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# Private Agricultural R&D in the United States

**Simla Tokgoz**

The objective of this study is to analyze the determinants of private agricultural R&D investment in the United States and the liaison between public and private R&D sectors. The empirical analysis employs U.S. agricultural data for the 1970–1996 period. The results show that federal R&D obligations for basic research, used as a proxy for the complementary role of public R&D, have a significant and positive impact on private agricultural R&D spending. In contrast, federal R&D obligations for applied research, used as a proxy for the substitute role of public R&D, are not found to have a significant impact.

*Key words:* applied public agricultural R&D, basic public agricultural R&D, private agricultural R&D, quality innovation model, technical change

## Introduction

The performance of U.S. agriculture during the post-war period is noteworthy. Agriculture has experienced one of the highest productivity growth rates of all industries, and productivity growth is a major source of output growth. An extensive literature has focused on the determinants of productivity growth in agriculture, particularly on the roles of public and private research and development (R&D). Ample empirical evidence shows that these activities play an important role in productivity gains.

The public sector has traditionally taken the lead in agricultural R&D activities, aided by a system which includes both federal and state institutions, as well as an extension system entrusted with helping to disseminate the new technology. However, recent developments in the agricultural R&D sector suggest the need to reexamine the role of public and private R&D sectors. The level and the composition of both public and private R&D investment have changed over the last two decades. Specifically, the growth rates of federal obligations for basic and applied R&D for the biological and agricultural sciences have decreased and have sometimes become negative in real terms. On the other hand, the level of private R&D investment has increased dramatically in real terms. Consequently, the private R&D sector appears to have emerged as an equally, if not more, important part of R&D activities for the U.S. agricultural sector.

Various factors have been identified as possible reasons for the increasing role of the private sector in agricultural R&D, such as improvements in the biotechnology sector and strengthened patent protection for biological inventions. These developments in the scope and amount of private and public R&D investment have generated a need to find a new way for analyzing the division of labor between public and private R&D sectors.

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As private R&D firms have gained the ability to appropriate the benefits from their own research, the rationale for government intervention in terms of providing the socially optimal amount of research has become weaker.

In light of the above discussion, the objective of this paper is to analyze the determinants of private agricultural R&D investment in the United States. In this context, the liaison between private agricultural R&D investment and public agricultural R&D investment is investigated as well. First, the relationship between R&D activities and technical change in the U.S. agricultural sector is modeled with a focus on how the mechanism of the domestic private R&D sector operates. Second, the model analyzes the determinants of private R&D spending, including its relation with the public R&D sector.

In an earlier empirical study focusing on factors that affect private agricultural R&D investments, Alafranca and Huffman (2001) examined the effects of economic incentives and institutions on national private agricultural R&D investments. They similarly analyzed the relation between public and private R&D sectors and found that, in their sample countries, lagged public research capital reduces current agricultural private R&D expenditure. There are two fundamental differences between the current study and the earlier Alafranca and Huffman work. First, this study investigates the U.S. agricultural sector, whereas Alafranca and Huffman examined seven European Union member countries. Second, their analysis also included the impact of institutions on private R&D investments in those EU countries. Because the empirical analysis portion of the current study relies on a theoretical model to identify the factors affecting private R&D investments, the focus is more on economic factors that are captured by the model, rather than on the institutional structure in the economy.

This study attempts to provide a framework for analyzing the role of the public R&D sector and the link between private and public R&D by examining how the private R&D sector operates. To this end, a quality innovation model is used in which both public and private sectors' R&D activities lead to technical change. The public R&D sector conducts research and patents its research results in the same manner as the private R&D sector. This type of public-sector R&D activity is a substitute for private-sector R&D. Another public-sector R&D activity is included through a subsidy that effectively lowers the cost of research for private firms, and through this mechanism, the public R&D sector is a complement to the private R&D sector.

The objective of the empirical work based on this model is to explore the factors that determine private agricultural R&D investment. To do this, in the empirical portion of the analysis, the implications of the model are tested using data for the U.S. agricultural sector for the period 1970 through 1996.

The remainder of this paper proceeds as follows. First, a discussion is provided on the changing role of public and private R&D sectors in the U.S. agricultural sector. Next, the quality innovation model is described. Empirical specification is then presented, followed by a description of the data and their sources. After a discussion on the empirical methodology and the results of the empirical analysis, the final section provides concluding remarks.

## The Changing Role of Public and Private R&D Sectors

Agricultural R&D activities in the United States historically have been dominated by the public sector. The economic rationale used to justify the government's intervention in R&D has been market failure. Because the knowledge acquired from some type of

**Table 1. U.S. Agricultural Sector: Research and Development Expenditures and Average Annual Growth Rates (1970–1996)**

| | Federal Basic R&D Obligations | | Federal Applied R&D Obligations | | Private Sector R&D Spending | |
|---|---|---|---|---|---|---|
| Decades | Expenditures ($000s) | Avg. Annual Growth Rate | Expenditures ($000s) | Avg. Annual Growth Rate | Expenditures ($000s) | Avg. Annual Growth Rate |
| 1970–1979 | 23,439,768 | 4.96% | 20,114,283 | 5.40% | 13,598,798 | 6.63% |
| 1980–1989 | 35,720,887 | 3.67% | 21,933,314 | -0.06% | 20,928,510 | 1.45% |
| 1990–1996 | 23,994,592 | -0.28% | 15,367,045 | 1.42% | 18,593,086 | 2.69% |

Note: Expenditures are in thousands of 1996 dollars.

**Table 2. Research Expenditures by Agricultural Industries (1970–1996)**

| | 1970 | | 1996 | |
|---|---|---|---|---|
| Research Program Area | Expenditures ($ mill.) | Percent of Total | Expenditures ($ mill.) | Percent of Total |
| Plant Breeding | 26.30 | 10.18% | 526.13 | 18.77% |
| Agricultural Chemicals | 98.00 | 37.94% | 1,458.66 | 51.83% |
| Farm Machinery | 89.00 | 34.46% | 505.66 | 17.97% |
| Veterinary Pharmaceuticals | 45.00 | 17.42% | 323.70 | 11.50% |
| Total | 258.30 | | 2,814.15 | |

Note: Expenditures are in millions of current dollars.

R&D activities is of a public good nature, private agents are unlikely to undertake the socially optimal level of R&D activity—i.e., if it is not possible to capture the benefits from their research, private-sector entrepreneurs are unwilling to invest sufficient funds in R&D, and therefore government must make up for this deficiency. As a result of this conceptualization, the division of labor between public and private R&D traditionally has been defined as the public sector concentrating on basic research (pre-technology research) and the private sector concentrating on applied research and technology development [U.S. Department of Agriculture/Economic Research Service (USDA/ERS), 1999; Huffman and Evenson, 1993].

Recent developments in the agricultural R&D sector, however, have necessitated rethinking the division of labor between the public and private sectors. Table 1 shows the level of federal obligations for basic R&D, federal obligations for applied R&D, and private agricultural R&D spending for different decades in thousands of 1996 dollars, as well as the corresponding average annual growth rate of these variables. Between 1970 and 1996, private R&D expenditure increased more than 165%, whereas federal obligations for basic R&D increased 97% and federal obligations for applied R&D increased 73%.

As reported in table 1, federal obligations for basic R&D had a negative average growth rate for the 1990–1996 period, and federal obligations for applied R&D had a negative average growth rate for the 1980–1989 period. However, private R&D spending always experienced a positive growth rate in all decades included in this study, achieving the highest growth rate in the 1970–1979 period. Hence, the private sector already has become an important factor in R&D activities for the U.S. agricultural sector.

The categories of private R&D investment changed over time, too. Table 2 shows that expenditures on "plant breeding" and "agricultural chemicals" as a ratio of total private R&D spending increased, whereas the ratio of research spending on "veterinary pharmaceuticals" and "farm machinery" decreased in total private R&D spending.

Different factors have been identified as possible reasons for the changing role of the private sector in agricultural R&D. It has been argued that improvements in the biotechnology sector in combination with strengthened patent protection for biological inventions helped private firms find new sources of profit from agricultural R&D and secure better returns from their investments (USDA/ERS, 1999; Fuglie et al., 1996).

## The Quality Innovation Model

The quality innovation model used in this study is an endogenous growth model with an R&D sector which is the source of technical change. The main feature of the model is that technical change is modeled to be the result of commercially motivated efforts of private-sector researchers responding to economic incentives and a public R&D sector. The contribution of the model is its exploration of the liaison between a private and a public R&D sector. Both of these sectors engage in research activities that lead to improvements in the quality of intermediate goods, which in turn are used in the production of output. The private sector represents the profit-maximizing behavior of entrepreneurs, whereas the public sector represents R&D conducted by public institutions which are not motivated by profit. The model is based on Barro and Sala-I-Martin (1995, chapter 7), and Grossman and Helpman (1991, chapter 4).

The link between public and private R&D consists of two channels. The public R&D sector acts as a substitute for the private R&D sector, as it not only engages in R&D but also earns exclusive property rights to the results of its research efforts, which may drive an incumbent private-sector firm out of business. The public sector acts as a complement to the private sector by lowering the cost of research for private firms. This can be achieved through various tools, such as conducting "basic research" and making the results publicly available, providing incentives for private R&D through tax breaks or direct subsidies, and providing public funds to private firms through competitive grants.

Although economic factors impact the level of public R&D spending in the United States, other critical determinants of public R&D spending are economic and political decisions on the federal and state levels, organization of the federal and state R&D institutions, and the scientific goals of these institutions. The public R&D sector consists of many different components, including the U.S. Department of Agriculture, State Agricultural Experiment Stations (SAES), and land-grant universities. Thus, there are various mechanisms through which these decisions are made, such as federal funds allocated to states by formula, and competitive grants. As public R&D sector spending incorporates many diverse spending categories which are also governed by forces other than economic incentives, the public R&D sector is taken as exogenous in this model.[1]

[1] For a more detailed discussion of public R&D funding, see Day-Rubenstein et al. (2000), who focused on USDA funding to states, and Khanna, Huffman, and Sandler (1994), who set up a model in which agricultural R&D spending by the states is modeled as a public good.

The main feature of the production technology assumed here is the disaggregation of capital into a finite number of distinct types of intermediate goods (indexed by $j = 1, ..., N$). Each intermediate good has a quality ladder along which improvements can occur. Research efforts are aimed at increasing the existing quality of each intermediate good and are based on the currently available technology.

When a product is improved, it tends to replace the lower-quality version in the market. In this study, it is assumed that a higher-quality product is a perfect substitute for its lower-quality counterpart—i.e., it renders the older version obsolete. So, in the equilibrium, only the highest-quality intermediate goods are produced by the R&D sector and used by the producers of the final good to generate output. (In other words, instantaneous adoption of new technology is assumed.)

The quality innovation model characterizes technical change in the form of a continuing series of improvements and refinements of existing goods and techniques rather than basic innovations that amount to dramatically new kinds of goods and methods of production (Barro and Sala-I-Martin, 1995). Examples of technical changes in the U.S. agricultural sector of this nature include use of hybrid seeds, adoption of improved livestock breeding practices, and more effective agricultural chemicals, fertilizers, and pesticides.[2] In the model, each successful researcher, whether private or public, gains exclusive property rights over the use of the higher-quality intermediate good he or she creates. Private R&D firms operate in an imperfectly competitive market setting. When a private R&D firm is successful in upgrading the quality of an intermediate good, it receives a flow of monopoly profit. The researcher who succeeds in upgrading the quality of an intermediate good is different from the person who has invented the previously highest-quality intermediate good. Consequently, the success of an innovator, whether public or private, terminates the profit flow to the previous private-sector innovator. As it is uncertain whether the outcome of any research effort will be successful, the duration of this profit flow for the current patent holder is random. Hence, not only the size of the profit flow, but also its duration, determines the amount of resources devoted to research by private firms.

