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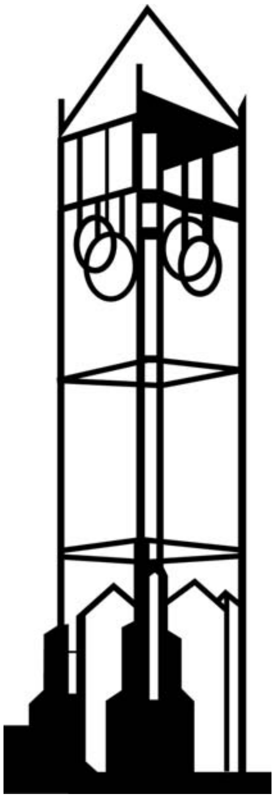

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JEL Classification : O3, O4, Q16, Q10

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Measuring Public Agricultural Research Capital and Its Contribution to State Agricultural Productivity

A half century ago, Schultz (1953, p. 109-111) argued that modern science is supported mainly for the fruits that it bears, measured in terms of new techniques. Furthermore, he proposed that pure science and its contribution to society are closely interrelated, and advances in science and technology require investments of real resources. These resources consist largely of scientist's effort, complementary inputs of assistants, laboratories, and equipment, such as computers, and use of the existing stock of knowledge. Schultz also argued that new techniques are a type of input that entrepreneurs would pay to obtain because new technologies increase expected productivity or output per unit of input of an enterprise.

Although Schultz saw that basic and applied research in the sciences contribute to advances in agricultural technologies, organized research is not undertaken by farm-firms but primarily by public agencies—the state agricultural experiment stations (SAESs) and the Agricultural Research Service of the U.S. Department of Agriculture. The reason that farm-firms do not undertake organized research is the large fixed costs, long gestation periods, and very specialized talent needed to successfully undertake research, relative to farm sales, and the public goods nature of the discoveries, i.e., benefits tends to be nonrival for many discoveries (Khanna et al. 1994, Cornes and Sandler1996). In contrast, in private industry most of the research is undertaken in large firms or corporations, and this research focuses on innovations of products and processes that are protected by patents, copyrights or trade secrets, thereby having the potential to enhance future profits.

Schultz also argued that the competitive structure of agriculture is conducive to the introduction and adoption of new technology. Most new technologies for agriculture are geo-climate sensitive—responding to climate, soils and the local eco-systems (Huffman and Evenson 2006, p. 271). Some new technologies reduce the expected cost of production to farmers in a particular geo-climate region. Some of these farmers will be early adopters, as with hybrid corn (Griliches 1960). When this technology is successful, it gives early adopters a competitive advantage over other farmers in their area. Hence, as the successes of new technologies are observed in an area, more farmers will try the technology and frequent adopt it. Diffusion of the new technology takes place when a large share of the farming population in similar geo-climatic regions adopts the technology.

Griliches is best know for his pioneering research in the field of productivity and economic analysis in which he employed econometric techniques to link productivity or output to past investments in research and development. Productivity change could occur at the micro or individual firm/farm level or at the aggregate level, e.g., state, regional or national level. At the heart of his research was the idea that technical change was a major source of productivity growth, and that technical change was the result itself of productive economic activity—activity designed to generate new things or change through organized public and private research (Griliches 1998, p. 1). Hence, knowledge and knowledge generation are the primary source of productivity growth in the long run. However, research capital is a form of intangible capital, creating major challenges in how to measure it well (Griliches 1998), and considerably more challenging than measuring physical capital, which has its challenges, too (Jorgenson et al. 2005; Ball et al. 2002).

The objective of this paper is to develop and describe a methodology for measuring public agricultural research capital, to present and evaluate new public agricultural research capital measures for each of the 48 contiguous US states, 1970-1999, and to obtain and discuss new econometric estimates of the contribution of public agricultural research capital to U.S. state agricultural productivity, 1970-1999.[1] This paper is focused on measurement and fundamental

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[1] The particular time period chosen facilitates comparison with earlier studies and does not stretch beyond existing needed complementary data series, for example, for public agricultural extension.

contributions of public agricultural research to agricultural productivity and not to issues of how the composition of the state agricultural experiment station funding affects agricultural productivity as for example in Huffman and Evenson (2006a). Furthermore, this paper is the first to describe in detail modern methods of measuring state public agricultural research capital. Also, the paper uses the USDA's most recently revised estimates of state agricultural productivity (USDA 2009) in its econometric analysis.

First, a new model of state agricultural productivity is developed, including the contribution of public agricultural research capital. Second, a new methodology is developed and described to generate public agricultural research capital at the state level. It involves choosing a subset of all public agricultural research, and thereby, excluding public agricultural post-harvest research, community and rural development research, agricultural policy research, human nutrition research and what has traditionally been called home economics research, which do not directly contribute to agricultural productivity. For any given state, the hypothesis is that public agricultural research capital that contributes to agricultural productivity is undertaken by intrastate research of the USDA and land grant institutions and by spillin public agricultural research undertaken in surrounding states within the same geo-climatic region. This latter research capital provides the opportunity for a state to borrow discoveries and innovations from other areas as it undertakes its own research, which is believed to be important. Third, new econometric evidence of the contribution of public (and private) agricultural research capital to state agricultural productivity is obtained and evaluated. In the final sections, some conclusions are presented.

The Model

Assume that agriculture of a given state can be adequately summarized by an aggregate production function

(1) $Y = \mathrm{F}(X, K, \mu)$

where Y is an index of outputs of all farms in a state; F( ) is some plausible algebraic form for the production function; X is an index of conventional inputs of land, labor, equipment, breeding stock, buildings and materials; K is the (current) state of agricultural technology; and μ represents all other factors affecting the conversion of conventional inputs and available agricultural technologies into agricultural output. Under special conditions, total factor productivity can be written as

(2) $\ln(TFP) = \ln(Y/X) = \mathrm{G}[\mathrm{W}(\mathbf{B})R, t, \nu]$

where G( ) is a production function for agricultural technologies or total factor productivity of a given state, R is a vector of current and lagged values of real agricultural research expenditures that produces discoveries and innovations impacting the techniques available to farmers in a given state,

(3) $\mathrm{W}(\mathbf{B})R = w_0 R_t + w_1 R_{t-1} + w_2 R_{t-2} + w_3 R_{t-3} + w_4 R_{t-4} + w_5 R_{t-5} + \ldots + w_m R_{t-m}$,

is a timing-weighted summation of current and past real research expenditures ($\Sigma\, w_\ell = 1$), t is a time trend to capture purely trend dominated factors affecting state TFP, and ν represents other factors that affect the technology available to farmers in a given state, for example agricultural extension and private agricultural research.

The production of useful techniques might related to research expenditures as follows

(4) $K_t = [\mathrm{W}(\mathbf{B})R_t]^{\eta} exp(\alpha + ct + \nu_t)$.

Or using equation (2), an econometric model to explain state agricultural productivity is

(5) $\ln(TFP)_t = \alpha + \eta \ln[\mathrm{W}(\mathbf{B})R_t] + ct + \nu_t$

Equation (5) incorporates the hypothesis that a state's agricultural research capital impacts state agricultural productivity, and its contribution is η. Moreover, this contribution is estimated while controlling for trend dominated factors (t) and other factors ν_t. It is also highly likely that the random disturbance term ν_t is generated by a first-order autoregressive process, i.e., $\nu_t = \rho\ \nu_{t-1} + \varepsilon_t$, where $|\rho| \leq 1$ and ε_t is identically distributed with zero mean and constant variance.

Measurement of Public Agricultural Research Capital

Early attempts to measure public agricultural research capital were due to Griliches (1964) and Evenson (1967, 1980). Griliches (1964) estimated an unrestricted production function (equation 1) with a Cobb-Douglas algebraic functional form, using separate variables for each of five major input categories, and introducing, in addition, a measure of education per worker and a measure of public expenditures on research and extension (dissemination of research results) capital per farm into the estimating equation. His observations were 39 of the largest 48 states for 1949, 1954 and 1959. Output and inputs are measured per farm.[2] His measure of public agricultural research and extension capital is the undeflated sum of total expenditures on research and extension by the respective state agricultural experiment stations and extension services averaged for the previous year and five years previous. This measure is quite crude: (i) It is both too broad and too narrow. It is too broad in the sense that it uses all public agricultural research and extension expenditures, irrespective of whether they might be reasonably expected to impact agricultural productivity. Of course, at this time it would have been hard to do much better. The measure is too narrow in the sense that it ignores all the agricultural research undertaken by the USDA in the states (Huffman and Evenson 2006). (ii) The timing weights are very crude. (iii) No allowance is made for spillin/spillover public agricultural research capital. (iv) Public research and extension are not expressed in constant prices or real terms. (v) Research capital produces local and regional public goods and should not be deflated by the number of farms. Given these limitations and the fact that Griliches ignored autocorrelation in the disturbances, the results are somewhat remarkable. His

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[2] Output is measured as the value of farm sales inventory change, home consumption, and government farm payments. Inputs are land and buildings, machinery, fertilizer, labor, and other inputs (purchased livestock and feed, seed and other current inputs.)

estimate of the regression coefficient for the natural log of public agricultural research and extension per farm is 0.059. Evaluated at the sample mean of the data, the marginal product of public agricultural research and extension was 0.059x7,205/32, or approximately 13 dollars of output per year for an additional dollar of public agricultural research and extension expenditure per year. His implied social rate of return was approximately 65 percent.

