed effects models with and without time effects in level and standardized form for the panel data, 1976 through 2006, confirmed Hypothesis 4 for each variable except soil erosion. The model found evidence in support of four of the five categories tested - agricultural research funding, climatic conditions, pest and pathogen control, and agricultural production. A summary of the qualitative results in support of these categories is provided below:

- increasing proportions of outside funding sources to self-funded sources within a state decrease the proportion of maintenance research within the overall agricultural research budget with a diminishing nonlinear effect,
- increasing agricultural research budgets relative to the values of agricultural output decrease the proportion of maintenance research,
- increasing expenditures on pests and pathogens increases the proportion spent on maintenance research,
- increasing temperatures increase the proportion spent on maintenance research,
- increasing the ratio of livestock to crop production decreases the proportion spent on maintenance research,
- increasing absolute values in deviations of precipitation from the norm increase the proportion spent on maintenance research.

Based upon the findings from the survey and empirical models, the fifth research objective is met below in which testable hypotheses about the impact of maintenance research on agricultural productivity are developed.

4.2. Testable Hypotheses

Agricultural research must balance current demands placed upon it as well as retain the capacity to meet the demands that the future will bring. Balancing such demands requires an understanding of the effects of maintenance and productivity enhancing research on agricultural productivity. When considering the benefits and costs of agricultural research, the benefits of losses avoided through maintenance research must be taken into consideration. Incorporating maintenance research into economic models of total factor productivity will help improve the accuracy and understanding of the returns to research. Objective 5 seeks to develop testable hypotheses about the impact of maintenance research on agricultural productivity.

The first hypothesis is that growth in agricultural productivity is positively influenced by maintenance research. *Ceteris paribus*, a state that conducts more maintenance research has higher returns to productivity enhancing research than a state that does not. That is because gains from any productivity enhancing research will be measured from a base line that is higher than from one which is decreasing. Alternatively, even if no productivity enhancing research is conducted but maintenance research is, productivity growth will be zero as opposed to negative. Statistical decompositions of TFP into productivity enhancing research and maintenance research will find the coefficients on both variables to be positive.

The second hypothesis is that the effect of maintenance research on agricultural productivity is greater now than it was 20 years ago. As the proportion of maintenance research has grown over time, so should its effect on agricultural productivity. Statistical decompositions of TFP into productivity enhancing research and maintenance research will find the coefficient on maintenance research to increase with time.

4.3. Implications and Discussion

Improvements on this research should seek additional variables from within agricultural research funding, climatic conditions, land degradation, pest and pathogen control, and agricultural production to be tested. The erosion variable suffers from a lack of data and either needs additional data or should be replaced by another variable altogether from land degradation. A more accurate list of agricultural research scientists would improve the response rate of the survey. Finally, an incentive to completing the survey such as a gift certificate awarded at random to one of the respondents would most likely have improved the response rate of the survey.

The proportion of agricultural research dedicated to maintenance research has risen over the past 20 years. As the size of the agricultural research budget has grown in absolute terms, the actual dollar amount of maintenance research has risen as well. Hypothesis 1 states that the proportional amount of maintenance research is unchanged over the past 20 years. Yet, the survey finds evidence to the contrary. Maintenance research as a proportion of total agricultural research is rising. Based upon the survey results, the proportion of commodity focused agricultural research that is devoted to maintenance research has risen in the past 20 years from

34.8% in 1986 to 40.8% in 2008. Overall, the percentage of agricultural research engaged in maintenance research is 39.4%.

Hypothesis 2 states that the real dollar amount of maintenance research is unchanged over the past 20 years. In 1986, the nominal aggregate agricultural research budget for the United States was a little over $2 billion. In 2006, the nominal aggregate agricultural research budget for the United States was a little over $5 billion. Using the percentages of 34.8 and 39.4 for the years 1986 and 2006, respectively, the absolute amount of maintenance research has, indeed, grown from roughly $0.7 billion to $2 billion. However, using the Consumer Price Index to adjust for inflation, $1.00 in 1986 is only worth $0.54 in 2006. Therefore, the real aggregate 2006 agricultural research budget for the United States was only $2.7 billion in 1986 dollars and the amount of maintenance research only grew from $0.7 billion to $1.1 billion. Nevertheless, hypothesis 2 is rejected.

It is interesting to compare the growth of agricultural research and maintenance research over the past 20 years. Adjusting for inflation, the size of the aggregate agricultural research budget grew by 34% whereas the amount of maintenance research grew by 52%. This suggests that maintenance research is growing faster than overall agricultural research. As productivity enhancing research continues year after year, the research pool of information and technology grows larger. Even if productivity enhancing research were to cease, maintenance research would still be needed to replace previous research as it deteriorates. If research funding were not an issue, scientists could always increase spending on productivity enhancing research without negating the ability to conduct maintenance research. However, research funding is a major issue which will increasingly make productivity enhancing research and maintenance research tradeoffs. Yet, productivity enhancing research conducted at the expense of maintenance research will yield lower returns due to research depreciation than if maintenance research had been conducted. Thus, the costs of productivity enhancing research will increase. Similarly, if maintenance research is conducted at the expense of productivity enhancing research, there is no hope to increase output through agricultural research. Instead, all output increases will come through increases in intermediate inputs, labor, and land. The Green Revolution would be over.

Like the Red Queen, agricultural research is running in place. It takes maintenance research just to stay in place. To move forward and increase productivity, productivity enhancing research is needed in order to run faster. In some cases, the amount of maintenance research may be inadequate to keep productivity constant. Therefore, the benefits of productivity enhancing research are being mitigated. For example, productivity advances have historically masked land degradation's impact on productivity. This suggests such advances have been undervalued. Failure to account for losses avoided through maintenance research will bias the rate of return to agricultural research downwards. In this case, it would be helpful to know the rate of return of maintenance research versus productivity enhancing research. At some point, it should become more cost effective and perhaps even necessary to address the, literally, eroding base conditions. Addressing research deterioration through maintenance research may improve output gains from productivity enhancing research more cost effectively by maintaining a constant level of base line productivity than continually funding productivity gains in the myriad individual research areas.