### *Production Technology*

The agricultural output is produced in a perfectly competitive market using land, labor, and a set of $N$ different types of intermediate goods. The production function is constructed as:

$$(1) \qquad Y = A(E) * L^{1-\alpha-\beta} * H^{\beta} * \sum_{j=1}^{N} (\tilde{X}_j)^{\alpha},$$

where $0 < \alpha < 1$, $0 < \beta < 1$, and $0 < \alpha + \beta < 1$; $Y$ denotes agricultural output; $L$ is land input; $H$ is labor input; and $\tilde{X}_j$ is the *quality-adjusted* amount employed of the $j$th type of intermediate good. The production function specifies diminishing marginal productivity of each input and constant returns to scale in all inputs together.[3]

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[2] Another type of technical change can be analyzed in a variety innovation model in which new goods and production processes are invented. Introduction of the tractor to agricultural production is a rather dramatic change representing an example of a variety innovation model.

[3] The additively separable form for $(\tilde{X}_j)^{\alpha}$ suggests the marginal product of intermediate good $X_{j\kappa_j}$ is independent of the quantity employed of intermediate good $X_{l\kappa_l}$, where $j \neq l$.

$A(E)$ is the other component of technology available to producers. Because extension services have been critically important in the United States in the dissemination and adoption of new technology, $A(E)$ is not modeled as a positive constant that illustrates the level of technology, but as a positive function of the extension services actually carried out in the agricultural sector.[4]

The potential quality grades of each intermediate good are arrayed along a quality ladder with rungs spread proportionately at an interval of $q$, where $q > 1$.[5] Inventions occur in the form of increases in the quality rungs of each intermediate good as a multiple of $q$. Therefore, the quality-adjusted input from sector $j$ can be written as:

$$\tilde{X}_j = \sum_{k=0}^{\kappa_j} q^k * X_{jk},$$

where $\kappa_j$ denotes the highest quality available to producers.

*Behavior of Firms*

The firms that produce agricultural output operate in a perfectly competitive market. Their profit-maximization problem is written as:

$$\text{(2)} \qquad \max_{L,H,X_{j\kappa_j}} \pi^Y = P_{AGR} * Y - i * L - w * H - \sum_{j=1}^{N} P_{j\kappa_j} * X_{j\kappa_j},$$

where $P_{AGR}$ is the price of output, $i$ is the rental rate of land, and $w$ is the wage rate of labor.

In contrast, the private R&D sector is monopolistically competitive. The researcher who creates a new and higher-quality intermediate good in sector $j$ gains the monopoly right to produce and sell that intermediate good. The marginal cost of producing an intermediate good is the same for all the qualities and is equal to 1. The monopolist producer of the intermediate good with quality level $\kappa_j$ will choose price $P_j$ to maximize its profits. Then, the profit-maximization problem for a private researcher is expressed as:

$$\text{(3)} \qquad \max_{P_{j\kappa_j}} \pi^{RD} = \left(P_{j\kappa_j} - 1\right) * X_{j\kappa_j}.$$

From this optimization problem, the price for each intermediate good is derived as $P_j = P = 1/\alpha$, which is a markup over the cost of production.[6]

In order to show that only the highest-quality intermediate goods are produced and used in equilibrium,[7] we need to look at the pricing of different qualities of the same intermediate good. Each unit of a leading-edge intermediate good is equivalent to $q$ units of the next-best good. If $P_{j\kappa_j}$ is the price of the highest-quality intermediate good, then $(P_{j\kappa_j}/q)$ is the price of the next-best available intermediate good. If $(1/\alpha * q) < 1$, then

[4] Makki, Thraen, and Tweeten (1999), and Huffman and Evenson (1993) are among the many researchers who have found a positive and significant impact of extension services on total factor productivity (TFP) in the U.S. agricultural sector.

[5] See Eaton and Kortum (1996) for a model in which the step size of the invention, $q$, is stochastic.

[6] The quantity produced of the $j$th intermediate good is derived by using the previous two optimization problems as:

$$X_{j\kappa_j} = P_{AGR}^{1/(1-\alpha)} * A(E)^{1/(1-\alpha)} * L^{(1-\alpha-\beta)/(1-\alpha)} * H^{\beta/(1-\alpha)} * \alpha^{2/(1-\alpha)} * q^{\kappa_j * \alpha/(1-\alpha)}.$$

[7] Otherwise, there is no closed-form solution for $X$ (intermediate goods) and $Y$ (output).

the producer of the next-best intermediate good will not be able to compete against the leader's monopoly price, and therefore monopoly pricing will prevail. So, if $q$ is sufficiently large, then lower-grade intermediate goods will be driven out of the market. If $(1/\alpha * q) > 1$, then the limit pricing strategy employed by Grossman and Helpman (1991) could be followed with the same result. In both cases, only the highest-quality intermediate goods are produced and used, and the price of the intermediate good is a markup over the marginal cost of production.

*Equilibrium R&D Effort*

Let $Q$ denote an aggregate quality index defined as

$$Q = \sum_{J=1}^{N} (q^{\kappa_j})^{\alpha/(1-\alpha)}.$$

Then, the equilibrium level of agricultural output is written as:

$$(4) \qquad Y = Q * A(E)^{1/(1-\alpha)} * P_{AGR}^{\alpha/(1-\alpha)} * \alpha^{2\alpha/(1-\alpha)} * L^{(1-\alpha-\beta)/(1-\alpha)} * H^{\beta/(1-\alpha)}.$$

Technical change in equation (4) is attained through the increases in $Q$, which in turn increase the output. $Q$ increases because of the R&D efforts of both public and private R&D sectors. To analyze the determinants of change in this aggregate quality index, we need to examine how the private R&D sector operates and the role of the public R&D sector in this process.

*Public and Private R&D Sectors*

The private-sector researcher who innovates the $\kappa_j$th quality of intermediate good $j$ will accrue his or her profits until a new researcher comes up with the $(\kappa_j + 1)$th quality intermediate good $j$. The duration of this profit is random, and it depends on the efforts of private R&D firms and the public R&D sector.

To illustrate this relationship, let $p^*$ be the probability per unit of time of an increase in quality from $\kappa_j$ to $(\kappa_j + 1)$, i.e., the society's probability of innovation. It is equal to the sum of the probability of innovation by the public sector, $p^P$, and the probability of innovation by the private sector, $p_{j\kappa_j}^Z$. The duration of monopoly profits for the private R&D firm depends on $p^*$, not on $p_{j\kappa_j}^Z$. As both public and private R&D sectors can invent the next higher-quality intermediate good, the probability of success of both of these sectors determines how long the current leader will accrue his or her monopoly profits.

This is clearer when the expected present value of the next invention to a private R&D firm is derived as:

$$(5) \qquad E(V_{j\kappa_j}) = \frac{\pi_{j\kappa_j}}{r + p^*} = \frac{\pi_{j\kappa_j}}{r + p^P + p_{j\kappa_j}^Z}.$$

The expected present value of the next innovation is lower when a public R&D sector exists, as in this case the denominator contains $p^P$ as well as $p_{j\kappa_j}^Z$. When both public- and private-sector researchers endeavor to come up with the next innovation, there is a higher probability that the next higher-quality intermediate good will be invented, thereby increasing the probability of the incumbent being driven out of business by the next innovator, and lowering the expected present value of his or her profits from the next invention by a private-sector researcher. That is why, in this model, the public-sector R&D may crowd out the private-sector R&D.

*Private-Sector Research Effort*

The flow of resources expended by the aggregate of private potential inventors in intermediate-good sector $j$, when the highest quality in that sector is $\kappa_j$, is denoted as $Z_{j\kappa_j}$. The relation between $p^Z_{j\kappa_j}$ and $Z_{j\kappa_j}$ is defined as:

$$p^Z_{j\kappa_j} = Z_{j\kappa_j} * \phi(\kappa_j). \tag{6}$$

As $Z_{j\kappa_j}$ increases, the probability of successful invention per unit of time in that sector increases. The second term, $\phi(\kappa_j)$, is added to reflect the complexity of a research project, and $\partial\phi(\kappa_j)/\partial\kappa_j < 0$. In this model, $p^*$ and $p^Z_{j\kappa_j}$ are assumed to follow a Poisson process.[8] Assuming free entry into the research business, the society's probability of innovation is derived as:

$$\begin{aligned} p^* = \phi(\kappa_j) * q^{(\kappa_j+1)*\alpha/(1-\alpha)} * \left(\frac{1-\alpha}{\alpha}\right) * P_{AGR}^{1/(1-\alpha)} * A(E)^{1/(1-\alpha)} \\ * L^{(1-\alpha-\beta)/(1-\alpha)} * H^{\beta/(1-\alpha)} * \alpha^{2/(1-\alpha)} - r. \end{aligned} \tag{7}$$

If constant returns to R&D are assumed, the functional form for $\phi(\kappa_j)$ becomes $(1/(s*\zeta)) * q^{-(\kappa_j+1)*\alpha/(1-\alpha)}$.[9] Then, the society's probability of innovation becomes:

$$\begin{aligned} p^* = \left(\frac{1}{s*\zeta}\right) * \left(\frac{1-\alpha}{\alpha}\right) * P_{AGR}^{1/(1-\alpha)} * A(E)^{1/(1-\alpha)} \\ * L^{(1-\alpha-\beta)/(1-\alpha)} * H^{\beta/(1-\alpha)} * \alpha^{2/(1-\alpha)} - r. \end{aligned} \tag{8}$$

The parameter $\zeta > 0$ represents the fixed cost of research: a higher $\zeta$ lowers the probability of success for given values of $Z_{j\kappa_j}$ and $\kappa_j$. The parameter $s$ takes a value between 0 and 1. This is the second channel through which public-sector activities affect the private R&D sector of the model. The parameter $s$ is a subsidy equivalent of public-sector activities which effectively lowers the cost of research for the private R&D sector. Here it lowers $\zeta$, which is the fixed cost of research for private R&D firms. Through this channel, the public R&D sector acts as a complement to the private R&D sector.

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[8] In equation (6), only the current level of private R&D spending is included through $Z_{j\kappa_j}$, and past R&D investments enter indirectly through $\kappa_j$. As $\kappa_j$ is the total number of inventions in intermediate-good sector $j$, it is directly related to all past research successes.

[9] In equation (7), the probability of innovation increases as $\kappa_j$ and $q^{(\kappa_j+1)*\alpha/(1-\alpha)}$ increase. The probability of innovation decreases as $\kappa_j$ increases and $\phi(\kappa_j)$ decreases. If the first effect dominates, the more advanced sectors will grow faster. If the second effect dominates, the more advanced sectors will grow slower. If the two forces offset each other, then all intermediate-good sectors will grow at the same rate and the growth rate of the agricultural sector will be constant over time and across intermediate-good sectors. In the rest of the solution, it will be assumed that these two forces offset each other, i.e., constant returns to R&D.