Evenson (1967) also estimated an unrestricted Cobb-Douglas production function but also a TFP equation using a more sophisticated stock variable for public agricultural research capital and reported on experiments with timing weights for research. In particular, he established the tradition that the contribution of agricultural research cannot be simply expressed in terms of a small number of important "breakthroughs," but rather a large number of more or less continuous changes, an idea suggested by Schultz (1953). Instead, he suggested that public agricultural research enhanced the quality of inputs—fertilizers, pesticides, feed, seed, breeds of livestock, etc. He also elaborates on possible sources of quality change: (i) A decrease in traditional resources used to produce a given quantity of an input. (ii) Formal education of farmers through its role in the development of improved labor skills and managerial ability. (iii) Research by private firms selling inputs to farmers. (iv) Extension-type efforts by private firms to encourage the adoption of improved purchased inputs. (v) Extension or dissemination of information about new technologies by state and federal agencies. (vi) A general increase in knowledge and understanding of phenomena not directly the result of mission-oriented research extension or education associated with the agricultural sector of the economy.

Evenson (1967) was the first to explore the combined contribution of public agricultural research of state agricultural experiment stations and the USDA' research agencies—primarily the Agricultural Research Service. Furthermore, he provided evidence that the share of federal and nonfederal funds spent on equipment and structures after 1940 was small, 5-6 percent, and the share allocated to scientific and support staff was the dominate input and the share spend on these categories were relatively constant after 1940.

Evenson (1967) pursued both a production and productivity function approach and focused on estimating the mean lag of public agricultural research expenditure as it affected output or productivity and measuring the contribution of public agricultural research to aggregate agricultural production or productivity. Relative to Griliches (1964) he presents modern and extensive discussions of the lag structure between expenditure of research funds (and presumably the allocation of effort to a project) and their contribution to projects and agricultural productivity. First, he suggested that a lag exists between the expenditures of funds on research and the development of new knowledge. Second, a lag exists from the development of knowledge to the adoption of new technology by farmers. Third, knowledge frequently depreciates, and this also affects construction of the stock of useful knowledge or technology. He summarizes the first of these two lags in a "research production function" where the output of knowledge (or technology) creation was represented as: $R_t = W(L)Z_t + C(L)\mu_t$ where W(L) is a lag operator providing timing weights for current and lagged values of real research expenditures R. $C(L)\mu_t$ is a distributed lag of errors terms (μ_t). He then hypothesized that the stock of existing knowledge (or technology) can be defined as $K^*_t = R_t + (1 - \delta)K^*_{t-1}$ where δ is the depreciation rate on the stock of knowledge (or technologies), $0 \leq \delta \leq 1$. New technology may be eroded by the adaptation of pests to the technology—pesticides, crop varieties, animal breeds. For example, it is well known that any new crop variety that contains insect resistance will be successful for only a short period of time when it is widely adopted by farmers because the pest evolves to erode resistant. In addition, depreciation of knowledge can also occur when existing knowledge (technology) is replaced by new knowledge and better technologies—i.e., through "creative destruction." Substituting the equation for R_t into the equation for $K^*_t = F(L)R_t$ we obtain $F(L)W(L)Z_t + F(L)C(L)\mu_t$ implying that the existing stock of knowledge is now a convolution or combination of the two distributed lags, one for research expenditures and one for error terms.

Evenson (1967) used time series data on aggregate U.S. agriculture, 1938-1963, and tested for the mean lag in a symmetric inverted-V lag structures, starting with a weight of zero for year t in the lag structure for public agricultural research. Given the general form of his lag structure, the appropriate mean lag length was estimated by systematically varying the total lag length and choosing the one that resulted in the smallest residual sum of squares in least squares estimation of the aggregate production or productivity function. He also adopted the Cobb-Doulas form of the aggregate agricultural production function and included variable inputs of farm labor (quality adjusted using education), fertilizer, seed and feed, machinery and land.[3]

In one set of results, research expenditures by agricultural experiment stations and by the USDA are aggregated together and deflated by a price index of university faculty salaries. Results from fitting the Cobb-Douglas production function showed a mean research lag of 6 to 7.5 years provided the largest R^2. The estimated coefficient for ln (public agricultural research capital) was 0.21 for this specification (t-value of 2.7). The implied marginal value of output for an additional dollar spent on public agricultural research is $10, with this output distributed over time. The implied marginal social rate of return is 54 percent. He also provides results after separating public agricultural research into two separate parts, one part undertaken by state agricultural experiment stations and a second part undertaken by the USDA. His thinking was that USDA research during the study period might be more intensely engaged in basic and less intensely engaged in applied

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[3] In some of his fitted models, he include a variable representing local extension capital also created using symmetric invert-V weights, but with a short length.

research than the research of the state agricultural experiment stations. If this were true, then the mean lag length would be longer for the USDA's research. However, he found weak support for this hypothesis: with two separate public agricultural research stock variables, a mean lag for state agricultural experiment station research of 6 years and of USDA research of 9 years gave slightly highest production function R^2.

Evenson's (1967) research represents several advances in methodology and data over that chosen by Griliches (1964). However, he ignores possible cross-state research spillin/spillover effects (and private R&D effects). He does provides evidence (Evenson 1968, p. 41) that autocorrelation in his production function is not serious in these data.

The first serious attempt to estimate the contribution of public agricultural research to state agricultural productivities was by Evenson (1980). He used annual data, 1948-1971, for 48 states, and his data for farm outputs and inputs by state were derived from the *Farm Income*, and *Farm Income Situation* reports of the USDA. His analysis consisted of two parts. First, he jointly investigated timing and spatial/contiguity weights to assess the best empirical measure of public agricultural research capital for explaining aggregate (state) agricultural productivity. Second, he undertook a more detailed analysis of the decomposition of state agricultural productivity. For the spatial or contiguity pattern, which determines how research spills in from other states, he used the geo-climatic region and sub-region designations from the U.S. Department of Agriculture (1957). For example, see Figure 1 and consider the Midlands Feed Region, region 6. It includes all of Iowa; roughly the Western half of Nebraska and South Dakota; Southern half of Minnesota, Wisconsin and Michigan; Northeastern half of Ohio; Northern two-thirds of Indiana and Illinois; Northern half of Missouri; and a small part of Northeastern Kansas. Sub-regions within this region are designated by number to right of the decimal point, e.g., 6.1 designates sub-region 1 in region 6.

He defined public agricultural research capital for a given state as: $R(a,b,c)_t = A(a,b,c)_t + \alpha_0 SA(a,b,c)_t$ or $A(a,b,c)_t + \beta_0 RA(a,b,c)_t$ where $A(a,b,c)_t$ is the within-state applied public agricultural research stock, $SA(a,b,c)_t$ is the stock of applied public agricultural research in similar sub-regions hypothesized to spillin to a given state, and $RA(a,b,c)_t$ is the stock of applied agricultural research in the same geo-climatic region (which includes the sub-regions) hypothesized to spillin to a given state. In this study Evenson limits his consideration to timing weights having a trapezoidal shape (Figure 2); the parameter *a* is the time period over which there is rising weights, the parameter *b* denotes the following period over which the timing weights are at a peak and constant, and parameter *c* denotes the length of the following period over which the timing weight is declining to zero. For example, $R(7, 8, 15)_t$ denotes a research stock variable containing trapezoidal timing weights that start at zero in period t, then increase linearly for the next 6 years, are constant at maximal contribution for the following 8 years and then decline linearly over the following 15 years. Hence, research effort depreciates only over the last 15 years of the 29 year "life," and the contiguity parameters α_0 and β_0 are bounded, $0 \leq \alpha_{0,} \beta_0 \leq 1$.