Does the amount of maintenance research conducted actually reflect the amount of deterioration taking place? Agricultural research funding sources have a significant impact on the amount of maintenance research conducted. Finding evidence that maintenance research has risen does not necessarily reflect the rate of research deterioration. To a degree, research funding is a tradeoff between productivity enhancing and maintenance research especially when funding sources dictate where funds are spent. But if these constraints were removed, and maintenance research was conducted purely on an ‘as needed’ basis, would the amount of agricultural research involved in maintenance research be even higher? If the answer is yes, then certain aspects of agriculture are being allowed to deteriorate.

In some cases, it may be feasible to allow certain aspects to deteriorate if others more than compensate for the difference. For example, fertility in livestock is declining, but pounds of meat per animal have increased to compensate for the difference. However, in other cases, this may not hold true. Failure to understand the significance of maintenance research and the losses it avoids can lead to a scenario in which maintenance research is underfunded. Science will lose ground on the commodities and research areas long taken for granted even as amazing advances are made in biofuels, bioterrorism, and other research topics of the day. Agriculture will not be able to sustain an additional three billion people on biofuel alone in the next fifty years.

Policy makers, university administrators, and scientists must understand the issues surrounding research deterioration and the factors responsible for maintenance research expenditures. The research budget proportion devoted to maintenance research is influenced over the long run by the accrual of small climatic changes and the pressure buildup from evolving pest and pathogen populations. In the short run, funding sources, the size of the agricultural research budget, and commodity production choices have a much more immediate effect on the proportion of maintenance research expenditures. Nonetheless, temperature variations across states have the largest short run influence on the proportion of maintenance research expenditures. Agricultural scientists will have increasing pressures placed on maintenance research due to global warming and productivity enhancing research due to a rising population.

Whereas policy makers have no direct control over the long run influences on maintenance research expenditures, they can directly control the short run influences such as how large the agricultural research budget will be and whether funds originate at the state or federal level. They can also recognize that maintenance research projects are often overlooked and taken for granted by funding sources whether at the federal, state, or university level. Instead, general funds need to be made available purely for the maintenance of past research without strings attached. Past research will deteriorate, and this point alone should be sufficient for the setting aside of funds purely for maintenance, assuming those past gains are valued by society.

The results of this survey suggest roughly 40% of the funds allocated to agricultural research are not being spent on increasing productivity to meet future demands compared to roughly 35% 20 years ago. Policy makers must account for the proportional rise in maintenance research over time when allocating funding to the agricultural research budget. The same amount of funding now buys less productivity enhancing research than it once did due to maintaining those past productivity increases. Changing climatic conditions will further increase the need for maintenance research. However, the largest obstacle to increasing agricultural productivity and maintaining past productivity gains may be society's ability to pay for it.

References

Adusei, E.O. and G.W. Norton. 1990. "The magnitude of agricultural maintenance research in the USA." Journal of Production Agriculture 3(1):1-6.

Alston, J.M., and P.G. Pardey. 1996. *Making science pay: the economics of agricultural R&D policy.* Washington, D.C.: AEI Press.

Alston, J.M., G.W. Norton, and P.G. Pardey. 1998. *Science under scarcity: principles and practice for agricultural research evaluation and priority setting*. Ithaca, New York: Oxford University Press.

Alston, J.M., C. Chan-Kang, M.C. Marra, P.G. Pardey, and T.J. Wyatt. 2000a. *A meta-analysis of rates of return to agricultural R&D: ex pede herculem?* Washington DC: International Food Policy Research Institute, Research Report 113.

Alston, J.M., M.C. Marra, P.G. Pardey, T.J. Wyatt. 2000b. "Research returns redux: a meta-analysis of the returns to agricultural R&D." *Australian Journal of Agricultural and Resource Economics* 44(2):185-215.

Alston, J.M. and P.G. Pardey. 2001. "Attribution and other problems in assessing the returns to agricultural R&D." *Agricultural Economics* 25(2-3):141-152.

Antle, J. 1983. "Infrastructure and Aggregate Agricultural Productivity: International Evidence." *Economic Development and Cultural Change* 31(3):609-619.

Araji, A.A. 1990. "The Functions, Focus, and Productivity of the State Agricultural Experiment Stations in the United States." *Agribusiness* 6(6):633-642.

Araji, A.A., R.J. Sim, and R.L. Gardner. 1978. "Returns to Agricultural Research and Extension Programs: An Ex-Ante Approach." *American Journal of Agricultural Economics* 60(5):964-968.

Ball, V.E. 1985. "Output, input, and productivity measurement in U.S. agriculture, 1948-79." *American Journal of Agricultural Economics* 67(3):475-486.

Ball, V.E. 2005. "Ag Productivity Drives Output Growth." *Amber Waves* 3(3):6.

Ball, V.E. 2009. *Agricultural Productivity in the United States: Data Documentation and Methods.* Washington DC: U.S. Department of Agriculture, Economic Research Service, http://www.ers.usda.gov/data/agproductivity/methods.htm, accessed 1/17/09.

Ball, V.E., J.C. Bureau, R. Nehring, and A. Somwaru. 1997. "Agricultural Productivity Revisited." *American Journal of Agricultural Economics* 79:1045-1063.

Ball, V.E., R. Färe, S. Grosskopf, and R. Nehring. 2001. "Productivity of the U.S. Agricultural Sector: The Case of Undesirable Outputs." In C. Hulten, E. Dean, and M.Harper, ed. *New Developments in Productivity Analysis*. Chicago: University of Chicago Press, pp. 541-585.