After solving for the probability of an innovation per unit of time by the private R&D sector, the aggregate private-sector R&D spending is derived as follows:

(9) $$Z = Q * q^{\alpha/(1-\alpha)} * \left[ \left( \frac{1-\alpha}{\alpha} \right) * P_{AGR}^{1/(1-\alpha)} * A(E)^{1/(1-\alpha)} * L^{(1-\alpha-\beta)/(1-\alpha)} * H^{\beta/(1-\alpha)} * \alpha^{2/(1-\alpha)} - (r + p^P) * (s * \zeta) \right].$$

Equation (9) shows that the private R&D spending is endogenously determined and depends on the decisions of economic agents and institutions taking part in the production and research process. It also gives information about which economic variables affect private R&D spending. First, both the aggregate quality index ($Q$) and the productivity parameter ($A(E)$) have a positive impact on private R&D spending. Second, public R&D sector activities affect $Z$ through two variables. Through the subsidy parameter ($0 < s < 1$), the public R&D sector increases private R&D spending. However, the probability of innovation by the public R&D sector ($p^P$) decreases private R&D spending, as it increases the probability of being driven out of business. The net effect of public-sector activities on the level of private R&D spending is ambiguous in the model; this is an empirical question that depends on the relative magnitude of these competing forces. The interest rate, $r$, is negatively related to the level of $Z$. As the interest rate increases, the rate of return required from the research project which will make the project feasible to undertake will be higher. With a higher interest rate, there will be fewer projects meeting this criterion in terms of profitability, and the amount of research will be lower. The price of output, land input, and labor input have a positive impact on the level of private R&D spending.

## Empirical Specification

The model provides an analysis of private R&D investment [equation (9)], where $Z = f(Q, P_{AGR}, A(E), L, H, r, p^P, s)$ as $q$ and $\zeta$ are constants. From the Taylor series expansion of this function, a linear approximation for equation (9) is obtained as follows:

(10) $$Z = f(Q^0, P_{AGR}^0, A(E)^0, L^0, H^0, r^0, p^{P,0}, s^0) + f_Q * (Q - Q^0) + f_{P_{AGR}} * (P_{AGR} - P_{AGR}^0) + f_A * [A(E) - A(E)^0] + f_L * (L - L^0) + f_H * (H - H^0) + f_r * (r - r^0) + f_p * (p^P - p^{P,0}) + f_s * (s - s^0).$$

Rearranging the terms of (10) will give:

(11) $$Z = \beta_1 + \beta_2 * Q + \beta_3 * P_{AGR} + \beta_4 * A(E) + \beta_5 * L + \beta_6 * H + \beta_7 * r + \beta_8 * p^P + \beta_9 * s.$$

As a proxy for $Q$, the aggregate quality index, we use the number of agricultural patents granted in the United States ($P_t$). In the model, the source of technical change is the increase in the aggregate quality index, which is defined as:

$$Q = \sum_{J=1}^{N} (q^{\kappa_j})^{\alpha/(1-\alpha)}.$$

As $\kappa_j$ is the total number of quality upgrades in intermediate-good sector $j$, $Q$ can be thought of as a measure of the total number of innovations in the R&D sector. Thus, as a proxy for the aggregate quality index, the number of granted patents manufactured by the firms operating in the agricultural sector is used.

In this context, it should be noted that although patents provide a good approximation to inventive activity, they provide an imperfect measure of it. First, not all inventions are patented. Second, not all patents are equally significant in an industry. And finally, not all patented inventions are adopted by producers.

Patent data have been used either as a proxy for input into inventive activity or as an output of inventive activity. Schimmelpfennig and Thirtle (1999) used patent data to calculate private and public R&D stocks in the agricultural sector, whereas Eaton and Kortum (1996) used patent data as an indirect measure of innovation while exploring implications of a quality innovation model on the relation between productivity and innovation. Because the aim of the current study is to use patent data to measure technical change, patent data are included as a proxy for output of inventive activity.

Another important point is that this study uses the number of granted patents rather than the number of patent applications. As emphasized by Griliches (1998), the trends in patent grants do not always follow the trends of the patent applications. "A patent is granted if it passes certain minimal standards of novelty and potential utility. These standards change over time. A change in the resources of the patent office or its efficiency will introduce changes in the lag structure of grants behind applications" (p. 322).

$P_{AGR,t}$ is the price of agricultural output, for which an index of prices received by farmers, deflated by the GDP deflator, is used as a proxy. $A(E)$, the productivity parameter, was defined as the other component of technology available to producers. Because extension services have played a significant role in the dissemination and adoption of new technology in the United States, $A(E)$ was modeled as a function of extension services. Hence, extension spending (denoted by $E_t$) is included as a proxy for $A(E)$. $L_t$ represents land input, and $H_t$ is labor input in the U.S. agricultural sector. For $r_t$, the ex post real interest rate is used.

The remaining two variables show the impact of public R&D spending on private R&D spending. The first of these is $s$, the subsidy parameter. In the model, parameter $s$ is the subsidy equivalent of public-sector activities which effectively lowers the cost of R&D for the private sector. Specifically, it is the portion of the public R&D sector activities that complements the private R&D sector. As a proxy for $s$, we use data for federal R&D obligations for basic research ($B_t$). The rationale for this choice is that the results of basic research create a knowledge base upon which the private R&D sector can rely to conduct research more geared toward the market. The second variable, $p^P$ is the probability of innovation by the public R&D sector. This variable shows the substitute effect of the public R&D sector to the private R&D sector—i.e., the public R&D sector can introduce a new intermediate good which can replace the lower-quality version, and therefore can capture the market away from the incumbent private R&D firm. As a proxy for $p^P$, data for federal R&D obligations for applied research are used ($C_t$). The reason for this choice is that public applied research is directed more toward generation of new products, i.e., activities similar in nature to private R&D sector activities.

Based on the above discussion, the empirical equation for private R&D investment is written as:

$$Z_t = g(P_t, P_{AGR,t}, E_t, L_t, H_t, r_t, B_t, C_t). \tag{12}$$

**Table 3. Summary Statistics: U.S. Agricultural Sector, 1970–1996 (*N* = 27 years)**

| Variable | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Federal Obligations for Basic R&D (1996 $000s) | 3,548,750 | 1,205,480 | 1,989,045 | 7,428,426 |
| Federal Obligations for Applied R&D (1996 $000s) | 2,393,324 | 613,427 | 1,560,754 | 4,523,439 |
| Private R&D (1996 $000s) | 1,967,421 | 564,980 | 1,036,735 | 2,817,141 |
| Patents (Sectors 1–7) | 17.86 | 10.52 | 9.15 | 56.11 |
| Patents (Sectors 1–8) | 18.71 | 10.63 | 9.85 | 57.16 |
| Extension Spending (1996 $000s) | 1,447,170 | 180,308 | 734,140 | 1,610,679 |
| Agricultural Employment (000s) | 3,332.70 | 112.58 | 3,115 | 3,515 |
| Land in Farms (000s of acres) | 1,024,384 | 44,061 | 958,675 | 1,102,371 |
| Real Interest Rate (%) | 1.62 | 3.12 | -3.87 | 7.88 |
| Price Index (1996 = 100) | 127.71 | 28.27 | 92.48 | 186.85 |

## Data Sources and Variables

This analysis uses U.S. agricultural sector data for the 1970–1996 period. All of the data are logarithms, except for the ex post real interest rate. The summary statistics for the data are given in table 3.

Private agricultural R&D spending data were estimated by Klotz, Fuglie, and Pray (1995) and are also provided on the USDA web site. All the spending data series used for this analysis are in thousands of 1996 dollars converted from current dollars by the Research Deflator.[10] The industries included in the data set are plant breeding, agricultural chemicals, farm machinery, and veterinary pharmaceuticals (as shown in table 2). Estimates of biotechnology expenditures in private-sector biotechnology firms are not included here to avoid double-counting. The agricultural industries that are included already incorporate biotechnology research expenditures within their R&D expenditures.

Federal obligations for basic and applied research were taken from the National Science Foundation (2004) publication, *Federal Funds for Research and Development: Fiscal Years 1970–2003; Federal Obligations for Research by Agency and Detailed Field of Science and Engineering*. The data set provides federal obligations for basic and applied research for biological and agricultural sciences in fiscal years. In this data set, basic research is defined as "systematic study directed toward fuller knowledge and understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes and products in mind." Applied research refers to "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met." Both series are in thousands of 1996 dollars converted from current dollars by the Research Deflator.

[10] The Research Deflator is from a study by Klotz, Fuglie, and Pray (1995) and it is used to deflate federal R&D obligations, private R&D spending, and extension funds. Previous studies have shown the cost of conducting research generally rises faster than the overall rate of inflation (Pardey, Craig, and Hallaway, 1989; Huffman and Evenson, 1993). Research activity uses a different set of goods than the bundle of goods included while calculating CPI or GDP deflators. Adjusting nominal research expenditures by CPI and GDP deflators may overstate the trend in real research spending over time. Klotz, Fuglie, and Pray (1995) construct the Research Deflator following the methodology developed by Pardey, Craig, and Hallaway (1989).

Agricultural extension spending includes total funds for cooperative extension by funding source—federal, state, and county. The sources for these data are Alston and Pardey (1996) for 1970–1994 and the USDA's Cooperative State Research, Education, and Extension Service (CSREES) for 1995–1996. Again, the series is in thousands of 1996 dollars converted from current dollars by the Research Deflator.

Agricultural patent data were taken from the U.S. Historical Patent Data Set, constructed by Johnson (1999). These agricultural patent data were created based on the Wellesley Technology Concordance (WTC) and the Yale Technology Concordance (YTC). The International Patent Classification (IPC) system distinguishes patents by type of product or process; it does not provide information on the number of patents granted by industry. Therefore, these data are of limited use for the type of analysis conducted in this study. YTC was designed to translate these IPC definitions of patents to industries of manufacture (IOMs) and sectors of use (SOUs).[11] WTC was developed by Johnson (1999) as a concordance between the U.S. Patent Classification (USPC) system and the internationally standard IPC. It uses information from patents granted in the United States to build a concordance between USPC and IPC systems. The output from WTC is used as input into YTC, and a historical patent series for the United States is created following an IOM and SOU structure. The patent data set used in this study is the total number of granted patents whose IOM is the agricultural sector. The sectors included in the calculation of patent data are seven agricultural sectors (livestock, crops and combo farms, fruits and vegetables, horticulture, service to livestock, service to crops, and other), and forestry and fishing as the eighth sector.

The price of output is an index of prices received for all farm products, deflated by the GDP deflator, taken from the USDA's National Agricultural Statistics Service Agricultural Statistics database. The real interest rate ($r_t$) is the annual interest rate on U.S. Treasury bills with one-year maturity from Federal Reserve Statistical Release minus the ex post inflation rate from the Consumer Price Index provided by the Bureau of Labor Statistics. Labor is employment in the U.S. agricultural and related industries (in thousands) obtained from the Bureau of Labor Statistics. Land is U.S. land in farms (in thousand acres) obtained from the USDA's National Agricultural Statistics Service Agricultural Statistics database.