Evenson grouped the 48 states into three regions, Southern States (Appalachian, South East and Delta regions), Northern States (Northeast, Corn Belt and Lake States regions) and Western States (Northern Plains, Southern Plains, Mountain and Pacific regions), and undertook the first analysis to define R_t. He regressed state ln(*TFP*) on a state business cycle indicator, index of years of schooling completed by farmers, and an scaling factor. He fit his productivity model separately to each of the three regions using data for all states within the region and then undertook a grid search across sets of timing weights and spillin/continuity weights looking for the pairs that gave the largest partial correlation factor between ln(*TFP*) and public agricultural research capital, $\ln R_t$. The highest partial correlation occurred for the Northern States at $R(7, 8, 15)$ and $\alpha_0 = 0.5$ ($\beta_0 = 0$), for the Southern States at *R*(5, 6, 11) and α_0 =0.25 (β_0 = 0), and for the Western States at *R*(7, 8, 15) and β_0 = .25 (α_0 =0).[4] He interpreted these results to imply that the trapezoidal timing weighting patterns were similar across the three regions, but that there was a somewhat broader technology transfer (borrowing) in the Western States.

Based on unpublished state agricultural experiment station records, Evenson distinguished 24 research commodity categories, 22 "applied" research categories and 2 "basic" research categories. There are six categories for livestock research; five "applied" categories—beef, dairy, hogs, poultry, and sheep, and one "basic" livestock research category for livestock research that was not directly linked to any of the five specific types of livestock. Similarly, he distinguished seventeen categories for "applied" crop research (on barley, corn and sorghum, cotton, flax, forestry and forest products, fruits, hay, oats, peanuts, potatoes, rice, soybeans, sugar beets, sugar cane, tobacco, vegetables and wheat), and one "basic" crop research category for crops research that was not directly linked to one of the seventeen detailed categories. Since official public agricultural research expenditures existed only at the state level, he prorated applied research across sub-regions of a state based upon farmers' revenue shares for these sub-regions in county data from the Census of Agriculture. The number of applied agricultural research commodities having positive research funding was used to convert applied research expenditures to a per commodity basis.

Evenson's 1980 model of agricultural productivity for a given state in year t is:

$$(6)\quad \ln(TFP)_t = \alpha_1 + \alpha_2 \ln(AR)_t + \alpha_3 \ln(AR)_t \times \ln(BR)_t + \alpha_4 \ln(AR)_t \times \ln(EXT)_t + \alpha_5 \ln(ED)_t + \alpha_6 \ln(EXT)_t + \alpha_7 \ln(ED)_t \times \ln(EXT)_t + \alpha_8 \ln(EXT)_t \times PL_t + \alpha_9 \ln(EXT)_t \times BC_t + \nu_t$$

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[4] For each region there were there were 12 different pairs of trapezoidal weights tested: *R*(3, 4, 7), *R*(3, 4, 11), *R*(5, 6, 11), *R*(5, 6, 15), *R*(7, 8, 15), *R*(7, 8, 19), *R*(7, 8, 25), *R*(11, 12, 25), and *R*(15, 20, 25). Nine sets of contiguity weights tested were: (α_0 =0, β_0 = 0), (α_0 =0.25, β_0 = 0), (α_0 =0.5, β_0 = 0), (α_0 =0.75, β_0 = 0), (α_0 =1.0, β_0 = 0), (α_0 =0, β_0 = 0.25), (α_0 =0, β_0 = 0.5), (α_0 =0, β_0 = 0.75), and (α_0 =0, β_0 = 1.0).

where AR_t is the state's stock of "applied" public agricultural research, and BR_t is the state's stock of "basic" public agricultural research with timing and contiguity weights of $BR(11, 12, 25)_t$ and $\alpha_0 = 0.25$ in the Southern region, $BR(15, 20, 25)_t$ and $\alpha_0 = 0.25$ in the Northern region, $BR(15, 20, 25)_t$ and $\beta_0 = 0.25$ in the Western region. EXT_t is the state's stock of extension (using exponentially declining weights starting at 0.5 in t), ED_t is an index of years of schooling completed by a state's farmers, and PL_t and BC_t is a state's scaling factor (economic slack) and business cycle index, respectively. ν_t is a zero mean random disturbance term.[5]

The model as described in equation (6) was fitted to state aggregate data, and he obtained relatively good results, except that the estimate of α_3 was not significantly different from zero. Then, in (6) he replaced $\alpha_2 \ln(AR)_t$ with $\alpha_{2S} \ln(AR)_t D_S + \alpha_{2N} \ln(AR)_t D_N + \alpha_{2W} \ln(AR)_t D_W$ where $D_\ell = 1$ if a state in region ℓ = S(Southern region), N(Northern region) or W(Western region) and zero otherwise. The new model gave estimated coefficients that were significantly different from zero at the 5% level (and the estimated coefficients for the applied research stock interacted with the basic research stock and extension stocks were positive). The implied marginal product from investing \$1,000 in applied research was \$21,000 (=\$14,100 intrastate plus \$7,100 spillover) in the South, \$11,600 (=5,070 + 6,530) in the North, and \$12,200 (= 8,270+3,930) in the West. He concluded that the implied internal rate of return was 130% in the Southern region, 95% in the Northern region and 55% in the Western region.

In the mid-1980s, we began a two-decade long research program to improve agricultural productivity statistics and public agricultural research capital measure for the 48 contiguous US states. Their efforts to improve productivity statistics were at least partially successful (Huffman and Evenson 1993), but about 1990, the Economic Research Service of the USDA undertook a large

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[5] Equation (6) also included regional dummy variables.

investment in generating start-of-the-art agricultural productivity statistics, using production theory methods of productivity measurement, for the U.S. and its states, 1960-1996 (Jorgenson 2002). This program was led by Eldon Ball, and the ERS data are described in Ball et al. (2002) and Ball et al. (1999). The ERS agricultural productivity statistics have most recently been updated to 2004 (USDA 2009).[6] Hence, the our state productivity data set was an intermediate step to the somewhat more refined USDA data on state agricultural productivity.

New work was initiated in 1998 to build a refined public agricultural research capital data set for US states; it has progressed significantly, being revised several times. To construct a measure of public agricultural research capital, we combine information from several types of sources. The richest in detail and the center piece of our work are data collected by the USDA in its Current Research Information System (CRIS), which was established in 1967.[7] CRIS is a data base collecting information on all research projects underway by principal investigators in the USDA's research institutions, largely the Agricultural Research Service and the Economic Resource Service, and in the state institutions undertaking agricultural research—the state agricultural experiments stations and the veterinary schools/colleges (Vet. Med. Cols.) of the land-grant universities.

For each new CRIS project, PIs characterize their project by the PI's location (for the location of work), his/her choice of one or more research commodities-resources, for example specific crops (corn, wheat, tomatoes, peaches, cotton etc.), animals (beef cattle, dairy cattle, swine, sheep, poultry, etc.) and/or resources (land, water, farm structures)(see Appendix A, Table 1 for the complete list) on which research is to be undertaken and one or more research problem areas, or RPAs, (such as soil, plant, water and nutrient relationships; control of weeds and other hazards of

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[6] Pardey and Alston also engaged in a separate effort to generate a new set of state productivity statistics (Acquaye et al. 2002) and a measure of public agricultural research capital and Alston et al. (1998).

[7] In the establishment of the new data system, the data were noisy for the first two years, and they do not match the quality of later data.

field crops and range; improving biological efficiency of field crops) (see Appendix A, Table 2 for the complete list) that will be the focus of the research project. He/she also designates the field(s) of science to be applied in the project (see Appendix A, Table 3 for the complete list). Over the lifetime of a research project (normally 3 to 5 years), the value of a scientist's time, research assistant's time, and other resources allocated to the project are reported to CRIS, and the USDA uses this data base to prepare annual reports, including the annual *Inventory of Agricultural Research*. Hence, CRIS contains a large data base describing how resources are allocated to all research projects undertaken by researchers in the USDA and in the agricultural experiment stations and veterinary medicine colleges/schools of the land-grant universities.