Ball, V.E., J.P. Butault, and R.F. Nehring. 2002. "U.S. Agriculture, 1960-96: A Multilateral Comparison of Total Factor Productivity." In E. Ball and G. Norton, ed. *Agricultural Productivity: Measurement and Sources.* Norwell, MA: Kluwer Academic Publishers, pp. 11-35.

Barnes, A.P. 2002. "Publicly-funded UK agricultural R&D and 'social' total factor productivity." *Agricultural Economics* 27:65-74.

Barton, G.T., and M.R. Cooper. 1948. "Relation of Agricultural Production to Inputs." *Review of Economics and Statistics* 30:117-126.

Blakeslee, L. 1987. "Measuring the requirements and benefits of productivity maintenance research." In W.B. Sundquist, ed. *Evaluating Agricultural Research and Productivity*. St. Paul: Minnesota Agricultural Research Station, pp. 67-83.

Byerlee, D., and R. Murgai. 2001. "Sense and sustainability revisited: the limits of total factor productivity measures of sustainable agricultural systems." *Agricultural Economics* 26:227–236.

Chavas, J.P. and T.L. Cox. 1992. "A Nonparametric Analysis of the Influence of Research on Agricultural Productivity." *American Journal of Agricultural Economics* 74(3):583-591.

Denison, E.F. 1962. *The Sources of Economic Growth in the United States and the Alternatives before Us.* New York: Committee for Economic Development.

Doll, J.P. 1967. "An Analytical Technique for Estimating Weather Indexes from Meteorological Measurements." *Journal of Farm Economics* 49:79-88.

Evenson, R.E. 1968. "The Contribution of Agricultural Research and Extension to Production." Ph.D. dissertation, University of Chicago.

Evenson, R.E. 1989. "Spillover Benefits of Agricultural Research: Evidence from U.S. Experience." *American Journal of Agricultural Economics*, 71(2):447-452.

Fuglie, K.O., J.M. MacDonald, and V.E. Ball. 2007. *Productivity Growth in U.S.* Agriculture. Washington DC: U.S. Department of Agriculture, Economic Research Service, Econ. Brief 9, September.

Fuglie, K.O., and P.W. Heisey. 2007. *Economic Returns to Public Agricultural Research.* Washington DC: U.S. Department of Agriculture, Economic Research Service, Econ. Brief 10, September.

Gopinath, M., and T. Roe. 1997. "Sources of Sectoral growth in an Economy Wide Context: The Case of U.S. Agriculture." Journal of Productivity Analysis 8(3):293-310.

Griliches, Z. 1958. “Research Costs and Social Returns: Hybrid Corn and Related Innovations.” *Journal of Political Economy* 66(5):419-431.

Griliches, Z. 1961. “An Appraisal of Long-Term Capital Estimates: Comment.” Output, Input and Productivity Measurement. A Report of the National Bureau of Economic Research. Princeton, N.J.: Princeton University Press.

Griliches, Z. 1963a. “Estimates of the Aggregate Agricultural Production Function from Cross Sectional Data.” *Journal of Farm Economics* 45:419-428.

Griliches, Z. 1963b. “The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960.” *Journal of Political Economy* 71:331-346.

Griliches, Z. 1964. “Research Expenditures, Education and the Aggregate Agricultural Production Function.” *American Economics Review* 54:961-974.

Huffman, W.E. 2000. “Human Capital: Education and Agriculture.” In B.L. Gardner and G. Rausser, ed. *Handbook of Agricultural Economics*, vol. I. Amerstdam: Elsevier Science/North-Holland, pp. 333-381.

Huffman, W.E. and R.E. Evenson. 2005. “New Econometric Evidence on Agricultural Total Factor Productivity Determinants: Impact of Funding Sources.” Iowa State University, Department of Economics, Working Paper #03029.

Huffman, W.E. and R.E. Evenson. 2006. *Science for agriculture: a long-term perspective*. Ames: Iowa State University Press.

Jorgenson, D., and F. Gollop. 1992. "Productivity Growth in U.S. Agriculture: A Postwar Perspective." *American Journal of Agricultural Economics* 74:745-50.

Jorgenson, D., F. Gollop, and B. Fraumeni. 1987. *Productivity and U.S. Economic Growth.* Cambridge MA: Harvard University Press.

Kendrick, J.W., and E.S. Grossman. 1980. *Productivity in the United States, Trends and Cycles.* Baltimore, MD: The Johns Hopkins University Press.

Kendrick, J.W. 1961. “Productivity Trends in the United States.” National Bureau of Economic Research, New York. Princeton, NJ: Princeton University Press.

Loomis, R.A., and G.T. Barton. 1961. *Productivity of Agriculture.* Washington DC: U.S. Department of Agriculture, ERS.

Marasas, C.N., M. Smale, and R.P. Singh. 2003. “The economic impact of productivity maintenance research: breeding for leaf rust resistance in modern wheat.” *Agricultural Economics* 29:253-263.

Morris, M.L., and P.W. Heisey. 2003. “Estimating the benefits of plant breeding research: methodological issues and practical challenges.” *Agricultural Economics* 29:241-252.

Oury, D. 1965. “Allowing for weather in crop production model building.” *Journal of Farm Economics* 47(2):270-283.

Plucknett, D.L. and N.J.H. Smith. 1986. "Sustaining agricultural yields." *BioScience* 36(1):40-45.

Ruttan, V.W. 1999. "The transition to agricultural sustainability." *Proceedings of the National Academy of Sciences of the United States of America* 96(11):5960-5967.

Ruttan, V.W. 2002. “Productivity Growth in World Agriculture: Sources and Constraints.” *Journal of Economic Perspectives* 16(4):161-184.

Schultz, T.W. 1953. *The Economic Organization of Agriculture*. New York, NY: McGraw-Hill Book Company.