## Empirical Methodology

First, autocorrelation and partial autocorrelation functions of the variables were plotted and stationarity tests were conducted using the augmented Dickey-Fuller test. These tests revealed that the variables are nonstationary (as reported in appendix A). Makki, Thraen, and Tweeten (1999) found there are problems associated with making inferences based on time-series regression analysis when variables have strong trends and are nonstationary. In cases like this, statistical tests of coefficient estimates can be biased toward accepting a spurious relationship. Thus, all variables are first-differenced to make them stationary. Plots of autocorrelation and partial autocorrelation functions, as well as augmented Dickey-Fuller tests, show that first-differencing has made the

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[11] The sectors of use are the demand sectors that use the new technology. The industries of manufacture are the supplying sectors that develop the innovations. For example, a pesticide sprayer has chemical fertilizer or agricultural machinery as its industry of manufacture, but its sector of use is field crop sector.

variables stationary (as seen in appendix B). Therefore, the final specification for private R&D spending is constructed as:

$$(13)\qquad \Delta\ln(Z_t) = g\big(\Delta\ln(B_{t-i}), \Delta\ln(C_{t-i}), \Delta\ln(P_{t-i}), \Delta\ln(P_{AGR,t-i}), \Delta\ln(E_{t-i}), \Delta\ln(L_{t-i}), \Delta\ln(H_{t-i}), \Delta r_{t-i}\big).$$

## Empirical Analysis Results

In the empirical analysis, two sets of patent data were tried. The first includes the following seven sectors: livestock, crops and combo farms, fruits and vegetables, horticulture, service to livestock, service to crops, and other. The second patent data set is formed by adding an eighth sector, forestry and fishing. The Schwarz Criterion (SC) and Akaike Information Criterion (AIC) were employed to choose between the two patent data sets. It was also necessary to choose the starting period of lags for the explanatory variables. Thus, SC and AIC were again employed to select the final model specification. Ordinary least squares regression is used to estimate the coefficients.

The results for the private R&D equation are reported in table 4. Columns [A] present the results for the first set of patent data, which includes the original seven agricultural sectors. Because this model yields the lowest SC and AIC values, it is the focus of the narrative discussion that follows. For ease of comparison, however, the results for the alternative model specification, incorporating patent data using eight sectors, are also presented in table 4 (columns [B]). Finally, for illustrative purposes, a subset of different model specifications and their respective SC values are given in table 5.

As shown by table 4, basic public R&D activity, measured by federal R&D obligations for basic research, has a positive and significant coefficient estimate. In the theoretical model, the basic public R&D activity that helped private R&D, captured by the subsidy parameter $s$, had a positive impact on the variable $Z$, the private R&D spending. It was incorporated into the theoretical model to show the portion of public R&D activities with a complementary nature, and this model proposed that basic R&D activities by the public sector would fall into this category. The above result suggests federal R&D obligations for basic research, used as a proxy for the complementary role of public R&D, have a significant and positive impact on private R&D spending.

Applied public R&D activity, as measured by federal R&D obligations for applied research, does not have a significant coefficient estimate (table 4). In the theoretical model, the applied portion of public R&D activity that competed with the private R&D sector was captured by the parameter $p^P$, the probability of innovation by the public R&D sector—i.e., the probability of the public R&D sector driving out the incumbent private R&D firm. This value had a negative relation with the variable $Z$, the private R&D spending. It was incorporated into the theoretical model to represent the portion of public R&D activities with a substitute nature, and it was hypothesized that applied R&D activities by the public sector would fall into this category. The above finding reveals that federal R&D obligations for applied research, used as a proxy for the substitute role of public R&D, do not have a significant impact on private R&D spending, which is contrary to what the theoretical model proposed.

The agricultural patents variable is added to capture the effect of past successes on private R&D, i.e., $Q$, the aggregate quality index in the model. The empirical results

**Table 4. OLS Regression Results for the Private R&D Equation Specifications**

| | [A] Private R&D Spending: 1st Patent Data Set, w/7 Sectors | | [B] Private R&D Spending: 2nd Patent Data Set, w/8 Sectors | |
|---|---|---|---|---|
| Variable | Coefficient | Std. Error | Coefficient | Std. Error |
| Intercept | -0.0204** | 0.0076 | -0.0203** | 0.0078 |
| *Basic Public R&D*$_{t-7}$ | 0.6936** | 0.1782 | 0.6895** | 0.1839 |
| *Applied Public R&D*$_{t-6}$ | 0.2349 | 0.1343 | 0.2329 | 0.1379 |
| *Patents*$_{t-5}$ | -0.2457** | 0.1060 | -0.2347* | 0.1100 |
| *Price*$_{t-2}$ | -0.0444 | 0.1951 | -0.0500 | 0.2002 |
| *Extension*$_{t-3}$ | -0.0926** | 0.0399 | -0.0954** | 0.0408 |
| *Land*$_{t-3}$ | -11.1192** | 2.4940 | -10.9072** | 2.5601 |
| *Labor*$_{t-2}$ | 0.7182** | 0.3179 | 0.7034* | 0.3260 |
| *Real Interest Rate*$_{t-3}$ | -0.4175* | 0.1997 | -0.4182* | 0.2049 |
| $N$ | 20 | | 20 | |
| $R^2$ | 0.8195 | | 0.8099 | |
| Schwarz Criterion | -7.5786 | | -7.5268 | |
| Akaike Information Criterion | -8.0266 | | -7.9749 | |

Notes: Single and double asterisks (*) denote statistical significance at the 10% and 5% levels, respectively. Specification [A] uses patents manufactured by the following seven agricultural sectors: livestock, crops and combo farms, fruits and vegetables, horticulture, service to livestock, service to crops, and other. Specification [B] uses patents manufactured by all eight sectors, which include the seven identified under [A] plus the forestry and fishing sector.

**Table 5. Sample Model Specifications and Their SC Values**

| Patent Data Set | Basic R&D Lag Number | Applied R&D Lag Number | Schwarz Criterion Value |
|---|---|---|---|
| Sectors 1–7 | 7 | 6 | -7.035 |
| Sectors 1–7 | 7 | 3 | -7.034 |
| Sectors 1–7 | 7 | 6 | -7.578 |
| Sectors 1–8 | 7 | 6 | -7.303 |
| Sectors 1–8 | 7 | 6 | -7.248 |
| Sectors 1–8 | 7 | 6 | -7.526 |

Notes: The first patent data set (sectors 1–7) includes the following seven sectors: livestock, crops and combo farms, fruits and vegetables, horticulture, service to livestock, service to crops, and other. The second patent data set (sectors 1–8) includes the original seven sectors identified above, plus the forestry and fishing sector. In the table, lag numbers of other explanatory variables also change; hence, we have different values of SC with the same lag numbers for basic R&D and applied R&D.

show that the coefficient estimate for agricultural patents is significant and negative (table 4), which is in contrast to the model's assumption.

The index of prices received by farmers does not have a significant coefficient estimate (table 4). Contrary to what the theoretical model predicted, the index of prices used as a proxy for the variable $P_{AGR,t}$, the price of output, does not appear to have a significant effect on the resources allocated to agricultural R&D by the private sector.

As reported in table 4, the coefficient estimate for extension spending is negative and significant. This variable was utilized as a proxy for the variable $A(E)$, the productivity parameter, given the importance of extension activities in the U.S. agricultural sector for the dissemination and adoption of new technology. However, within the framework of this analysis and data set, this impact is found to be negative, rather than positive.

The theoretical model indicates private R&D investment and the two inputs to the production process—land and labor—have a positive relationship. The private R&D sector produces intermediate goods used in the production of agricultural output. Thus, a higher demand for intermediate goods translates into a higher private R&D investment. As shown by footnote 6, demand for intermediate goods is positively linked to land and labor. Thus, the model predicts the coefficient estimates of the land and labor variables should be positive. Indeed, table 4 confirms a positive and significant coefficient estimate for the labor variable. The land variable, however, is found to have a significant but negative coefficient estimate. Both land in farms and agricultural employment in the United States exhibit a significant downward trend in the period of this study, although for agricultural employment this trend appears to be less steep over the last two decades. This distinct trend is in contrast to the strong upward trend in private R&D investment in the agricultural sector. General economic pressure that led to the shrinkage of U.S. agricultural land may be responsible for the land variable's significantly negative coefficient estimate. Forces such as industrialization of the agricultural sector and urbanization have contributed to this steady decline in farmland, and were not included in this study.

Finally, the real interest rate represents the opportunity cost of private R&D investment in the model (table 4). This variable has a negative and significant coefficient estimate, consistent with the model's results.

## Concluding Remarks

This study utilizes a quality innovation model in which technical change is the result of commercially motivated efforts of researchers responding to economic incentives and a public R&D sector. First, a model is presented to show the mechanism of how the domestic R&D sector operates. In the model, both public and private R&D sectors directly affect the creation of new technology, which in turn increases output. The public R&D investment directly affects the private R&D sector and contributes indirectly to inventions and productivity as well. The analysis of the liaison between these two sectors in a quality innovation model is a departure from previous research.

Public R&D's complementary role to the private R&D sector is included through the parameter $s$, a subsidy equivalent of public-sector activities which decreases the cost of R&D for the private R&D sector, such as basic research. Public R&D's substitute role to the private R&D sector is included through the probability of innovation by the public R&D sector. By engaging in activities which attempt to create higher-quality intermediate goods, the public R&D sector can displace the incumbent private R&D firm that produces the highest-quality intermediate good, and thereby potentially "crowd out" private R&D spending. The combined effect of these two activities on private R&D spending depends on the parameter values in the theoretical model.

In the empirical analysis, the implications of the model are tested for the U.S. agricultural sector using 1970–1996 data. Basic public R&D, as measured by federal R&D obligations for basic research, has a positive and significant coefficient estimate. Findings of the empirical analysis reveal that federal R&D obligations for basic research, used as a proxy for the complementary role of public R&D, have a significant and positive impact on private R&D spending, which is consistent with the theoretical model prediction. Applied public R&D, as measured by federal R&D obligations for applied research, is not found to have a significant coefficient estimate. Based on the empirical analysis, federal R&D obligations for applied research, used as a proxy for the substitute role of public R&D, do not have a significant impact on private R&D spending—a finding contrary to the prediction of the theoretical model.

The agricultural patents variable is added to capture the effect of past innovations on private R&D investment. The coefficient estimate for agricultural patents is significant and negative, which is in contrast to the model's prediction. Contrary to what the theoretical model suggested, the index of prices received by farmers used as a proxy for the price of output does not have a significant effect on the resources allocated to agricultural R&D by the private sector.

Extension spending was utilized as a proxy for the productivity parameter, as extension activities have been significant in the U.S. agricultural sector for the dissemination and adoption of new technology. However, within the framework of this analysis and data set, this impact is negative rather than positive. The empirical results show the labor variable, one of the inputs to the production process, has a positive and significant coefficient estimate, as predicted by the model. The land variable, on the other hand, has a negative and significant coefficient estimate. Both land in farms and agricultural employment in the United States have experienced a downward trend in the period of this study, in contrast to the strong upward trend in private R&D investment in the agricultural sector. Forces such as industrialization of the agricultural sector and urbanization which have contributed to this decline in farmland are not included in this study and may be responsible for the significantly negative coefficient estimate for the land variable. The real interest rate, representing the opportunity cost of private R&D investment in the model, has a negative and significant coefficient estimate, which is in agreement with the model's results.

In summary, this study provides a theoretical and empirical analysis of private agricultural R&D spending in the United States for the period 1970–1996. Our findings suggest that public R&D sector activities which focus on basic research benefit the private R&D sector. Accordingly, this positive impact needs to be considered when designing a role for the public R&D sector.