Realizing that some CRIS collected data on research expenditures do not contribute directly to agricultural productivity, we exclude a number of research commodities and RPAs from the total set of CRIS research commodities and RPAs. In Appendix A, Table 1, the research commodities-resources that have a check mark √ on the left side of the table are included in our most recent data set, and likewise RPA's in Appendix A, Table 2, that have a check mark √ in the left margin are included. The types of commodities-resources that are excluded include post-harvest commodities-resources—research on farmer cooperatives, marketing systems, communities, families—and likewise RPAs are excluded that are most associated with these commodities.[8]

How much of a difference does it make? In 1970, 69.5 percent of the combined research of the USDA, state agricultural experiment stations and veterinary colleges was directly focused on agricultural productivity. The national share in 1984 was 71% and in 1995 was 69%. Hence, at the national aggregate level, this share is quite stable over the period covered by the CRIS data. Moreover, failing to exclude the non-productivity research from state research totals (or to include

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[8] My most recent measures of public agricultural research expenditures also exclude all types of forestry research. The primary reason is that forest products are a relatively unimportant output of farms in all but a few states. Much of the logging in the US is undertaken on federally owned and managed lands.

the research undertaken by the USDA in a state) creates measurement errors in agricultural research capital. This includes the public agricultural research data set developed by Alston and Pardey (2001). This is important in productivity analysis because measurement error in the agricultural research capital generally can be expected to bias the regression coefficient research capital toward zero or downward for positive coefficients (Greene 2003). This could be a reason why Alston and Pardey report substantially lower estimates of the social rate of return to public agricultural research than those commonly reported in the literature of 40-55 percent (Evenson 2001) and Huffman and Evenson (2006a).

To develop a measure of public agricultural research capital starting in 1970, public agricultural research expenditures are needed by state extending back about 35 years or to 1935. We build on the rich detail of CRIS data over 1970 to 1999 but must devise new methods for measuring intrastate public agricultural research expenditures over 1929-1969. Over 1948-1965, respectable quality data exist on research expenditures by commodity for each state agricultural experiment stations (Huffman and Evenson 1993, p.115-117), but we do not have any state level data on the USDA's agricultural research programs. The SAES data arise from the fact that for accountability purposes the USDA required the state agricultural experiment stations to file research expenditure reports for 35 subject matter areas, and these unpublished worksheets were available to us (plus published annual totals by state). Twenty of these subject areas were directly tied to a type of farm crop or livestock, similar to CRIS commodities.

The larger problem for this period is that we do not have an allocation of the USDA's agricultural research to the various states (or to agricultural productivity), and we know that it was not all conducted in one or two locations (Huffman and Evenson 1994, p. 30-32, 50-54). In fact for the research stock variable created in the late 1980s, a simple exponential trending methods was used to work backward from 1970 totals for each state. This trending procedure, which reached back in the 1920s, ignored some important information that was and is available. The new work incorporates more information into the early (pre-1970) estimates and to apply the methodology of interpolation of a time series by a related series (Friedman 1962).

Given that state and national totals exist for SAES research in all years, it is useful to undertake some comparisons. First, in 1970, the national total for public agricultural productivity research expenditures (for USDA research agencies and the SAES plus Vet Med Schools) is equal to the national total of SAES research on all commodities and RPAs. In 1984, the ratio is 1.13 but in 1995 is 1.02. Hence, over this post-1970 period, the national total for direct agricultural productivity research expenditures is approximately equal to the total for all SAES research. Second, during the pre-1970 period, we can only make comparisons of the national total of SAES and USDA research expenditures; not that of agricultural productivity research expenditures. For example, in 1970, the ratio of the USDA's research expenditures to that of all SAES research expenditures is 0.51, in 1960 it is 0.52, and in 1950 it is 0.45. There is a dramatic change in relative and absolute research expenditures of the USDA and SAES system over 1948 to 1950 and then greater stability in the ratio of these research expenditures after 1950 (Huffman and Evenson 2006, p. 104-107). For example, in 1948, this ratio is 1.40, in 1940 it is 1.53 and in 1930 it is 1.98. *In this new work, public agricultural research expenditures of the USDA, SAES and Vet. Med. Schools directed to enhancing agricultural productivity, 1929-1969, are measured as an arbitrary re-scaling of state and national totals for all SAES research expenditures.* This ratio at the national level is 2.01 over 1929 to 1948 and 1.55 in 1949 and 1.04 in 1950 to 1969, and all states have a similar scaling factor, except that a small adjustment was made based on a state's own ratio of agricultural productivity- oriented research undertaken by the USDA, SAES and Vet. Med. Colleges to all SAES research in1970. The national total of my newly constructed public agricultural expenditures are 72% of all USDA and SAES agricultural research expenditures over 1930 to 1948, 61% in 1950, which compares to 70% in 1970.

Nominal research expenditures directly impacting agricultural in each state and year are converted into constant price expenditures using the Huffman and Evenson price index for agricultural research (Huffman and Evenson 2006, p. 105-106, 1984 = 1.00). This index consists of two components: scientists' time and other inputs. The compensation (salary plus benefits) of scientists' time is approximated by the AAUP index of faculty salaries at major *public research* (Doctoral Level) *universities* for assistant, associate and (full) professors (AAUP). The price index for all other inputs is proxied by the National Income and Products Account price index for goods and services purchased by state and local governments (US President 2002). The share weights for these two parts are fixed over time at 0.70 for value of scientists' time and 0.30 for other expenditures. This conversion from nominal to real magnitudes is extremely important when the agricultural expenditures series is quite long because prices of research inputs have changed by a large magnitude from the beginning to the end of our study period (Huffman and Evenson 2006b, p. 105-107).[9]

In this paper, timing weights take a trapezoidal shape, e.g., Huffman and Evenson (2006a), which is an imposition of deterministic prior beliefs about the lag structure. Furthermore, it is assumed that for the year in which the expenditure is made (t) and for one additional year, no impact on agricultural productivity occurs, i.e., a two year lag with zero weights, then a positive weight starts in year 3 and rises linearly to 0.05128207 in year 9 (7 years of rising weights), the weight remains at a maximum and constant to year 15 (or a total of 7 years), and then the weights

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[9] Appendix B describes a procedure for deriving expenditures on 20 research commodities by the USDA and state SAES and Vet. Med. Colleges over 1929 to 1969.

decline linearly to zero in year 35 (or after 20 years) or *R*(1, 7, 7, 20). Hence, the mean lag is 14.5 years, which is 3 years shorter than the median lag length. The rationale for using weighted real research expenditures goes back to Griliches (1964) and the shape of the timing weights have evolved through Evenson's research (Evenson 1968, 1980) and Huffman and Evenson (1994). Moreover, Griliches (1998) provides intuition for this lag pattern, e.g., the impact of research and development on productivity (or farm output) most likely has a short gestation period (with no impact), then blossoms (a period of rising weights), and eventually becomes obsolete (deprecates away). Our lag pattern conforms to his intuition and also reduces the likelihood of reverse causation.[10]

To determine research spillins or borrowing potential, i.e., the impact on a given state of direct public agricultural research undertaken by other states in the same geo-climatic area, we use spatial or contiguity weights derived from the geo-climatic sub-region map (Figure 1).[11] These weights are based on the share of all agricultural production in a state that is in each of its sub-regions. In particular, these geo-climatic weights performed significantly better (t-values and R^2) than weights formed by grouping state into the 10 ERS farm production regions, which has appeal for SAES funding decisions (see Table 2 for state groups).

New measure of intrastate public agricultural research capital have been tabulated and plotted by state and year, 1970-1999. These research capital measures are in natural log units, and the patterns or shapes of these plots can be classified into five groups: (i) approximately linear, representing a constant rate of research capital growth, (ii) a somewhat tipped forward and stretched

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[10] A few researchers have included free-form lags of public agricultural research expenditures without much structure in aggregate productivity analysis (Alston, Craig and Pardey 1998). An alternative is to impose a symmetric quadratic lag pattern over period t-1 to t-35, but our particular set of trapezoidal timing weights (which have the same area on a graph) skews benefits toward the early years. Our approach has similarities to Bayesian smoothing patterns for lag patterns (Kitagawa and Gersch 1996; Geweke and Kean 2005).