Swallow, B.M., G.W. Norton, T.B. Brumback, and G.R. Buss. 1985. “Agricultural research depreciation and the importance of maintenance research.” Department of Agricultural Economics, Research Report 56, Virginia Polytechnic Institute and State University.

Stallings, J.L. 1958. “Indexes of the Influence of Weather on Agricultural Output.” PhD dissertation, Michigan State University.

Thornthwaite, C.W. 1948. “An Approach toward a Rational Classification of Climate.” *Geographical Review* 38:55-94.

Townsend, R., and C. Thirtle. 2001. “Is livestock research unproductive? Separating health maintenance from improvement research.” *Agricultural Economics* 25:177–189.

U.S. Department of Agriculture, National Resources Conservation Service. 2003. *2003 Annual National Resources Inventory: Soil Erosion*. http://www.nrcs.usda.gov/technical/NRI/2003/nri03eros-mrb.html, accessed 12/17/08.

U.S. Department of Agriculture. 2007. *Agricultural Prices: 2006 Summary*. National Agricultural Statistics Service, Washington DC, July.

U.S. Department of Agriculture, Economic Research Service. 2008a. *Data Sets – Farm Income: Data Files*. http://www.ers.usda.gov/Data/FarmIncome/FinfidmuXls.htm, accessed 12/17/08.

U.S. Department of Agriculture, National Resources Conservation Service. 2008b. *National Resources Inventory*. http://www.nrcs.usda.gov/technical/NRI/, accessed 12/17/08.

U.S. Department of Commerce, Bureau of the Census. 2008a. *International Data Base*. http://www.census.gov/ipc/www/idb/, accessed 12/17/08.

U.S. Department of Commerce, National Oceanic and Atmospheric Adminsistration. 2008b. *Earth System Research Laboratory: Create a monthly or seasonal time series of climate variables*. http://www.cdc.noaa.gov/Timeseries/index.html, accessed 12/17/08.

White, F.C., and A.A. Araji. 1990. "An Analysis of Experiment Station Funding Decisions." *Western Journal of Agricultural Economics* 15(2):282-290.

Wiebe, K. 2003. *Linking Land Quality, Agricultural Productivity, and Food Security.* Washington DC: U.S. Department of Agriculture, ERS Agr. Econ. Rep. 823, June.

Yee, J., W. Huffman, M. Ahearn, and D. Newton. 2002. "Sources of Productivity Growth at the State Level, 1960-1993," In E. Ball and G. Norton, ed. *Agricultural Productivity: Measurement and Sources.* Norwell, MA: Kluwer Academic Publishers, pp. 185-209.

Zhang, B., and C.A. Carter. 1997. "Reforms, the Weather, and Productivity Growth in China's Grain Sector." *American Journal of Agricultural Economics* 79(4):1266-1277.

Appendix A

2008 Scientist Survey on Magnitude of Maintenance Research

Dear Agricultural Scientist:

We are conducting a study of the importance of maintenance research to U.S. agriculture. Because the effects of research can "depreciate" or deteriorate over time, the absence of on-going research may lead to declines in agricultural productivity. Maintenance research is defined as the research needed to prevent crop and livestock productivity from declining. Maintenance research has also been referred to as "protective" research and "defense-of-gains" research.

The following are examples of research depreciation leading to maintenance research:

- A new strain of southern corn leaf blight provided an average 15% drop in U.S. maize yields in 1970. This spurred research which resulted in new hybrids based on other parents.

- Asian soybean rust was discovered in the United States in 2004. It causes significant yield losses in other countries and has the potential to do the same in the United States. Research is underway to breed resistant soybean cultivars.

- Pasteurella and other livestock respiratory pathogens that developed resistance to antibiotics in the 1980s required research to develop new vaccine and immuno-regulatory agents to supplant the previous ones to maintain productivity.

- Reduced tillage is seen as a way to mitigate yield-reducing soil loss. However, maintenance research was needed to adapt seeding practices, crop rotation practices, weed control methods, and specialized machinery to sustain production under reduced tillage.

While it is frequently recognized that research increases agricultural productivity, these examples illustrate that a portion of the benefits of research stems from the maintaining of previous productivity gains. Unless we measure that maintenance effort, we may undervalue agricultural research.

We would greatly appreciate your assistance in filling out the attached brief questionnaire (seven questions) to help us assess the importance of maintenance research in your field. Thank you for your cooperation.

Survey Questions

1. Which agricultural commodities (for example, corn, wheat, dairy) or other subjects are the focus of your research program? Please list below the percentages of your research time devoted to each.

Commodity	Percent of research time
1.	
2.	
3.	
4.	
5.	
Non-commodity research subject	
1.	
2.	

2. What is (are) the major objective(s) of your research?

____
____
____

3. Have you observed an example(s) of research depreciation related to research in your field?
Yes___ No___
If yes, please describe briefly (If no, please go to question 5):

____
____
____
____

4. If the answer to (3) is yes, was maintenance research undertaken to replace the depreciated research? Yes___ No___
If yes, please describe briefly:

____
____
____
____

5. What is the approximate annual budget of your research program, not including your own salary? _________________

6. What percentage of your overall research effort is devoted to maintenance research? ______

7. If you listed more than one commodity (or type of non-commodity) research in question 1, does the percentage of your research devoted to maintenance research vary by commodity (or type of non-commodity) research? Yes____ No____

If yes, please list this percentage for each commodity or other type of research.

Commodity or other research	Percent of research devoted to maintenance research

Please provide any additional comments below:

____

____

____

____

Appendix B

1986 Scientist Survey on Magnitude of Maintenance Research

Dear Agricultural Scientist:

We are in the process of conducting a study of the importance of maintenance research to U.S. agriculture. Because the effects of any particular research result can "depreciate" or deteriorate over time, the absence of ongoing research may lead to declines in agricultural productivity. Maintenance research is defined as the research needed to prevent crop and livestock productivity form declining. Maintenance research has also been referred to as "protective" research, "productivity sustaining" research, and "defense-of-gains" research.