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## APPENDIX A: Results of Augmented Dickey-Fuller Unit Root Tests for Variables in Levels

**Table A1. U.S. Private R&D Spending**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | 0.0914 | 0.6974 | 3.58 | 0.9998 | | |
| | 1 | 0.0895 | 0.6967 | 2.92 | 0.9987 | | |
| | 2 | 0.0851 | 0.6955 | 2.23 | 0.9925 | | |
| | 3 | 0.0823 | 0.6947 | 1.87 | 0.9831 | | |
| | 4 | 0.0797 | 0.6938 | 2.03 | 0.9880 | | |
| | 5 | 0.0690 | 0.6911 | 1.79 | 0.9798 | | |
| | 6 | 0.0679 | 0.6906 | 2.23 | 0.9923 | | |
| Single Mean | 0 | -0.9312 | 0.8865 | -1.05 | 0.7253 | 7.15 | 0.0010 |
| | 1 | -1.0436 | 0.8757 | -1.13 | 0.6946 | 5.08 | 0.0442 |
| | 2 | -1.0798 | 0.8720 | -1.02 | 0.7367 | 3.10 | 0.3055 |
| | 3 | -1.2294 | 0.8568 | -1.05 | 0.7242 | 2.39 | 0.4786 |
| | 4 | -1.0625 | 0.8733 | -1.03 | 0.7304 | 2.69 | 0.4044 |
| | 5 | -0.3987 | 0.9282 | -0.40 | 0.8968 | 1.66 | 0.6557 |
| | 6 | -0.1396 | 0.9442 | -0.18 | 0.9302 | 2.43 | 0.4688 |
| Trend | 0 | -7.8525 | 0.5516 | -1.94 | 0.6123 | 2.12 | 0.7586 |
| | 1 | -9.9581 | 0.3793 | -2.05 | 0.5558 | 2.38 | 0.7087 |
| | 2 | -18.6230 | 0.0463 | -2.41 | 0.3666 | 3.10 | 0.5743 |
| | 3 | -53.4308 | < 0.0001 | -2.79 | 0.2101 | 4.10 | 0.3851 |
| | 4 | -104.4930 | 0.0001 | -2.50 | 0.3263 | 3.37 | 0.5228 |
| | 5 | 62.7536 | 0.9999 | -2.69 | 0.2468 | 3.62 | 0.4752 |
| | 6 | 72.0690 | 0.9999 | -2.31 | 0.4158 | 2.68 | 0.6537 |

**Table A2. U.S. Extension Spending**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | 0.0302 | 0.6835 | 0.42 | 0.7999 | | |
| | 1 | 0.0304 | 0.6834 | 0.71 | 0.8646 | | |
| | 2 | 0.0299 | 0.6831 | 0.98 | 0.9101 | | |
| | 3 | 0.0291 | 0.6827 | 1.11 | 0.9270 | | |
| | 4 | 0.0284 | 0.6823 | 1.16 | 0.9331 | | |
| | 5 | 0.0279 | 0.6819 | 1.23 | 0.9412 | | |
| | 6 | 0.0272 | 0.6815 | 1.24 | 0.9417 | | |
| Single Mean | 0 | -13.2151 | 0.0422 | -2.94 | 0.0502 | 4.46 | 0.0720 |
| | 1 | -7.0564 | 0.2429 | -2.05 | 0.2653 | 2.40 | 0.4751 |
| | 2 | -4.6253 | 0.4480 | -1.73 | 0.4090 | 2.03 | 0.5663 |
| | 3 | -3.9494 | 0.5228 | -1.64 | 0.4540 | 2.01 | 0.5708 |
| | 4 | -3.7062 | 0.5512 | -1.59 | 0.4739 | 2.01 | 0.5716 |
| | 5 | -3.4102 | 0.5870 | -1.56 | 0.4920 | 2.04 | 0.5626 |
| | 6 | -3.3301 | 0.5963 | -1.54 | 0.4980 | 2.03 | 0.5648 |
| Trend | 0 | -33.1644 | 0.0003 | -5.22 | 0.0008 | 13.74 | 0.0010 |
| | 1 | -30.0764 | 0.0010 | -3.51 | 0.0538 | 6.37 | 0.0659 |
| | 2 | -24.6919 | 0.0068 | -2.59 | 0.2885 | 3.68 | 0.4644 |
| | 3 | -28.7322 | 0.0014 | -2.26 | 0.4445 | 2.97 | 0.5979 |
| | 4 | -50.3737 | < 0.0001 | -2.12 | 0.5155 | 2.74 | 0.6416 |
| | 5 | -116.4100 | 0.0001 | -1.93 | 0.6160 | 2.42 | 0.7019 |
| | 6 | 84.6953 | 0.9999 | -1.85 | 0.6559 | 2.33 | 0.7191 |

**Table A3. Patents (Sectors 1–7)**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | 0.8700 | 0.8808 | 2.24 | 0.9928 | | |
| | 1 | 0.8351 | 0.8737 | 2.88 | 0.9986 | | |
| | 2 | 0.8179 | 0.8700 | 2.18 | 0.9917 | | |
| | 3 | 0.7800 | 0.8619 | 2.28 | 0.9933 | | |
| | 4 | 0.6988 | 0.8439 | 2.13 | 0.9905 | | |
| | 5 | 0.6915 | 0.8419 | 1.77 | 0.9790 | | |
| | 6 | 0.5898 | 0.8177 | 2.05 | 0.9883 | | |
| Single Mean | 0 | 1.5740 | 0.9937 | 0.68 | 0.9900 | 2.48 | 0.4550 |
| | 1 | 1.8749 | 0.9959 | 1.11 | 0.9968 | 4.29 | 0.0812 |
| | 2 | 1.9394 | 0.9962 | 0.93 | 0.9947 | 2.49 | 0.4527 |
| | 3 | 1.8707 | 0.9957 | 1.00 | 0.9956 | 2.73 | 0.3945 |
| | 4 | 2.7199 | 0.9988 | 1.76 | 0.9995 | 3.36 | 0.2403 |
| | 5 | 2.7546 | 0.9988 | 1.65 | 0.9993 | 2.58 | 0.4325 |
| | 6 | 2.7936 | 0.9988 | 2.77 | 0.9999 | 5.56 | 0.0315 |
| Trend | 0 | -5.2086 | 0.7857 | -1.02 | 0.9280 | 1.35 | 0.9038 |
| | 1 | -0.9881 | 0.9855 | -0.24 | 0.9893 | 0.93 | 0.9752 |
| | 2 | -3.0259 | 0.9283 | -0.54 | 0.9765 | 0.98 | 0.9687 |
| | 3 | -1.4416 | 0.9780 | -0.28 | 0.9880 | 0.79 | 0.9874 |
| | 4 | 0.9730 | 0.9981 | 0.23 | 0.9972 | 1.67 | 0.8441 |
| | 5 | 0.6560 | 0.9972 | 0.13 | 0.9962 | 1.52 | 0.8724 |
| | 6 | 2.4260 | 0.9996 | 0.94 | 0.9998 | 3.70 | 0.4599 |

**Table A4. Patents (Sectors 1–8)**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | 0.8222 | 0.8714 | 2.23 | 0.9926 | | |
| | 1 | 0.7865 | 0.8639 | 2.84 | 0.9984 | | |
| | 2 | 0.7671 | 0.8595 | 2.12 | 0.9903 | | |
| | 3 | 0.7347 | 0.8522 | 2.24 | 0.9927 | | |
| | 4 | 0.6599 | 0.8350 | 2.09 | 0.9895 | | |
| | 5 | 0.6520 | 0.8328 | 1.71 | 0.9761 | | |
| | 6 | 0.5566 | 0.8097 | 1.97 | 0.9863 | | |
| Single Mean | 0 | 1.6179 | 0.9941 | 0.69 | 0.9904 | 2.48 | 0.4554 |
| | 1 | 1.9316 | 0.9962 | 1.13 | 0.9969 | 4.22 | 0.0849 |
| | 2 | 2.0673 | 0.9968 | 0.97 | 0.9952 | 2.41 | 0.4740 |
| | 3 | 1.9606 | 0.9963 | 1.03 | 0.9960 | 2.70 | 0.4016 |
| | 4 | 2.7437 | 0.9988 | 1.74 | 0.9995 | 3.28 | 0.2605 |
| | 5 | 2.8116 | 0.9989 | 1.64 | 0.9993 | 2.49 | 0.4527 |
| | 6 | 2.8192 | 0.9989 | 2.69 | 0.9999 | 5.25 | 0.0395 |
| Trend | 0 | -4.8781 | 0.8123 | -0.97 | 0.9358 | 1.31 | 0.9121 |
| | 1 | -0.8653 | 0.9871 | -0.22 | 0.9900 | 0.95 | 0.9727 |
| | 2 | -2.9169 | 0.9332 | -0.52 | 0.9774 | 1.04 | 0.9597 |
| | 3 | -1.2542 | 0.9813 | -0.25 | 0.9889 | 0.83 | 0.9840 |
| | 4 | 0.9274 | 0.9980 | 0.22 | 0.9971 | 1.65 | 0.8477 |
| | 5 | 0.4596 | 0.9965 | 0.09 | 0.9957 | 1.56 | 0.8651 |
| | 6 | 2.2967 | 0.9996 | 0.87 | 0.9997 | 3.53 | 0.4931 |

**Table A5. Real Interest Rate**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -6.8651 | 0.0635 | -1.92 | 0.0527 | | |
| | 1 | -14.7174 | 0.0046 | -2.59 | 0.0111 | | |
| | 2 | -6.0017 | 0.0837 | -1.57 | 0.1084 | | |
| | 3 | -9.8462 | 0.0233 | -1.79 | 0.0705 | | |
| | 4 | -4.7780 | 0.1245 | -1.27 | 0.1824 | | |
| | 5 | -7.4172 | 0.0519 | -1.37 | 0.1556 | | |
| | 6 | -12.6941 | 0.0086 | -1.53 | 0.1150 | | |
| Single Mean | 0 | -9.2387 | 0.1342 | -2.24 | 0.1966 | 2.51 | 0.4496 |
| | 1 | -22.6009 | 0.0017 | -3.20 | 0.0283 | 5.12 | 0.0432 |
| | 2 | -9.8521 | 0.1114 | -1.94 | 0.3114 | 1.88 | 0.6021 |
| | 3 | -20.7016 | 0.0033 | -2.30 | 0.1771 | 2.65 | 0.4136 |
| | 4 | -9.5223 | 0.1207 | -1.63 | 0.4566 | 1.33 | 0.7370 |
| | 5 | -23.1276 | 0.0012 | -1.88 | 0.3370 | 1.78 | 0.6267 |
| | 6 | -174.5970 | 0.0001 | -2.03 | 0.2748 | 2.05 | 0.5601 |
| Trend | 0 | -10.1175 | 0.3692 | -2.39 | 0.3782 | 2.95 | 0.6021 |
| | 1 | -24.5979 | 0.0075 | -3.34 | 0.0757 | 5.61 | 0.1001 |
| | 2 | -11.7707 | 0.2607 | -2.14 | 0.5038 | 2.37 | 0.7111 |
| | 3 | -28.4159 | 0.0016 | -2.58 | 0.2895 | 3.39 | 0.5184 |
| | 4 | -14.8170 | 0.1247 | -1.97 | 0.5954 | 2.03 | 0.7761 |
| | 5 | -51.8678 | < 0.0001 | -2.18 | 0.4831 | 2.39 | 0.7078 |
| | 6 | 48.2304 | 0.9999 | -2.63 | 0.2726 | 3.53 | 0.4921 |