[11] The sixteen geo-climatic regions in Figure 1 are very similar to the USDA's twenty Land Resource Regions for the contiguous US (USDA 2006)

"S" shape, (iii) a roughly "j" or "∪" shape with a slight counterclockwise rotation, (iv) a "∩" shape with a slight counterclockwise rotation, and (v) a greatly tipped forward "S" shape. Only 5 of the 48 states are included in the first group (Georgia, Idaho, Illinois, Minnesota, and Utah), e.g., see Figure 3 for Idaho; 17 are included in the second group (Alabama, Arizona, Arkansas, Kentucky, Maine, Michigan, Mississippi, Missouri, Nebraska, Nevada, North Carolina, Ohio, Oklahoma, Tennessee, and South Dakota), e.g., see Figure 4 for Alabama; 17 are included in the third group (Colorado, Delaware, Florida, Iowa, Indiana, Kansas, Maryland, Montana, New Mexico, North Dakota, Oklahoma, Pennsylvania, S. Carolina, Texas, W. Virginia, Wisconsin, and Wyoming), e.g., see Figure 5 for S. Carolina; 4 states are included in the fourth group (California, Louisiana, Virginia, and Washington), e.g., see Figure 6 for Louisiana; and 5 states are included in the fifth group (Connecticut, Massachusetts, New Hampshire, New Jersey, Rhode Island), e.g., see Figure 7 for Connecticut.[12] If you examine and compare the patterns of public agricultural research capital growth for all 48 states (see Appendix C, where states are arranged in alphabetical order by their two-letter postal code abbreviation), it is apparent my measure of state public agricultural research capital grows at different rates across the forth eight states over 1970-1999, and the growth rate is not best described as a constant or a linear trend. Hence, there is value added from investing in deriving a good measure of public agricultural research capital by state.

Table 2 provides information on the average growth rate of intrastate public agricultural research (productivity-oriented) capital for each of the 48 contiguous states, 1970-1999. Here, the states are grouped by USDA farm production regions for convenience of comparison. Table 2 shows that over 1970-1999 public agricultural research capital grew most rapidly in the Appalachian region, Southeast region, and the Northern Plains at about 2.5 percent; relatively rapid

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[12] No spillin public agricultural research capital is included in these measures.

in the Lakes States, Pacific region, and Mountain States; and somewhat slower in the Corn Belt region, Delta States, Northeast region, and Southern Plains region. Public agricultural research capital grew most slowly in the New England region, being roughly 1 percent. Individual states that show very rapid growth of public agricultural research capital are Georgia (5.5%), Arizona (4.6%), N. Carolina (4.5%), Nebraska (4.4%), and Nevada and N. Dakota (4.1%). In contrast, states with less than 1% growth of public agricultural research are Massachusetts (0.02), Connecticut (0.2), New Hampshire and Ohio (0.8%), Wyoming (0.9%) and New Jersey (1.0%). All other states experience between 1 and 4 percent growth rates in public agricultural research capital over 1970-1999. Hence, a substantial about of variation exists in the rate of growth of public agricultural research capital across the 48 states, which is need to be able to explain agricultural productivity rates that differ across states.

Contribution of Public Agricultural Research Capital to State Agricultural Productivity

Based upon the most recent USDA data (USDA 2009), the level and rate of growth of TFP for agriculture by state, 1970-1999, are presented in Table 2. In the first column, the ranking of states by their agricultural TFP level in 1996 is presented; they are measured relative Alabama in 1996 (1.00). States with the highest TFP level are Florida (1.62), California (1.55), North Carolina (1.46), Georgia (1.33), and Washington (1.31). On the other end, the states with the lowest level of TFP are West Virginia (0.57), Wyoming (0.58), Oklahoma (0.70), Montana (0.74), and Texas (0.79). Turning to the growth rates of agricultural TFP over 1970-1999, the rate exceeding 2% in the Delta States and is almost 2% for the Southeast region. TFP growth is also relatively high in the Lakes States, Corn Belt, Northern Plains, Pacific and Appalachian regions. In contrast, TFP growth rates in the New England, Northeast, Southern Plains, and Mountain regions are relatively low. The rank correlation between TFP and public agricultural research capital growth across the 48 states is 0.2, suggesting an association.

Building on earlier TFP models and to undertake a more rigorous analysis of the contribution of public agricultural research capital to state agricultural productivity, consider the following econometric model:

$$(7)\quad \ln(TFP)_{ilt} = \beta_1 + \beta_2 \ln(RPUB)_{ilt} + \beta_3 \ln(RPUBSPILL)_{ilt} + \beta_4 \ln(EXT)_{ilt} + \beta_5 \ln(RPRI)_{ilt} + \beta_6 \ln(RPUB)_{ilt} \times \ln(RPUBSPILL)_{ilt} + \beta_7 \ln(RPUB)_{ilt} \times \ln(EXT)_{ilt} + \beta_8 \ln(RPUB)_{ilt} \times \ln(RPRI)_{ilt} + \tau\, trend + \Sigma\, \delta_l D_l + u_{ilt},$$

where TFP_{ilt} is total factor productivity in state i in region l in year t, $RPUB_{ilt}$ is public agricultural research capital in state i in region l in year t, $RPUBSPILL_{ilt}$ is public agricultural research capital spilling in state i in region l in year t, EXT_{ilt} is the stock of public agricultural extension capital in state i in region l in year t, and $RPRI_{ilt}$ private agricultural research capital is a state's stock of private patents of agricultural technologies. *trend* is a linear annual time trend.

To take some account of the fact that federal and state agricultural science and economic funding policies follow natural boundaries around states and regional groupings of states, seven regional dummy variables are defined. Starting from the ten ERS production regions (Table 2), we reduce them to seven by combining the New England and Northeast regions into a new *Northeast* region, the Appalachian region and the Southeast region into a new *Southeast* region, the Lake States and Corn Belt into a new *Central* region, and the Southern Plains and Delta regions into a new *South Plains* region. Other regions are the *Northern Plains, Mountains*, and *Pacific*. If there are omitted variables, as there may be, the regional fixed effects and trend will partially account for these otherwise omitted effects. This will improve the quality of the final estimates. See Table 3 for definitions of symbols and summary definitions of variables. Hence, $D_\ell = 1$ if state i is located in region ℓ (Northeast, Southeast, Central, Northern Plains, Southern Plains, Mountain, and Pacific) and zero otherwise. u_{ilt} is zero mean random disturbance term that follows a first-order autoregressive process, $u_{ilt} = \rho\ u_{ilt-1} + \xi_{ilt}$ where ξ_{ilt} is assumed to have a zero mean and constant variance. Note: this specification of the autoregressive process imposes the constraint of a single autocorrelation coefficient across all 48 states.

Public agricultural extension capital by state is constructed as follows. Data on full-time equivalent professional extension staff years by state allocated to agricultural and natural resource extension are used to construct public extension capital (Ahearn, Lee and Bottom 2002). Then, public agricultural extension capital a five-year exponentially declining weighted average of current and past extension staff years in a given state, where the current year's input receives a weight of one-half and the weights decline geometrically over the next four years.

To represent intrastate private agricultural R&D capital, data on agricultural patents by residence of inventor prepared by Johnson and Brown (2002) are used. We start with the annual flow of all private agricultural patents awarded in the U.S. to domestic and foreign inventors in four areas: field crops and crop services; fruits and vegetables; horticultural and green house crops; and livestock and livestock services. For each state, we apply local production weights to each of the four totals, and then public agricultural research capital is created by applying trapezoidal timing weights over a nineteen year period. The nineteen year total lag length reflects the fact that the current patent life is nineteen years. This means that benefits from private sector patenting are moved considerably forward relative to those of public agricultural research. The mean lag is 10.5 years, which is considerably shorter than for public agricultural research.

Equation (7) is fitted with a panel structure for the forty-eight states and thirty observations over time with a linear trend using the Prais-Winsten estimator in STATA9.0 and providing panel-corrected-standard errors (PCSE). The estimates of the first-order autocorrelation coefficient (ρ) in the three models reported in Table 4 are 0.68. The fact that these values are much less than 1 suggests that weak dependence exists in the disturbances and that a unit root is unlikely to be a problem (Greene 2003). The estimated regression coefficients of all variables, except for some of the regional indicators and one coefficient for intrastate public agricultural research capital, are significantly different from zero at the 5% significance level. The results also show that a small positive and statistically significant time trend (at about 1% per year) exists in the state agricultural productivity equations.

Given that the state agricultural productivity equations are fitted with intrastate public agricultural research capital [$\ln(RPUB)_t$] interacted with $\ln(RPRI)_t$, $\ln(EXT)_t$, and $\ln(RPUBSPILL)_t$, the results provide evidence about the general substitute or a complement nature of these variables with intrastate public agricultural research capital, $\ln(RPUB)_t$. Across all three regression equation, the estimated coefficient on the interaction term between intrastate public agricultural research capital and private agricultural research capital is always negative, implying that these two types of research capital are substitutes. Likewise, regressions (2) and (3) report a negative coefficient for the interaction term between intrastate public agricultural research capital and public agricultural extension capital, implying that they also are substitutes. In contrast, regression (3) reports a positive estimated coefficient for the interaction term between intrastate public agricultural research and spillin public agricultural research capital, implying that intrastate and spillin research capital are complements. In particular, intrastate public agricultural research is more productive in those states that are surrounded by geo-climatic regions where a large amount of public agricultural research is undertaken, e.g., as in Midlands Feed or Corn Belt region. This result is strong evidence of positive externalities of public agricultural research undertaken in one state on agricultural productivity in surrounding states as reflected in Figure 1.