The following are examples of research depreciation leading to maintenance research:

- Race 15 b of wheat rust in the United States reduced wheat production in 1953-54 and was followed by research to develop new resistant varieties.

- A new strain of southern corn leaf blight provided an average 15% drop in U.S. maize yields in 1970. This spurred research which resulted in new hybrids based on other parents.

- In S. E. Asia, new hopper populations against rice variety IR36 appeared in 1982. Researchers at the International Rice Research Institute were prepared for changes in the hopper populations; IR56 was multiplied to replace IR36, and IR60 was released in 1983 to ensure that there will not be further declines in rice production.

While it is frequently recognized that research increases agricultural productivity, these three examples illustrated that a portion of the benefits of research stems from the maintaining of past productivity gains. Unless we measure that maintenance effort we may undervalue agricultural research.

Not all maintenance research relates to insects or diseases as the above examples might suggest. We would greatly appreciate your assistance in filling out the attached questionnaire to help us assess the importance of maintenance research in your field. If you have any questions or comments concerning this survey, please do not hesitate to call us. Thank you for your cooperation.

Survey Questions

1.) Are you conducting research related to a particular commodity? Yes___ No___
If yes, which commodity or commodities? Please indicate the percentage of your research devoted to each commodity.

2.) What is(are) the major objective(s) of your research?

3.) Have you observed an example(s) of research depreciation related to research in your field?
Yes___ No___
If yes, please describe briefly (If no, please go to question 5):

4.) If the answer to (3) is yes, was maintenance research undertaken to replace the depreciated research? Yes___ No___
If yes, please describe briefly:

5.) What is the approximate annual budget of your research program, not including your salary?

6.) What percentage of your research effort is devoted to maintenance research?

7.) If you listed more than one commodity in question 1, does the percentage of your research devoted to maintenance research vary by commodity? Yes____ No____
If yes, please list this percentage by commodity.

Please provide any additional comments on the reverse side of this sheet.

Appendix C: 2008 Differences between means of commodities and non-commodities

Table 10: Commodity and non-commodity comparisons for which the differences between means of the percentages of research effort devoted to maintenance research were significant at the 5% level

Commodity/Non-Commodity Comparison	Differences between means of research effort
Oats - Human Resources	41.2
Oats - Pasture and Forage Crops (Hay)	36.6
Oats - Poultry	34.8
Oats - All Noncommodities	33.8
Oats - Soil, Air, Water	33.1
Wheat - Human Resources, Organization, and Institutions	31.8
Sugar Crops - Human Resources, Organizations, and Institutions	30.9
Sorghum - Human Resources, Organization, and Institutions	28.9
Soybeans - Human Resources, Organization, and Institutions	28.1
Wheat - Pasture and Forage Crops (Hay)	27.2
Pasture and Forage Crops (Hay) - Sugar Crops	26.3
Barley - Human Resources, Organization, and Institutions	25.8
Wheat - Poultry	25.4
Poultry - Sugar Crops	24.5
Wheat - All Noncommodities	24.4
Sorghum - Pasture and Forage Crops (Hay)	24.3
Wheat - Soil, Air, Water	23.7
Pasture and Forage Crops (Hay) - Soybeans	23.5
Sugar Crops - All Noncommodities	23.5
Soil, Air, Water - Sugar Crops	22.8
Sorghum - Poultry	22.5
Poultry - Soybeans	21.7
Sorghum - All Noncommodities	21.5
Sorghum - Soil, Air, Water	20.8
Soybeans - All Noncommodities	20.7
Other Crops - Human Resources	20.0
Soil, Air, Water - Soybeans	20.0
All Commodities - Human Resources	19.7
Fruits - Human Resources	19.3
Livestock - Human Resources, Organizations, and Institutions	18.6
Wheat - Corn	18.3
Wheat - Vegetables	18.2
Wheat - Potato	17.7
Wheat - Ornamental and Turf	17.7
Wheat - Natural Resources	17.7

Table 6: continued

Commodity/Non-Commodity Comparison	Differences between means of research effort
Pasture and Forage Crops (Hay) - Other Crops	15.4
Pasture and Forage Crops (Hay) - All Commodities	15.1
Fruits - Pasture and Forage Crops (Hay)	14.7
Soybeans - Corn	14.6
Soybeans - Vegetables	14.5
Pasture and Forage Crops (Hay) - Livestock	14.0
Poultry - All Commodities	13.3
Wheat - Livestock	13.2
Fruits - Poultry	12.9
Other Crops - All Noncommodities	12.6
Wheat - Fruits	12.5
All Commodities - All Noncommodities	12.3
Wheat - All Commodities	12.1
Fruits - All Noncommodities	11.9
Soil, Air, Water - Other Crops	11.9
Wheat - Other Crops	11.8
Soil, Air, Water - All Commodities	11.6
Fruits - Soil, Air, Water	11.2
Livestock - All Noncommodities	11.2
Soil, Air, Water - Livestock	10.5

Appendix D: Maintenance Research Areas from CRIS Manual VII, VI, and V

Table 11: CRIS Manual VII Research Classifications with Maintenance Research Designations