**Table A6. Land in Farms**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -0.0147 | 0.6735 | -9.93 | < 0.0001 | | |
| | 1 | -0.0142 | 0.6734 | -5.16 | < 0.0001 | | |
| | 2 | -0.0137 | 0.6734 | -3.74 | 0.0005 | | |
| | 3 | -0.0134 | 0.6732 | -3.54 | 0.0008 | | |
| | 4 | -0.0130 | 0.6731 | -3.42 | 0.0012 | | |
| | 5 | -0.0126 | 0.6729 | -3.18 | 0.0024 | | |
| | 6 | -0.0122 | 0.6728 | -2.60 | 0.0111 | | |
| Single Mean | 0 | -0.4732 | 0.9239 | -1.39 | 0.5740 | 51.42 | 0.0010 |
| | 1 | -0.4537 | 0.9251 | -1.38 | 0.5793 | 14.51 | 0.0010 |
| | 2 | -0.4282 | 0.9267 | -1.30 | 0.6177 | 7.93 | 0.0010 |
| | 3 | -0.3903 | 0.9292 | -1.38 | 0.5789 | 7.33 | 0.0010 |
| | 4 | -0.4160 | 0.9272 | -1.76 | 0.3920 | 7.74 | 0.0010 |
| | 5 | -0.4198 | 0.9267 | -2.11 | 0.2440 | 7.82 | 0.0010 |
| | 6 | -0.4087 | 0.9273 | -2.12 | 0.2381 | 6.02 | 0.0208 |
| Trend | 0 | -8.0941 | 0.5305 | -1.98 | 0.5949 | 2.79 | 0.6329 |
| | 1 | -8.7303 | 0.4751 | -1.88 | 0.6429 | 2.60 | 0.6678 |
| | 2 | -10.2275 | 0.3580 | -1.84 | 0.6617 | 2.43 | 0.6996 |
| | 3 | -7.8991 | 0.5433 | -1.53 | 0.7984 | 2.01 | 0.7784 |
| | 4 | -5.5259 | 0.7561 | -1.24 | 0.8852 | 2.19 | 0.7455 |
| | 5 | -3.6497 | 0.8949 | -1.00 | 0.9290 | 2.56 | 0.6751 |
| | 6 | -2.9227 | 0.9318 | -0.86 | 0.9482 | 2.45 | 0.6961 |

**Table A7. Agricultural Employment**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -0.0579 | 0.6639 | -2.47 | 0.0148 | | |
| | 1 | -0.0495 | 0.6656 | -1.46 | 0.1327 | | |
| | 2 | -0.0405 | 0.6674 | -1.04 | 0.2636 | | |
| | 3 | -0.0168 | 0.6725 | -0.31 | 0.5646 | | |
| | 4 | 0.0075 | 0.6776 | 0.11 | 0.7112 | | |
| | 5 | 0.0171 | 0.6795 | 0.24 | 0.7500 | | |
| | 6 | 0.0086 | 0.6774 | 0.20 | 0.7366 | | |
| Single Mean | 0 | -4.9668 | 0.4143 | -4.86 | 0.0004 | 16.50 | 0.0010 |
| | 1 | -5.3634 | 0.3754 | -4.15 | 0.0024 | 10.07 | 0.0010 |
| | 2 | -5.6832 | 0.3458 | -3.96 | 0.0041 | 8.58 | 0.0010 |
| | 3 | -5.9922 | 0.3189 | -3.39 | 0.0181 | 5.81 | 0.0248 |
| | 4 | -6.9209 | 0.2491 | -3.22 | 0.0278 | 5.18 | 0.0414 |
| | 5 | -8.1219 | 0.1784 | -3.59 | 0.0116 | 6.48 | 0.0120 |
| | 6 | -7.2378 | 0.2266 | -2.50 | 0.1255 | 3.15 | 0.2931 |
| Trend | 0 | -3.6776 | 0.8949 | -2.13 | 0.5121 | 12.17 | 0.0010 |
| | 1 | -4.0097 | 0.8742 | -2.26 | 0.4449 | 8.87 | 0.0080 |
| | 2 | -3.9909 | 0.8750 | -2.37 | 0.3878 | 8.35 | 0.0163 |
| | 3 | -4.3260 | 0.8520 | -2.33 | 0.4047 | 6.15 | 0.0760 |
| | 4 | -5.8305 | 0.7294 | -2.55 | 0.3054 | 5.11 | 0.1938 |
| | 5 | -7.5974 | 0.5671 | -3.02 | 0.1429 | 6.19 | 0.0741 |
| | 6 | -5.8793 | 0.7230 | -1.97 | 0.5957 | 3.12 | 0.5702 |

**Table A8. Price Index**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -0.0880 | 0.6572 | -0.95 | 0.2997 | | |
| | 1 | -0.0846 | 0.6578 | -0.72 | 0.3998 | | |
| | 2 | -0.0876 | 0.6569 | -1.05 | 0.2595 | | |
| | 3 | -0.0843 | 0.6575 | -1.03 | 0.2683 | | |
| | 4 | -0.0799 | 0.6583 | -1.10 | 0.2408 | | |
| | 5 | -0.0824 | 0.6575 | -0.90 | 0.3192 | | |
| | 6 | -0.0853 | 0.6566 | -1.10 | 0.2382 | | |
| Single Mean | 0 | -2.0854 | 0.7585 | -0.88 | 0.7838 | 0.80 | 0.8664 |
| | 1 | -4.3597 | 0.4774 | -1.31 | 0.6161 | 1.08 | 0.7980 |
| | 2 | -1.6776 | 0.8074 | -0.68 | 0.8380 | 0.75 | 0.8787 |
| | 3 | -1.5150 | 0.8259 | -0.59 | 0.8591 | 0.67 | 0.8980 |
| | 4 | -0.6090 | 0.9130 | -0.27 | 0.9188 | 0.61 | 0.9162 |
| | 5 | -2.5244 | 0.7007 | -0.68 | 0.8371 | 0.61 | 0.9167 |
| | 6 | -1.3342 | 0.8449 | -0.45 | 0.8869 | 0.67 | 0.8964 |
| Trend | 0 | -6.7633 | 0.6491 | -1.91 | 0.6306 | 1.92 | 0.7966 |
| | 1 | -12.8166 | 0.2086 | -2.44 | 0.3536 | 3.02 | 0.5891 |
| | 2 | -7.2356 | 0.6041 | -1.74 | 0.7132 | 1.64 | 0.8482 |
| | 3 | -7.7281 | 0.5584 | -1.69 | 0.7317 | 1.62 | 0.8523 |
| | 4 | -6.1577 | 0.7000 | -1.52 | 0.8006 | 1.59 | 0.8590 |
| | 5 | -13.3247 | 0.1778 | -1.77 | 0.6974 | 1.74 | 0.8296 |
| | 6 | -8.1472 | 0.5163 | -1.40 | 0.8403 | 1.16 | 0.9407 |

**Table A9. Federal Obligations for Basic R&D**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | 0.0449 | 0.6833 | 2.70 | 0.9973 | | |
| | 1 | 0.0441 | 0.6830 | 2.30 | 0.9931 | | |
| | 2 | 0.0351 | 0.6806 | 1.23 | 0.9393 | | |
| | 3 | 0.0423 | 0.6805 | 1.78 | 0.9783 | | |
| | 4 | 0.0396 | 0.6806 | 1.47 | 0.9606 | | |
| | 5 | 0.0333 | 0.6783 | 0.75 | 0.8681 | | |
| | 6 | 0.0237 | 0.6747 | 0.29 | 0.7601 | | |
| Single Mean | 0 | -1.6404 | 0.8079 | -1.78 | 0.3831 | 5.65 | 0.0290 |
| | 1 | -1.8093 | 0.7879 | -2.01 | 0.2810 | 5.14 | 0.0517 |
| | 2 | -1.7347 | 0.7962 | -1.41 | 0.5622 | 1.82 | 0.6312 |
| | 3 | -1.9536 | 0.7696 | -2.19 | 0.2166 | 4.39 | 0.0871 |
| | 4 | -1.9629 | 0.7678 | -2.25 | 0.1957 | 3.97 | 0.1343 |
| | 5 | -2.4785 | 0.7022 | -2.20 | 0.2108 | 2.82 | 0.3988 |
| | 6 | -3.3912 | 0.5822 | -2.88 | 0.0650 | 4.24 | 0.0942 |
| Trend | 0 | -1.5164 | 0.9753 | -0.49 | 0.9773 | 1.52 | 0.8725 |
| | 1 | -0.8288 | 0.9862 | -0.27 | 0.9869 | 1.99 | 0.7850 |
| | 2 | -3.3825 | 0.9066 | -0.67 | 0.9645 | 0.99 | 0.9630 |
| | 3 | -0.1662 | 0.9923 | -0.06 | 0.9924 | 2.43 | 0.7085 |
| | 4 | 0.8284 | 0.9971 | 0.37 | 0.9977 | 3.00 | 0.6081 |
| | 5 | 0.4962 | 0.9958 | 0.18 | 0.9960 | 2.61 | 0.6768 |
| | 6 | -0.2013 | 0.9915 | -0.07 | 0.9915 | 4.09 | 0.4181 |

**Table A10. Federal Obligations for Applied R&D**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | 0.0373 | 0.6815 | 1.63 | 0.9715 | | |
| | 1 | 0.0334 | 0.6804 | 1.16 | 0.9316 | | |
| | 2 | 0.0265 | 0.6785 | 0.77 | 0.8731 | | |
| | 3 | 0.0278 | 0.6770 | 0.73 | 0.8655 | | |
| | 4 | 0.0211 | 0.6760 | 0.78 | 0.8750 | | |
| | 5 | 0.0229 | 0.6758 | 1.24 | 0.9392 | | |
| | 6 | 0.0254 | 0.6751 | 1.01 | 0.9113 | | |
| Single Mean | 0 | -4.2459 | 0.4860 | -1.96 | 0.3028 | 3.44 | 0.2224 |
| | 1 | -5.8619 | 0.3193 | -1.98 | 0.2930 | 2.74 | 0.4174 |
| | 2 | -7.7199 | 0.1872 | -1.82 | 0.3646 | 1.99 | 0.5906 |
| | 3 | -16.6302 | 0.0090 | -2.35 | 0.1664 | 3.10 | 0.3342 |
| | 4 | -9.1594 | 0.1184 | -1.51 | 0.5073 | 1.49 | 0.7072 |
| | 5 | -3.9433 | 0.5146 | -0.88 | 0.7741 | 1.15 | 0.7857 |
| | 6 | -67.8006 | < 0.0001 | -1.63 | 0.4503 | 1.91 | 0.6088 |
| Trend | 0 | -6.1334 | 0.6944 | -2.01 | 0.5672 | 2.29 | 0.7257 |
| | 1 | -9.7507 | 0.3707 | -2.27 | 0.4318 | 2.69 | 0.6617 |
| | 2 | -19.5330 | 0.0229 | -2.52 | 0.3153 | 3.18 | 0.5762 |
| | 3 | -410.3600 | 0.0001 | -3.37 | 0.0808 | 5.68 | 0.1403 |
| | 4 | 936.2688 | 0.9999 | -2.48 | 0.3334 | 3.08 | 0.5940 |
| | 5 | -45.5576 | < 0.0001 | -1.61 | 0.7538 | 1.32 | 0.9019 |
| | 6 | 13.4693 | 0.9999 | -2.76 | 0.2276 | 3.80 | 0.4691 |