Table 5 presents the estimates of the elasticity of state agricultural *TFP* with respect to the public and private research capital and extension capital variables, including the contribution from interaction terms that are included in the regression equations. For intrastate public agricultural research capital, the agricultural *TFP* elasticity ranges from 0.114 in regression (1) to 0.140 in regression (2), which contains two interaction terms. The size of the productivity elasticity in regression (3) of 0.140, which is my preferred one, is almost exactly equal to the second specification reported by Huffman and Evenson (2006a). Consistent with equation (7), both models a linear time trend as a regressor, and it controlled for trends in the dependent variable and all of the other regressors. However, the impact of public research capital on output or productivity, measured as an elasticity, is somewhat smaller than that reported by Evenson (1967) of 0.21 (from fitting a Cobb-Douglas production function), and in his ln(*TFP*) equation (Evenson 1980). This is expected because in this study variables are included for both public agricultural research capital spillin and private agricultural research capital, which are excluded from his econometric models.

Although a state does not have control over the amount of public agricultural research undertaken in surrounding states (although it might be able to affect the amount that it effectively borrows from them), the estimated impact of spillin public agricultural research capital on state *TFP* measured as an elasticity is 0.059, which is significantly larger than the 0.036 reported by Huffman and Evenson (2006a, model 2). However, the contribution of spillin public agricultural research capital to a state's agricultural TFP is roughly one-half the contribution of intrastate public agricultural research capital. Thus, a state obtains a greater impact on its TFP from public agricultural research untaken within its borders than from research which spills in from surrounding areas. This is just one indication that public agricultural research capital that spills in to a state is somewhat different from that undertaken within its borders, e.g., it might consist of a greater proportion of basic or general scientific discoveries and less of applied discoveries.

The elasticity of state agricultural productivity with respect to public agricultural extension capital is 0.111 for regression (2) and a smaller value of 0.098 in regression (3). The elasticity estimate in regression (2) is similar to the value obtained by Huffman and Evenson (2006, model 2), but the preferred estimate here is in regression (3), 0.098, and it is somewhat smaller.

The elasticity of state agricultural productivity with respect to private agricultural research capital is negative in all three specification (evaluated at the sample mean of ln(*RPUB*)), varying from -0.088 to -0.140 (Table 5). This result implies that additional private agricultural research capital reduces state agricultural productivity. Given that private agricultural research investments are made with the expectation of future profits, its impact on state agricultural productivity is expected to be different from that of public agricultural research capital, so a negative impact is possible.[13] However, for private innovators to convince farmers to adopt their newly developed technologies and to make repeat purchases, the innovators must price new technologies so that many farmers find the technologies profitable (see the case of hybrid corn, Griliches 1960). This means that innovating companies must share the total surplus of their innovation with farmers (Huffman 2006; Moschini and Lapan 1997). For a quantification of the sharing, see the research on the adoption of GM cotton by Falck-Zepeda et al. (2000a,b) and on soybeans by Moschini et al. (2000). One plausible interpretation of the negative productivity elasticity is that intrastate public agricultural research capital is too large, given that public and private research capital are a type of substitute, but certainly not perfect substitutes.

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[13] The estimated coefficient of the exact same private agricultural research capital variable had a positive but not significantly different from zero impact on state agricultural productivity in Huffman and Evenson (2006).

The results have additional implications. First, given the fitted model of state agricultural TFP in Table 4, the lagged pattern converting public agricultural research expenditures in research capital (Figure 1), and the patterns of public agricultural research capital growth (Appendix C, Figure 1-48), I predict that Louisiana and other states included in research capital growth pattern group (iv), i.e., California, Virginia, and Washington, and Connecticut and other states include in research capital growth pattern group (v), e.g., Massachusetts, New Hampshire, New Jersey, and Rhode Island, are currently experiencing a major slow down in agricultural TFP growth relative to their performance during the 1990s and relative to the current performance of the other thirty eight states.

Second, investments in public agricultural research come at a social cost and this, and other studies, have shown that it creates future social benefits in the form of reduced prices of agricultural products. The implied marginal real social rate of return to an incremental investment in public agricultural research capital (intrastate and spillin/spillover effects) on state agricultural TFP is about 60 percent, which is very large and suggests under investment. Moreover, this estimate is larger than that reported in Huffman and Evenson (2006a) because the estimated marginal impact of spillin agricultural research capital is 50 percent larger in the current study. For a comparison with other rates of return to public agricultural research, see Evenson (2001).

Finally, we must remember that productivity growth is not simply a matter of technological change, but also depends on the efficiency with which existing industrial enterprises and other social institutions, including extension, are operating (Griliches 2000).

Conclusion

In this paper, a new model of state agricultural productivity has been developed, including the contribution of public agricultural research capital. Second, a methodology for intangible public agricultural research capital has been developed, described and used to generate public agricultural research capital at the state level for the contiguous forty eight states, 1970-1999. This required constructing estimates of public agricultural research expenditures extending back to 1935. Public agricultural research expenditures that are not directed to research on commodities and research problems areas that have an agricultural productivity component are excluded the measure of public agricultural research expenditures. These exclusions include post-harvest research, community and rural development research, agricultural policy research, human nutrition research and what has traditionally been called home economics research and associated research problem areas. For each state, a measure of public agricultural research capital for each state is reported and they are used along with geo-climatic region map to construct spillin public agricultural research capital measures.

Third, starting with new and updated TFP data and the new measures of public agricultural research capital, a new estimate of the contribution of public agricultural research capital to state agricultural productivity has been obtained and evaluated. Intrastate and spillin public agricultural research capital measures are shown to be strongly complementary. These results reveal that the marginal social rate of return to public agricultural is quite large, but also that significant positive externalities exist across states in similar geo-climatic regions. Hence, state level decision making on public agricultural research expenditures would be inefficient, and in fact, the current public agricultural research system has shared decision-making on intrastate expenditures on agricultural research. They are made by state governments for state agricultural experiment station and veterinary college research and by the federal government for agricultural research in outlying research stations and laboratories of the Agricultural Research Services and Economic Research Service. The federal government also allocates some funds for agricultural research to the state agricultural experiment stations through the regular Hatch Act and regional research program of the Hatch Act (Huffman and Evenson 2006b). Fourth, California, Washington, and the New England states are most likely experiences an agricultural productivity slowdown due to the slowing or negative growth of public agricultural research capital starting in the mid-90s.

Almost a half century ago, Griliches initiated the first attempt to econometrically estimation the contribution of public agricultural research (and extension) to agricultural productivity. Others have followed in his footsteps and have improved upon and refined the data, measures and models of productivity. The research on productivity decomposition in agriculture continues to lead the research on the measurement of intangible research capital and its contribution to productivity.

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Figure 1. U.S. agricultural geo-climatic regions and sub-regions (Adapted from U.S. Department of Agriculture, 1957 and from Evenson 1996).