Knowledge Area	Topic Description
Topic I. Natural Resources and Environment	
	Soil
KA101	Appraisal of Soil Resources
KA102	***Soil, Plant, Water, Nutrient Relationships***
KA103	***Management of Saline and Sodic Soils and Salinity***
KA104	Protect Soil from Harmful Effects of Natural Elements
	Water
KA111	***Conservation and Efficient Use of Water***
KA112	***Watershed Protection and Management***
	Forest and Range Resources
KA121	Management of Range Resources
KA122	Management and Control of Forest and Range Fires
KA123	Management and Sustainability of Forest Resources
KA124	Urban Forestry
KA125	Agroforestry
	Natural Resources, General
KA131	Alternative Uses of Land
KA132	***Weather and Climate***
KA133	***Pollution Prevention and Mitigation***
KA134	Outdoor Recreation
KA135	Aquatic and Terrestrial Wildlife
KA136	Conservation of Biological Diversity
	Air
KA141	***Air Resource Protection and Management***
Topic II. Plants and Their Systems	
	Plant Production
KA201	Plant Genome, Genetics, and Genetic Mechanisms
KA202	Plant Genetic Resources
KA203	***Plant Biological Efficiency and Abiotic Stresses Affecting Plants***

KA204	Plant Product Quality and Utility (Preharvest)
KA205	Plant Management Systems
KA206	Basic Plant Biology

Plant Protection

KA211	***Insects, Mites, and Other Arthropods Affecting Plants***
KA212	***Pathogens and Nematodes Affecting Plants***
KA213	***Weeds Affecting Plants***
KA214	***Vertebrates, Mollusks, and Other Pests Affecting Plants***
KA215	***Biological Control of Pests Affecting Plants***
KA216	***Integrated Pest Management Systems***

Topic III. Animals and Their Systems

Animal Production

KA301	Reproductive Performance of Animals
KA302	Nutrient Utilization in Animals
KA303	Genetic Improvement of Animals
KA304	Animal Genome
KA305	Animal Physiological Processes
KA306	***Environmental Stress in Animals***
KA307	Animal Management Systems
KA308	Improved Animal Products (Before Harvest)

Animal Protection

KA311	***Animal Diseases***
KA312	***External Parasites and Pests of Animals***
KA313	***Internal Parasites in Animals***
KA314	***Toxic Chemicals, Poisonous Plants, Naturally Occurring Toxins, and Other Hazards Affecting Animals***
KA315	Animal Welfare/Well-Being and Protection

Topic IV. Agricultural, Natural Resource and Biological Engineering

KA401	Structures, Facilities, and General Purpose Farm Supplies
KA402	Engineering Systems and Equipment
KA403	Waste Disposal, Recycling, and Reuse
KA404	Instrumentation and Control Systems
KA405	Drainage and Irrigation Systems and Facilities

Topic V. Food and Non-Food Products: Development, Processing, Quality, and Delivery

	Food
KA501	New and Improved Food Processing Technologies
KA502	New and Improved Food Products
KA503	Quality Maintenance in Storing and Marketing Food Products
KA504	Home and Commercial Food Service
	Non-Food
KA511	New and Improved Non-Food Products and Processes
KA512	Quality Maintenance in Storing and Marketing Non-Food Products

Topic VI. Economics, Markets, and Policy

KA601	***Economics of Agricultural Production and Farm Management***
KA602	***Business Management, Finance, and Taxation***
KA603	***Market Economics***
KA604	***Marketing and Distribution Practices***
KA605	***Natural Resource and Environmental Economics***
KA606	***International Trade and Development***
KA607	***Consumer Economics***
KA608	***Community Resource Planning and Development***
KA609	***Economic Theory and Methods***
KA610	***Domestic Policy Analysis***
KA611	***Foreign Policy and Programs***

Topic VII. Human Nutrition, Food Safety, and Human Health and Well-Being

	Human Nutrition
KA701	Nutrient Composition of Food
KA702	Requirements and Function of Nutrients and Other Food Components
KA703	Nutrition Education and Behavior
KA704	Nutrition and Hunger in the Population
	Food Safety
KA711	Ensure Food Products Free of Harmful Chemicals, Including Residues from Agricultural and Other Sources
KA712	***Protect Food from Contamination by Pathogenic Microorganisms, Parasites, and Naturally Occurring Toxins***

	Human Health
KA721	***Insects and Other Pests Affecting Humans***
KA722	***Zoonotic Diseases and Parasites Affecting Humans***
KA723	Hazards to Human Health and Safety
KA724	Healthy Lifestyle

Topic VIII. Families, Youth, and Communities

KA801	Individual and Family Resource Management
KA802	Human Development and Family Well-Being
KA803	Sociological and Technological Change Affecting Individuals, Families, and Communities
KA804	Human Environmental Issues Concerning Apparel, Textiles, and Residential and Commercial Structures
KA805	Community Institutions, Health, and Social Services
KA806	Youth Development

Topic IX. Program and Project Support, Administration, and Communication

KA901	Program and Project Design, and Statistics
KA902	Administration of Projects and Programs
KA903	Communication, Education, and Information Delivery

Knowledge Areas in ***Bold Italics*** represent Maintenance Research Knowledge Areas

Table 12: CRIS Manual VI Research Classifications with Maintenance Research Designations

Research Problem Area	Topic Description
Topic I. Natural Resources and Environment	
	Soil
RPA101	Appraisal of Soil Resources
RPA102	***Soil, Plant, Water, Nutrient Relationships***
RPA103	***Management of Saline and Sodic Soils and Salinity***
RPA104	Protect Soil from Harmful Effects of Natural Elements
	Water
RPA111	***Conservation and Efficient Use of Water***
RPA112	***Watershed Protection and Management***
	Forest and Range Resources
RPA121	Management of Range Resources
RPA122	Management and Control of Forest and Range Fires
RPA123	Management and Sustainability of Forest Resources
RPA124	Urban Forestry
RPA125	Agroforestry
	Natural Resources, General
RPA131	Alternative Uses of Land
RPA132	***Weather and Climate***
RPA133	***Pollution Prevention and Mitigation***
RPA134	Outdoor Recreation
RPA135	Aquatic and Terrestrial Wildlife
Topic II. Plants and Their Systems	
	Plant Production
RPA201	Plant Genome, Genetics, and Genetic Mechanisms
RPA202	Plant Genetic Resources and Biodiversity
RPA203	***Plant Biological Efficiency and Abiotic Stresses Affecting Plants***
RPA204	Plant Product Quality and Utility (Preharvest)
RPA205	Plant Production Management Systems
RPA206	Basic Plant Biology
	Plant Protection
RPA211	***Insects, Mites, and Other Arthropods Affecting Plants***