## APPENDIX B: Results of Augmented Dickey-Fuller Unit Root Tests for First-Differenced Variables

**Table B1. U.S. Private R&D Spending**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -25.3271 | < 0.0001 | -4.40 | < 0.0001 | | |
| | 1 | -14.1970 | 0.0055 | -2.61 | 0.0104 | | |
| | 2 | -9.1012 | 0.0299 | -1.94 | 0.0505 | | |
| | 3 | -10.2971 | 0.0199 | -1.89 | 0.0565 | | |
| | 4 | -8.9555 | 0.0310 | -1.99 | 0.0456 | | |
| | 5 | -12.3215 | 0.0098 | -2.08 | 0.0379 | | |
| | 6 | -10.0005 | 0.0212 | -1.55 | 0.1111 | | |
| Single Mean | 0 | -34.9750 | 0.0002 | -5.71 | 0.0002 | 16.31 | 0.0010 |
| | 1 | -28.2965 | 0.0002 | -3.59 | 0.0110 | 6.44 | 0.0129 |
| | 2 | -24.6167 | 0.0007 | -2.79 | 0.0706 | 3.89 | 0.1120 |
| | 3 | -52.8970 | 0.0002 | -2.88 | 0.0584 | 4.16 | 0.0882 |
| | 4 | -61.4800 | 0.0002 | -2.70 | 0.0855 | 3.79 | 0.1356 |
| | 5 | 58.1812 | 0.9999 | -3.12 | 0.0351 | 5.04 | 0.0453 |
| | 6 | 22.9724 | 0.9999 | -3.05 | 0.0415 | 4.67 | 0.0604 |
| Trend | 0 | -35.3558 | < 0.0001 | -5.71 | 0.0002 | 16.33 | 0.0010 |
| | 1 | -29.3405 | 0.0012 | -3.59 | 0.0455 | 6.45 | 0.0624 |
| | 2 | -26.0590 | 0.0039 | -2.81 | 0.2038 | 3.96 | 0.4120 |
| | 3 | -61.8055 | < 0.0001 | -2.92 | 0.1702 | 4.26 | 0.3539 |
| | 4 | -61.8991 | < 0.0001 | -2.60 | 0.2818 | 3.49 | 0.4997 |
| | 5 | 59.4666 | 0.9999 | -3.01 | 0.1453 | 4.67 | 0.2772 |
| | 6 | 22.5167 | 0.9999 | -3.00 | 0.1499 | 4.50 | 0.3100 |

**Table B2. U.S. Extension Spending**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -51.6193 | < 0.0001 | -9.78 | < 0.0001 | | |
| | 1 | -97.6653 | < 0.0001 | -6.79 | < 0.0001 | | |
| | 2 | -241.8210 | 0.0001 | -4.87 | < 0.0001 | | |
| | 3 | 10,739.91 | 0.9999 | -3.76 | 0.0005 | | |
| | 4 | 159.9175 | 0.9999 | -3.17 | 0.0025 | | |
| | 5 | 115.1337 | 0.9999 | -2.64 | 0.0099 | | |
| | 6 | 56.0177 | 0.9999 | -2.37 | 0.0192 | | |
| Single Mean | 0 | -51.9480 | 0.0002 | -9.74 | 0.0002 | 47.44 | 0.0010 |
| | 1 | -103.5330 | 0.0001 | -6.86 | 0.0002 | 23.56 | 0.0010 |
| | 2 | -449.6750 | 0.0001 | -5.02 | 0.0003 | 12.59 | 0.0010 |
| | 3 | 208.4110 | 0.9999 | -3.96 | 0.0044 | 7.86 | 0.0010 |
| | 4 | 65.1405 | 0.9999 | -3.43 | 0.0169 | 5.91 | 0.0229 |
| | 5 | 40.2625 | 0.9999 | -2.95 | 0.0510 | 4.37 | 0.0764 |
| | 6 | 23.6790 | 0.9999 | -2.77 | 0.0745 | 3.86 | 0.1193 |
| Trend | 0 | -52.1177 | < 0.0001 | -9.66 | 0.0001 | 46.61 | 0.0010 |
| | 1 | -106.6120 | 0.0001 | -6.86 | 0.0001 | 23.51 | 0.0010 |
| | 2 | -737.7340 | 0.0001 | -5.07 | 0.0013 | 12.85 | 0.0010 |
| | 3 | 150.4995 | 0.9999 | -4.06 | 0.0166 | 8.25 | 0.0180 |
| | 4 | 54.7632 | 0.9999 | -3.57 | 0.0492 | 6.40 | 0.0649 |
| | 5 | 33.8220 | 0.9999 | -3.13 | 0.1176 | 4.93 | 0.2279 |
| | 6 | 20.5696 | 0.9999 | -3.02 | 0.1432 | 4.62 | 0.2871 |

**Table B3. Patents (Sectors 1–7)**

| Type | Lags | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -41.1918 | < 0.0001 | -6.15 | < 0.0001 | | |
| | 1 | -20.2064 | 0.0006 | -2.71 | 0.0082 | | |
| | 2 | -18.6902 | 0.0011 | -2.13 | 0.0338 | | |
| | 3 | -15.6374 | 0.0032 | -1.82 | 0.0658 | | |
| | 4 | -6.6430 | 0.0671 | -1.11 | 0.2346 | | |
| | 5 | -11.2857 | 0.0140 | -1.33 | 0.1665 | | |
| | 6 | -1.1187 | 0.4486 | -0.33 | 0.5571 | | |
| Single Mean | 0 | -46.4277 | 0.0002 | -7.20 | 0.0002 | 26.09 | 0.0010 |
| | 1 | -31.9349 | 0.0002 | -3.47 | 0.0149 | 6.10 | 0.0193 |
| | 2 | -46.5721 | 0.0002 | -3.04 | 0.0410 | 4.76 | 0.0555 |
| | 3 | -61.0309 | 0.0002 | -2.62 | 0.0985 | 3.48 | 0.2132 |
| | 4 | -28.4865 | 0.0002 | -1.85 | 0.3503 | 1.78 | 0.6260 |
| | 5 | 298.0394 | 0.9999 | -2.12 | 0.2395 | 2.27 | 0.5081 |
| | 6 | -6.7574 | 0.2542 | -0.89 | 0.7770 | 0.47 | 0.9573 |
| Trend | 0 | -47.3322 | < 0.0001 | -7.40 | 0.0001 | 27.53 | 0.0010 |
| | 1 | -35.2549 | < 0.0001 | -3.68 | 0.0377 | 7.00 | 0.0437 |
| | 2 | -55.4945 | < 0.0001 | -3.25 | 0.0926 | 5.49 | 0.1224 |
| | 3 | -112.8930 | 0.0001 | -3.06 | 0.1329 | 5.45 | 0.1303 |
| | 4 | -61.2124 | < 0.0001 | -2.36 | 0.3936 | 3.43 | 0.5107 |
| | 5 | 55.8385 | 0.9999 | -3.04 | 0.1378 | 6.06 | 0.0797 |
| | 6 | -44.7237 | < 0.0001 | -2.09 | 0.5293 | 4.00 | 0.4034 |

**Table B4. Patents (Sectors 1–8)**

| Type | Lags | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -41.0632 | < 0.0001 | -6.10 | < 0.0001 | | |
| | 1 | -19.8435 | 0.0007 | -2.68 | 0.0087 | | |
| | 2 | -18.9890 | 0.0009 | -2.14 | 0.0328 | | |
| | 3 | -15.9039 | 0.0029 | -1.82 | 0.0662 | | |
| | 4 | -6.5785 | 0.0685 | -1.11 | 0.2348 | | |
| | 5 | -11.6466 | 0.0124 | -1.33 | 0.1657 | | |
| | 6 | -1.2612 | 0.4260 | -0.36 | 0.5452 | | |
| Single Mean | 0 | -46.2547 | 0.0002 | -7.12 | 0.0002 | 25.51 | 0.0010 |
| | 1 | -30.9055 | 0.0002 | -3.40 | 0.0174 | 5.87 | 0.0237 |
| | 2 | -46.0468 | 0.0002 | -3.03 | 0.0424 | 4.71 | 0.0581 |
| | 3 | -60.3811 | 0.0002 | -2.60 | 0.1022 | 3.43 | 0.2239 |
| | 4 | -26.0351 | 0.0004 | -1.82 | 0.3660 | 1.72 | 0.6418 |
| | 5 | 378.9620 | 0.9999 | -2.10 | 0.2476 | 2.22 | 0.5185 |
| | 6 | -7.0537 | 0.2342 | -0.91 | 0.7695 | 0.49 | 0.9522 |
| Trend | 0 | -47.1728 | < 0.0001 | -7.32 | 0.0001 | 27.00 | 0.0010 |
| | 1 | -34.3264 | 0.0001 | -3.64 | 0.0416 | 6.88 | 0.0466 |
| | 2 | -55.4395 | < 0.0001 | -3.25 | 0.0923 | 5.50 | 0.1200 |
| | 3 | -115.0540 | 0.0001 | -3.05 | 0.1350 | 5.37 | 0.1445 |
| | 4 | -56.3990 | < 0.0001 | -2.34 | 0.3996 | 3.42 | 0.5138 |
| | 5 | 55.7816 | 0.9999 | -3.02 | 0.1436 | 5.89 | 0.0874 |
| | 6 | -47.8166 | < 0.0001 | -2.09 | 0.5323 | 3.83 | 0.4360 |

**Table B5. Real Interest Rate**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -26.0759 | < 0.0001 | -4.52 | < 0.0001 | | |
| | 1 | -73.1074 | < 0.0001 | -5.88 | < 0.0001 | | |
| | 2 | -44.3846 | < 0.0001 | -3.45 | 0.0011 | | |
| | 3 | 193.6401 | 0.9999 | -4.06 | 0.0002 | | |
| | 4 | -137.2790 | 0.0001 | -2.76 | 0.0074 | | |
| | 5 | -107.2740 | 0.0001 | -2.29 | 0.0232 | | |
| | 6 | 92.3869 | 0.9999 | -2.31 | 0.0225 | | |
| Single Mean | 0 | -26.0736 | 0.0005 | -4.45 | 0.0011 | 9.91 | 0.0010 |
| | 1 | -73.0942 | 0.0002 | -5.79 | 0.0002 | 16.75 | 0.0010 |
| | 2 | -44.3126 | 0.0002 | -3.39 | 0.0182 | 5.76 | 0.0261 |
| | 3 | 194.0955 | 0.9999 | -3.98 | 0.0041 | 7.94 | 0.0010 |
| | 4 | -135.7270 | 0.0001 | -2.70 | 0.0848 | 3.67 | 0.1666 |
| | 5 | -107.2370 | 0.0001 | -2.24 | 0.1959 | 2.52 | 0.4469 |
| | 6 | 92.9558 | 0.9999 | -2.26 | 0.1920 | 2.58 | 0.4313 |
| Trend | 0 | -26.1340 | 0.0044 | -4.38 | 0.0071 | 9.62 | 0.0010 |
| | 1 | -73.7599 | < 0.0001 | -5.72 | 0.0003 | 16.35 | 0.0010 |
| | 2 | -44.7821 | < 0.0001 | -3.35 | 0.0762 | 5.61 | 0.1000 |
| | 3 | 187.4199 | 0.9999 | -3.93 | 0.0221 | 7.76 | 0.0262 |
| | 4 | -142.3930 | 0.0001 | -2.65 | 0.2628 | 3.52 | 0.4952 |
| | 5 | -131.3900 | 0.0001 | -2.23 | 0.4589 | 2.49 | 0.6887 |
| | 6 | 94.0852 | 0.9999 | -2.18 | 0.4799 | 2.43 | 0.7009 |