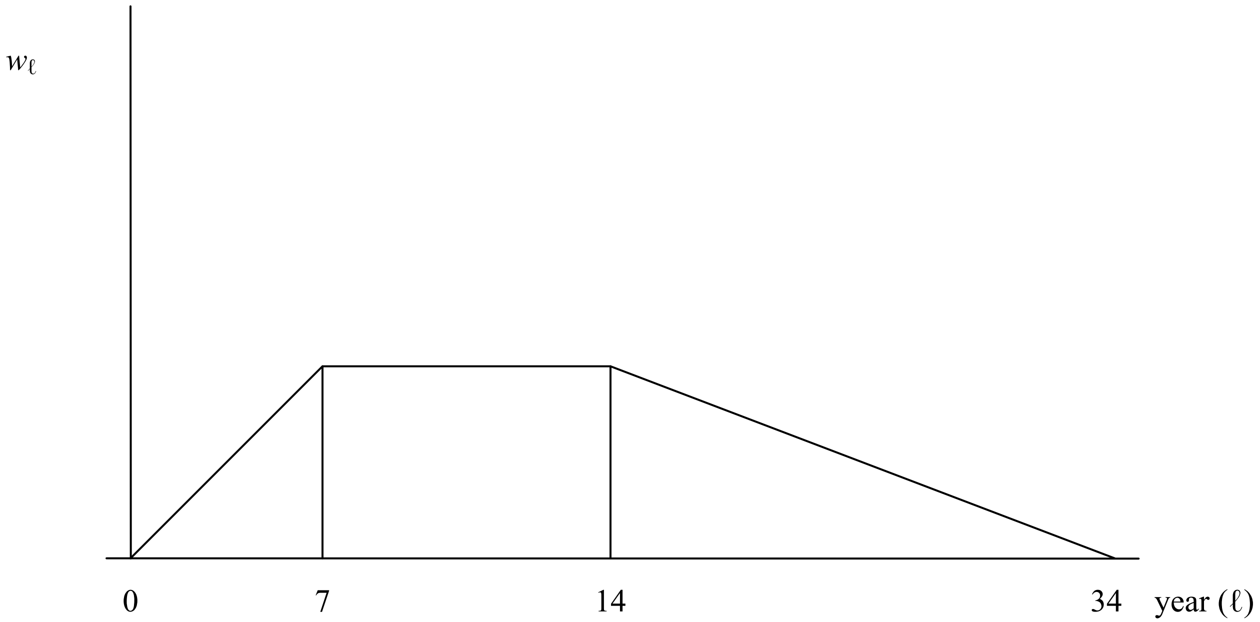


Figure 2. Public agricultural research timing weights: trapezoidal pattern

Figure 3. Public Agricultural Research Capital, 1970-1999: Idaho

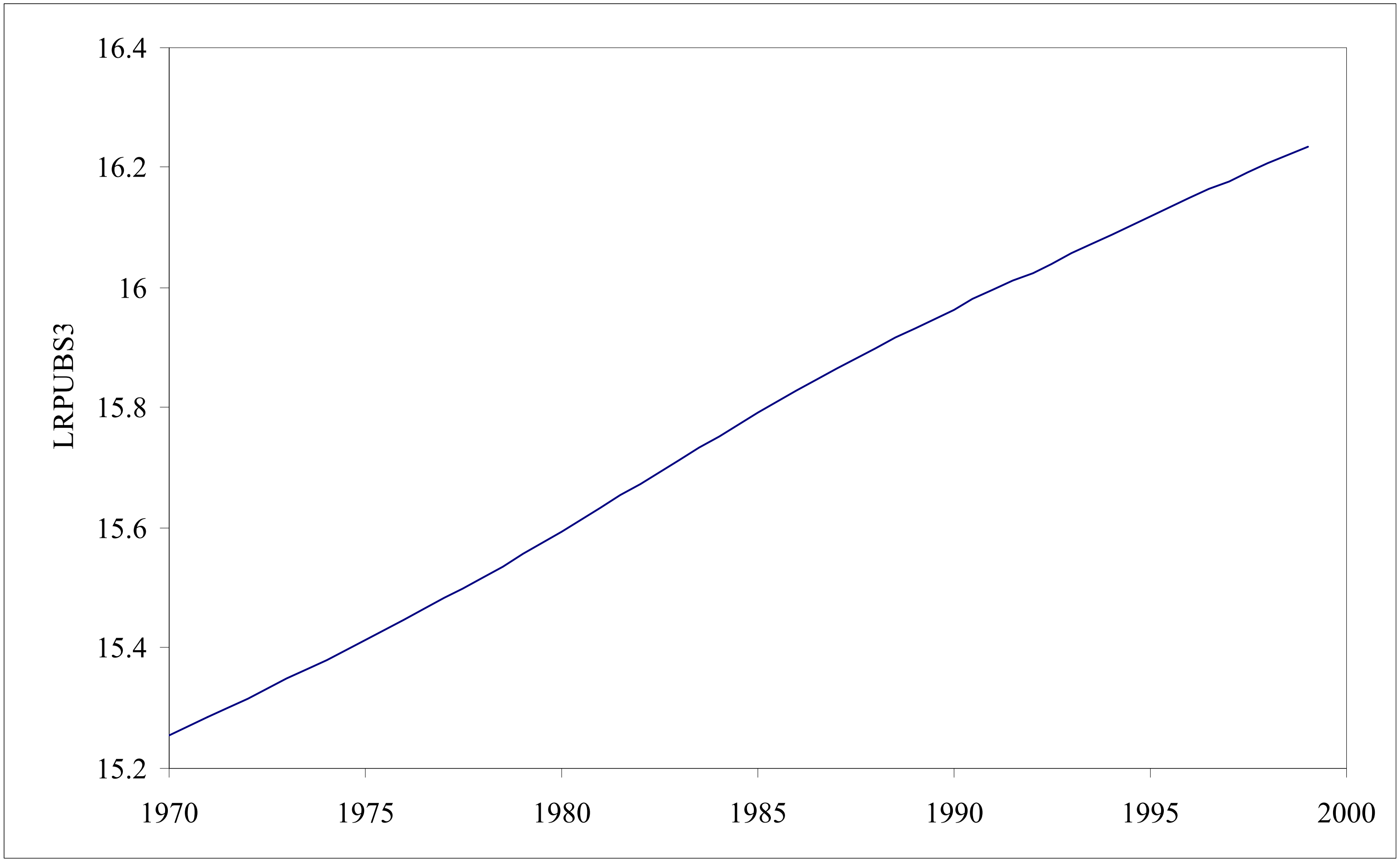


Figure 5. Public Agricultural Research Capital, 1970-1999: South Carolina

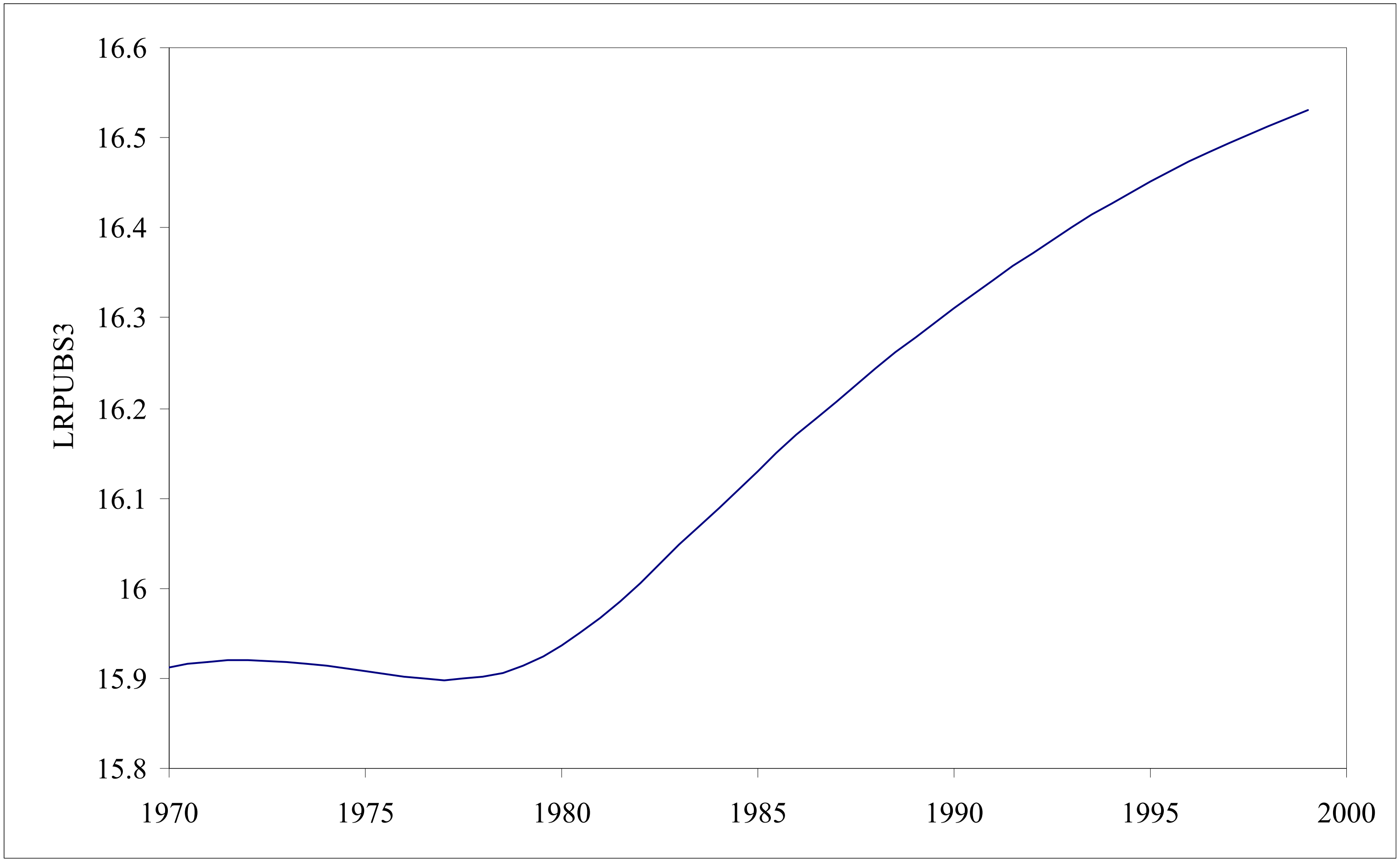
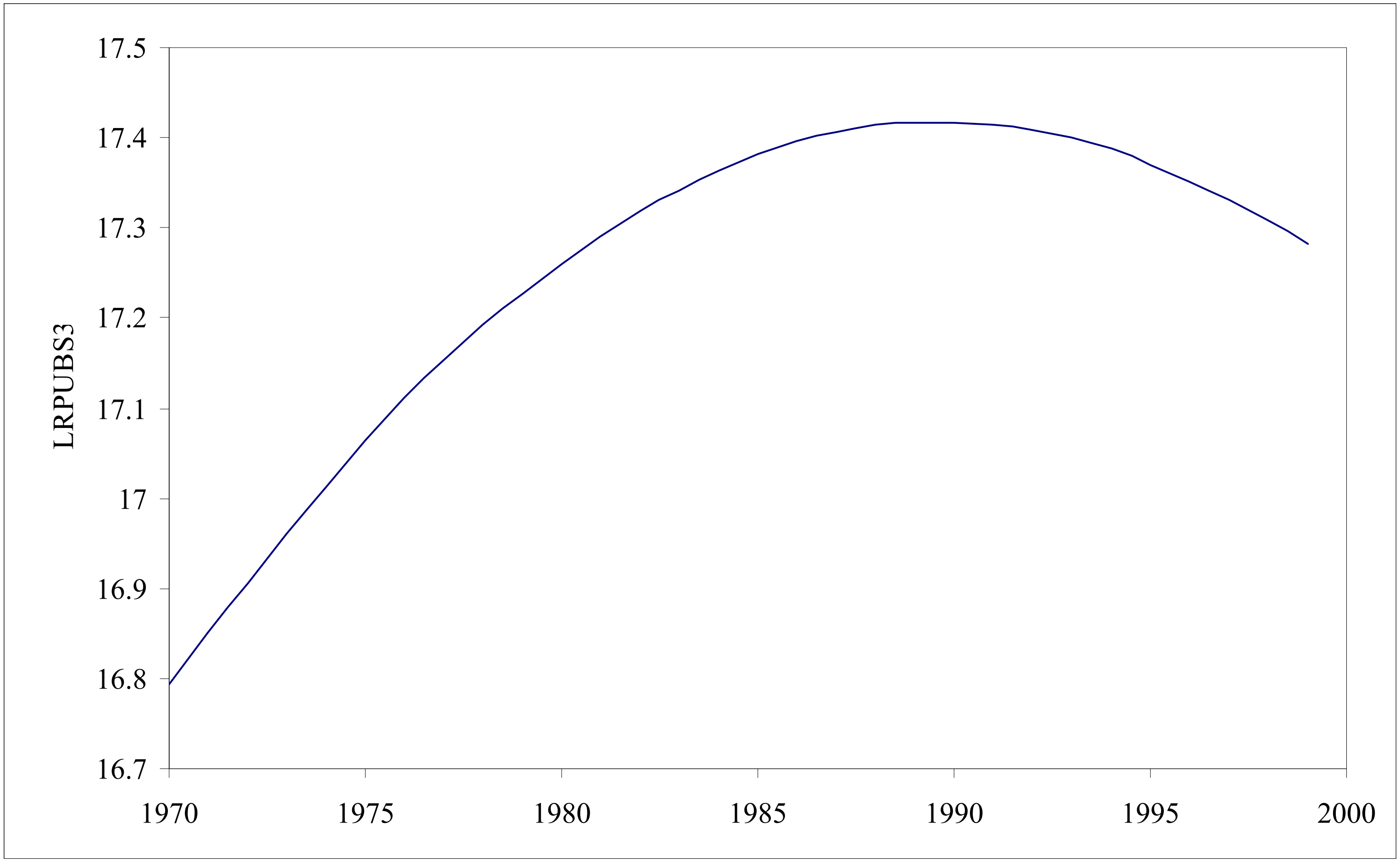