RPA212	***Pathogens and Nematodes Affecting Plants***
RPA213	***Weeds Affecting Plants***
RPA214	***Vertebrates, Mollusks, and Other Pests Affecting Plants***
RPA215	***Biological Control of Pests Affecting Plants***
RPA216	***Integrated Pest Management Systems***

Topic III. Animals and Their Systems

Animal Production

RPA301	Reproductive Performance of Animals
RPA302	Nutrient Utilization in Animals
RPA303	Genetic Improvement of Animals
RPA304	Animal Genome
RPA305	Animal Physiological Processes
RPA306	***Environmental Stress in Animals***
RPA307	Animal Production Management Systems
RPA308	Improved Animal Products (Before Harvest)

Animal Protection

RPA311	***Animal Diseases***
RPA312	***External Parasites and Pests of Animals***
RPA313	***Internal Parasites in Animals***
RPA314	***Toxic Chemicals, Poisonous Plants, Naturally Occuring Toxins, and Other Hazards Affecting Animals***
RPA315	Animal Welfare/Well-Being and Protection

Topic IV. Engineering and Support Systems

RPA401	Structures, Facilities, and General Purpose Farm Supplies
RPA402	Engineering Systems and Equipment
RPA403	Waste Disposal, Recycling, and Reuse
RPA404	Instrumentation and Control Systems
RPA405	Drainage and Irrigation Systems and Facilities

Topic V. Food and Non-Food Products: Development, Processing, Quality, and Delivery

Food

RPA501	New and Improved Food Processing Technologies
RPA502	New and Improved Food Products

RPA503	Quality Maintenance in Storing and Marketing Food Products
RPA504	Home and Commercial Food Service
	Non-Food
RPA511	New and Improved Non-Food Products and Processes
RPA512	Quality Maintenance in Storing and Marketing Non-Food Products

Topic VI. Economics, Markets, and Policy

RPA601	***Economics of Agricultural Production and Farm Management***
RPA602	***Business Management, Finance, Taxation, and Estate Planning***
RPA603	***Market Economics***
RPA604	***Marketing and Distribution Practices***
RPA605	***Natural Resource and Environmental Economics***
RPA606	***International Trade and Development Economics***
RPA607	***Consumer Economics***
RPA608	***Community Resource and Development Economics***
RPA609	***Economic Theory and Methods***
RPA610	***Domestic Policy Analysis***
RPA611	***Foreign Policy and Programs***

Topic VII. Human Nutrition, Food Safety, and Human Health and Well-Being

	Human Nutrition
RPA701	Nutrient Composition of Food
RPA702	Requirements and Function of Nutrients and Other Food Components
RPA703	Nutrition Education
	Food Safety
RPA711	Ensure Food Products Free of Harmful Chemicals, Including Residues from Agricultural and Other Sources
RPA712	***Protect Food from Contamination by Pathogenic Microorganisms, Parasites, and Naturally Occurring Toxins***
	Human Health
RPA721	***Insects and Other Pests Affecting Humans***
RPA722	***Zoonotic Diseases and Parasites Affecting Humans***
RPA723	Hazards to Human Health and Safety

Topic VIII. Family and Community Systems

RPA801	Family Resource Management
RPA802	Human Development and Family Well-Being
RPA803	Sociological and Technological Change Affecting Individuals, Families, and Communities
RPA804	Human Environmental Issues Concerning Apparel, Textiles, and Residential and Commercial Structures
RPA805	Community Institutions and Social Services

Topic IX. Research Support, Administration, and Communication

RPA901	Research Design and Statistics
RPA902	Research on Administration of Research
RPA903	Communication, Education, and Information Delivery

Research Problem Areas in ***Bold Italics*** represent Maintenance Research Problem Areas

Table 13: CRIS Manual V Research Classification with Maintenance Research Designations

Research Problem Area	Topic Description
Goal I. Insure a Stable and Productive Agriculture for the Future Through Wise Management of Natural Resources	
RPA101	Appraisal of Soil Resources
RPA102	***Soil, Plant, Water, Nutrient Relationships***
RPA103	***Management of Saline and Sodic Soils and Salinity***
RPA104	Alternative Uses of Land
RPA105	***Conservation and Efficient Use of Water***
RPA106	Efficient Drainage and Irrigation Systems and Facilities
RPA107	***Watershed Protection and Management***
RPA108	***Economic and Legal Problems in Management of Water and Watersheds***
RPA109	***Adaptation to Weather and Weather Modification***
RPA110	***Appraisal of Forest and Range Resources***
RPA111	Biology, Culture, and Management of Forests and Timber-Related Crops
RPA112	Improvement of Range Resources
RPA113	Remote Sensing
RPA114	Research on Management of Research
Goal II. Protect Forests, Crops, and Livestock from Insects, Diseases, and Other Hazards	
RPA201	***Control of Insects Affecting Forests***
RPA202	***Control of Diseases, Parasites, and Nematodes Affecting Forests***
RPA203	Prevention and Control of Forest and Range Fires
RPA204	***Control of Insects, Mites, Slugs, and Snails on Fruit and Vegetable Crops***
RPA205	***Control of Diseases and Nematodes of Fruit and Vegetable Crops***
RPA206	***Control of Weeds and Other Hazards of Fruit and Vegetable Crops***
RPA207	***Control of Insects, Mites, Snails, and Slugs Affecting Field Crops and Range***
RPA208	***Control of Diseases and Nematodes of Field Crops and Range***
RPA209	***Control of Weeds and Other Hazards of Field Crops and Range***