**Table B6. Land in Farms**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -10.1229 | 0.0216 | -2.45 | 0.0157 | | |
| | 1 | -4.2419 | 0.1493 | -1.51 | 0.1202 | | |
| | 2 | -2.8839 | 0.2372 | -1.24 | 0.1917 | | |
| | 3 | -1.8900 | 0.3384 | -0.96 | 0.2920 | | |
| | 4 | -1.2621 | 0.4238 | -0.79 | 0.3678 | | |
| | 5 | -0.8486 | 0.4929 | -0.70 | 0.4038 | | |
| | 6 | -0.6274 | 0.5351 | -0.70 | 0.4056 | | |
| Single Mean | 0 | -36.9898 | 0.0002 | -6.07 | 0.0002 | 18.43 | 0.0010 |
| | 1 | -37.7523 | 0.0002 | -4.12 | 0.0027 | 8.53 | 0.0010 |
| | 2 | -69.8891 | 0.0002 | -3.80 | 0.0066 | 7.25 | 0.0010 |
| | 3 | -1,417.41 | 0.0001 | -3.57 | 0.0120 | 6.38 | 0.0140 |
| | 4 | 82.6818 | 0.9999 | -3.26 | 0.0253 | 5.34 | 0.0373 |
| | 5 | 68.0888 | 0.9999 | -2.66 | 0.0925 | 3.58 | 0.1886 |
| | 6 | 228.5791 | 0.9999 | -2.06 | 0.2600 | 2.21 | 0.5209 |
| Trend | 0 | -38.4521 | < 0.0001 | -6.24 | 0.0001 | 19.48 | 0.0010 |
| | 1 | -42.2367 | < 0.0001 | -4.31 | 0.0088 | 9.28 | 0.0015 |
| | 2 | -95.6600 | < 0.0001 | -4.04 | 0.0170 | 8.17 | 0.0193 |
| | 3 | 147.2472 | 0.9999 | -4.04 | 0.0174 | 8.18 | 0.0191 |
| | 4 | 41.0814 | 0.9999 | -4.00 | 0.0194 | 8.04 | 0.0213 |
| | 5 | 27.1371 | 0.9999 | -3.50 | 0.0576 | 6.14 | 0.0765 |
| | 6 | 22.5951 | 0.9999 | -2.86 | 0.1888 | 4.10 | 0.3853 |

**Table B7. Agricultural Employment**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -21.7728 | 0.0003 | -4.05 | 0.0002 | | |
| | 1 | -15.3870 | 0.0036 | -2.92 | 0.0046 | | |
| | 2 | -8.6427 | 0.0349 | -2.17 | 0.0309 | | |
| | 3 | -5.3514 | 0.1031 | -1.84 | 0.0633 | | |
| | 4 | -4.8545 | 0.1211 | -1.74 | 0.0773 | | |
| | 5 | -7.9778 | 0.0428 | -2.55 | 0.0124 | | |
| | 6 | -7.8409 | 0.0444 | -2.47 | 0.0154 | | |
| Single Mean | 0 | -24.8329 | 0.0007 | -4.33 | 0.0015 | 9.43 | 0.0010 |
| | 1 | -18.8288 | 0.0066 | -3.06 | 0.0392 | 4.77 | 0.0551 |
| | 2 | -9.7163 | 0.1150 | -1.94 | 0.3130 | 2.31 | 0.4965 |
| | 3 | -4.9876 | 0.4091 | -1.42 | 0.5614 | 1.64 | 0.6612 |
| | 4 | -4.1407 | 0.4991 | -1.26 | 0.6338 | 1.49 | 0.6965 |
| | 5 | -7.0971 | 0.2355 | -1.95 | 0.3083 | 3.15 | 0.2926 |
| | 6 | -6.4992 | 0.2730 | -1.87 | 0.3398 | 2.97 | 0.3366 |
| Trend | 0 | -37.1931 | < 0.0001 | -5.98 | 0.0001 | 17.91 | 0.0010 |
| | 1 | -49.5996 | < 0.0001 | -4.63 | 0.0039 | 10.78 | 0.0010 |
| | 2 | -41.4299 | < 0.0001 | -3.21 | 0.1005 | 5.15 | 0.1876 |
| | 3 | -22.0916 | 0.0149 | -2.29 | 0.4283 | 2.63 | 0.6631 |
| | 4 | -21.9989 | 0.0146 | -2.02 | 0.5669 | 2.06 | 0.7699 |
| | 5 | -44.3042 | < 0.0001 | -2.32 | 0.4092 | 3.03 | 0.5866 |
| | 6 | -47.1228 | < 0.0001 | -2.14 | 0.5031 | 2.65 | 0.6592 |

**Table B8. Price Index**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -27.0775 | < 0.0001 | -4.56 | < 0.0001 | | |
| | 1 | -52.6954 | < 0.0001 | -4.89 | < 0.0001 | | |
| | 2 | -54.6767 | < 0.0001 | -3.64 | 0.0006 | | |
| | 3 | -123.7030 | 0.0001 | -3.32 | 0.0016 | | |
| | 4 | -23.9665 | 0.0001 | -2.15 | 0.0323 | | |
| | 5 | -80.9794 | < 0.0001 | -2.23 | 0.0271 | | |
| | 6 | -11.4861 | 0.0127 | -1.51 | 0.1201 | | |
| Single Mean | 0 | -27.8331 | 0.0002 | -4.57 | 0.0008 | 10.44 | 0.0010 |
| | 1 | -57.7191 | 0.0002 | -5.00 | 0.0003 | 12.51 | 0.0010 |
| | 2 | -69.9089 | 0.0002 | -3.78 | 0.0069 | 7.15 | 0.0010 |
| | 3 | -598.4270 | 0.0001 | -3.49 | 0.0144 | 6.13 | 0.0187 |
| | 4 | -40.8226 | 0.0002 | -2.31 | 0.1760 | 2.67 | 0.4100 |
| | 5 | 166.4765 | 0.9999 | -2.49 | 0.1285 | 3.09 | 0.3073 |
| | 6 | -19.1036 | 0.0052 | -1.60 | 0.4697 | 1.30 | 0.7443 |
| Trend | 0 | -28.0649 | 0.0021 | -4.49 | 0.0054 | 10.17 | 0.0010 |
| | 1 | -59.9458 | < 0.0001 | -4.95 | 0.0017 | 12.33 | 0.0010 |
| | 2 | -79.8960 | < 0.0001 | -3.76 | 0.0317 | 7.15 | 0.0403 |
| | 3 | 405.5205 | 0.9999 | -3.59 | 0.0472 | 6.47 | 0.0617 |
| | 4 | -65.6348 | < 0.0001 | -2.31 | 0.4145 | 2.76 | 0.6376 |
| | 5 | 71.2034 | 0.9999 | -2.46 | 0.3458 | 3.18 | 0.5594 |
| | 6 | -46.2344 | < 0.0001 | -1.74 | 0.7069 | 1.52 | 0.8713 |

**Table B9. Federal Obligations for Basic R&D**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -19.4948 | 0.0005 | -3.92 | 0.0004 | | |
| | 1 | -8.7444 | 0.0307 | -2.17 | 0.0310 | | |
| | 2 | -9.4707 | 0.0231 | -1.87 | 0.0596 | | |
| | 3 | -6.6183 | 0.0643 | -1.48 | 0.1244 | | |
| | 4 | -2.6083 | 0.2564 | -0.99 | 0.2741 | | |
| | 5 | -1.3231 | 0.4133 | -0.72 | 0.3922 | | |
| | 6 | -1.7033 | 0.3567 | -0.91 | 0.3103 | | |
| Single Mean | 0 | -25.5895 | 0.0002 | -4.87 | 0.0006 | 11.88 | 0.0010 |
| | 1 | -14.2246 | 0.0236 | -2.50 | 0.1287 | 3.22 | 0.3081 |
| | 2 | -33.0167 | < 0.0001 | -2.69 | 0.0906 | 3.62 | 0.2145 |
| | 3 | -38.2239 | < 0.0001 | -2.15 | 0.2288 | 2.34 | 0.5095 |
| | 4 | -8.3089 | 0.1516 | -1.21 | 0.6506 | 0.80 | 0.8663 |
| | 5 | -2.7997 | 0.6592 | -0.65 | 0.8377 | 0.30 | 0.9885 |
| | 6 | -2.1906 | 0.7368 | -0.49 | 0.8728 | 0.38 | 0.9747 |
| Trend | 0 | -28.7448 | 0.0004 | -5.56 | 0.0007 | 15.50 | 0.0010 |
| | 1 | -19.0051 | 0.0276 | -2.82 | 0.2032 | 3.99 | 0.4362 |
| | 2 | -87.9564 | < 0.0001 | -3.67 | 0.0460 | 6.97 | 0.0601 |
| | 3 | 119.4563 | 0.9999 | -3.43 | 0.0725 | 6.12 | 0.0920 |
| | 4 | 238.8002 | 0.9999 | -2.61 | 0.2782 | 3.73 | 0.4800 |
| | 5 | 92.9105 | 0.9999 | -2.77 | 0.2229 | 4.80 | 0.2945 |
| | 6 | 44.2286 | 0.9999 | -2.25 | 0.4389 | 2.93 | 0.6206 |

**Table B10. Federal Obligations for Applied R&D**

| | | Augmented Dickey-Fuller Unit Root Tests | | | | | |
|---|---|---|---|---|---|---|---|
| Type | Lags | Rho | Pr < Rho | Tau | Pr < Tau | F | Pr > F |
| Zero Mean | 0 | -19.0444 | 0.0006 | -3.88 | 0.0004 | | |
| | 1 | -12.5270 | 0.0079 | -2.50 | 0.0146 | | |
| | 2 | -9.8427 | 0.0203 | -1.90 | 0.0559 | | |
| | 3 | -27.2700 | < 0.0001 | -2.45 | 0.0169 | | |
| | 4 | 74.9997 | 0.9999 | -2.84 | 0.0067 | | |
| | 5 | -19.0326 | 0.0004 | -1.48 | 0.1240 | | |
| | 6 | -373.6350 | 0.0001 | -1.89 | 0.0572 | | |
| Single Mean | 0 | -20.8877 | 0.0018 | -4.08 | 0.0042 | 8.33 | 0.0010 |
| | 1 | -14.5267 | 0.0212 | -2.60 | 0.1072 | 3.38 | 0.2699 |
| | 2 | -12.3758 | 0.0429 | -2.02 | 0.2765 | 2.04 | 0.5785 |
| | 3 | -43.0996 | < 0.0001 | -2.54 | 0.1202 | 3.25 | 0.3011 |
| | 4 | 33.0675 | 0.9999 | -3.14 | 0.0386 | 4.94 | 0.0612 |
| | 5 | -74,076.10 | 0.0001 | -1.80 | 0.3723 | 1.63 | 0.6752 |
| | 6 | 29.4769 | 0.9999 | -2.01 | 0.2793 | 2.07 | 0.5729 |
| Trend | 0 | -21.2334 | 0.0131 | -4.03 | 0.0212 | 8.12 | 0.0343 |
| | 1 | -14.5212 | 0.1142 | -2.47 | 0.3373 | 3.21 | 0.5717 |
| | 2 | -12.6555 | 0.1846 | -1.94 | 0.6003 | 1.94 | 0.7928 |
| | 3 | -40.7144 | < 0.0001 | -2.36 | 0.3867 | 3.04 | 0.6011 |
| | 4 | 34.5014 | 0.9999 | -2.96 | 0.1656 | 4.64 | 0.3223 |
| | 5 | -3,497.51 | 0.0001 | -1.70 | 0.7130 | 1.49 | 0.8723 |
| | 6 | 47.7210 | 0.9999 | -1.81 | 0.6591 | 2.26 | 0.7374 |