RPA210	***Control of Insects and External Parasites Affecting Livestock, Poultry, Fish, and Other Animals***
RPA211	***Control of Diseases of Livestock, Poultry, Fish, and Other Animals***
RPA212	***Control of Internal Parasites of Livestock, Poultry, Fish, and Other Animals***
RPA213	***Protect Livestock, Poultry, Fish, and Other Animals from Toxic Chemicals, Poisonous Plants, and Other Hazards***
RPA214	***Protection of Plants, Animals, and Man from Harmful Effects of Pollution***

Goal III. Produce an Adequate Supply of Farm and Forest Products at Decreasing Real Production Costs

RPA301	Genetics and Breeding of Forest Trees
RPA302	New and Improved Forest Engineering Systems
RPA303	***Economics of Timber Production***
RPA304	Improvement of Biological Efficiency of Fruit and Vegetable Crops
RPA305	Mechanization of Fruit and Vegetable Crop Production
RPA306	Production Management Systems for Fruits and Vegetables
RPA307	Improvement of Biological Efficiency of Field Crops
RPA308	Mechanization of Production of Field Crops
RPA309	Production Management Systems for Field Crops
RPA310	Reproductive Performance of Livestock, Poultry, Fish, and Other Animals
RPA311	Improvement of Biological Efficiency in Production of Livestock, Poultry, Fish, and Other Animals
RPA312	***Environmental Stress in Production of Livestock, Poultry, Fish, and Other Animals***
RPA313	Production Management Systems for Livestock, Poultry, Fish, and Other Animals
RPA314	Bees and Other Pollinating Insects
RPA315	Improvement of Structures, Facilities, and General Purpose Farm Supplies and Equipment
RPA316	***Farm Business Management***
RPA317	Mechanization and Structures Used in Production of Livestock, Poultry, Fish, and Other Animals
RPA318	Non-Commodity-Oriented Biological Technology and Biometry

Goal IV. Expand the Demand for Farm and Forest Products by Developing New and Improved Products and Processes and Enhancing Product Quality

RPA401	New and Improved Forest Products
RPA402	Production of Fruits and Vegetable Crops with Improved Acceptability
RPA403	New and Improved Fruit and Vegetable Products and Byproducts
RPA404	Quality Maintenance in Storing and Marketing Fruits and Vegetables
RPA405	Production of Field Crops with Improved Acceptability
RPA406	New and Improved Food Products from Field Crops
RPA407	New and Improved Feed, Textile, and Industrial Products from Field Crops
RPA408	Quality Maintenance in Storing and Marketing Field Crops
RPA409	Production of Animal Products with Improved Acceptability
RPA410	New and Improved Meat, Milk, Eggs, and Other Animal Food Products
RPA411	New and Improved Non-Food Animal Products
RPA412	Quality Maintenance in Marketing Animal Products

Goal V. Improve Efficiency in the Marketing System

RPA501	Improvement of Grades and Standards—Crop and Animal Products
RPA502	***Development of Markets and Efficient Marketing of Timber and Related Products***
RPA503	***Efficiency in Marketing Agricultural Products and Production Inputs***
RPA506	***Supply, Demand, and Price Analysis—Crop and Animal Products***
RPA507	***Competitive Interrelationships in Agriculture***
RPA508	***Development of Domestic Markets for Farm Products***
RPA509	***Performance of Marketing Systems***
RPA510	***Group Action and Market Power***
RPA511	***Improvement in Agricultural Statistics***
RPA512	Improvement of Grades and Standards—Forest Products
RPA513	***Supply, Demand, and Price Analysis—Forest Products***

Goal VI. Expand Export Markets and Assist Developing Nations

RPA601	***Foreign Market Development***
RPA602	***Evaluation of Foreign Food Aid Programs***
RPA603	***Technical Assistance to Developing Countries***

RPA604	***Product Development and Marketing for Foreign Markets***

Goal VII. Protect Consumer Health and Improve Nutrition and Well-Being of the American People

RPA701	Insure Food Products Free of Toxic Contaminants, Including Residues from Agricultural and Other Sources
RPA702	***Protect Food and Feed Supplies from Harmful Microorganisms and Naturally Occurring Toxins***
RPA703	Food Choices, Habits, and Consumption
RPA704	Home and Commercial Food Service
RPA705	Selection and Care of Clothing and Household Textiles
RPA706	***Control of Insect Pests of Man and His Belongings***
RPA707	***Prevent Transmission of Animal Diseases and Parasites to Man***
RPA708	Human Nutrition
RPA709	Reduction of Hazards to Health and Safety

Goal VIII. Assist Rural Americans to Improve their Level of Living

RPA801	Housing
RPA802	Individual and Family Decision Making and Resource Use and Family Functioning
RPA803	Causes of Poverty Among Rural People
RPA804	Improvement of Economic Potential of Rural People
RPA805	Communication and Education Processes
RPA806	Individual and Family Adjustment to Change
RPA807	***Structural Changes in Agriculture***
RPA808	***Government Programs to Balance Farm Output and Market Demand***

Topic IX. Promote Community Improvement Including Development of Beauty, Recreation, Environment, Economic Opportunity, and Public Services

RPA901	***Alleviation of Soil, Water, and Air Pollution and Disposal of Wastes***
RPA902	Outdoor Recreation
RPA903	Multiple Use Potential of Forest Land and Evaluation of Forestry Programs
RPA904	Fish and Other Aquatic Life, Fur-Bearing Animals, and Other Wildlife
RPA905	Trees to Enhance Rural and Urban Environment

RPA906	Culture and Protection of Ornamentals and Turf
RPA907	***Improved Income Opportunities in Rural Communities***
RPA908	Improvement of Rural Community Institutions and Services

Research Problem Areas in ***Bold Italics*** represent Maintenance Research Problem Areas