Figure 6. Public Agricultural Research Capital, 1970-1999: Louisiana



LRPUBS3
17.5
17.4
17.3
17.2
17.1
17
16.9
16.8
16.7
1970
1975
1980
1985
1990
1995
2000

Figure 7. Public Agricultural Research Capital, 1970-1999: Connecticut

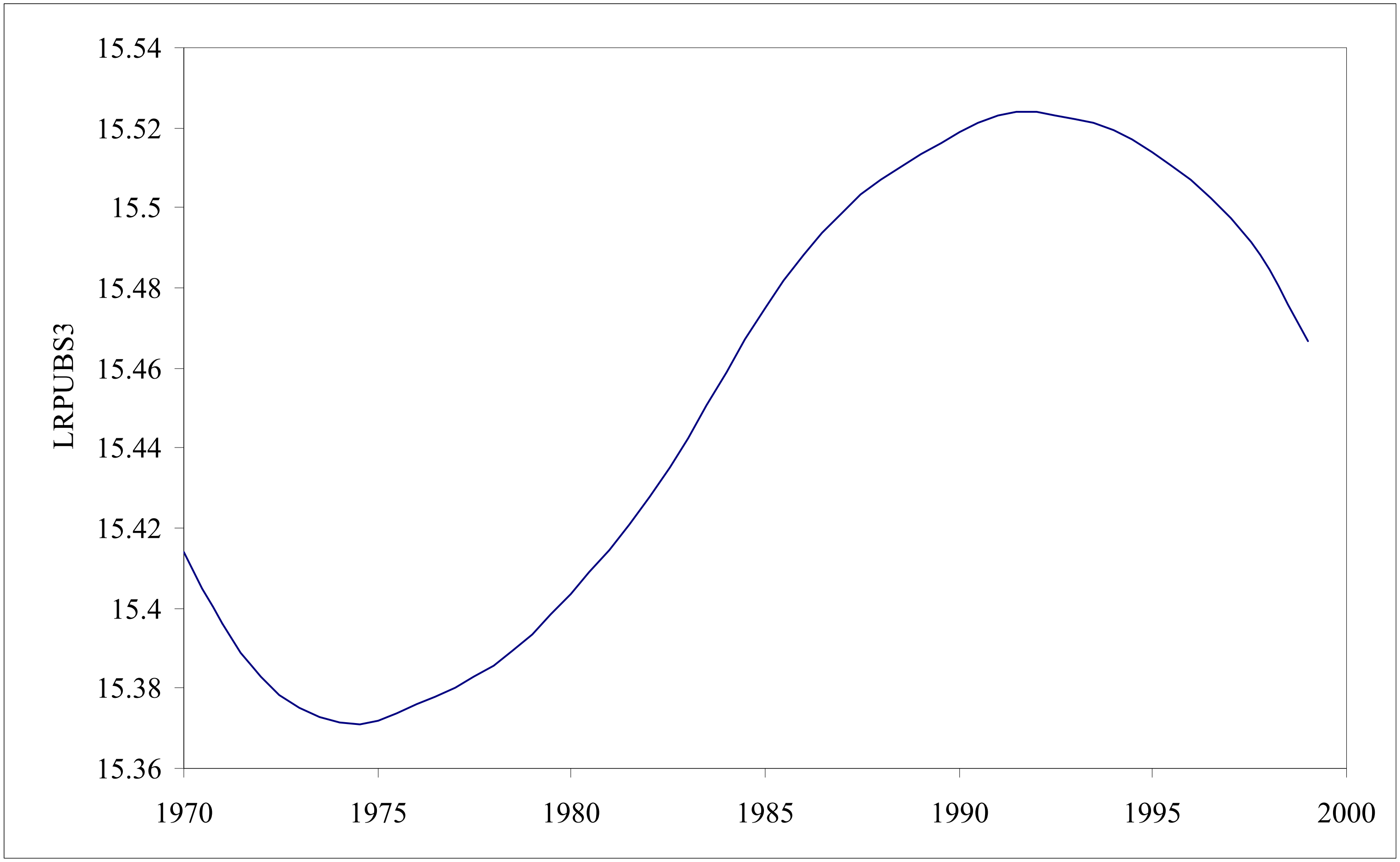


Table 1. Specific Spillin Weight by States Across Top into States on Left (Geo-Climate Sub-Region based)

State	MN	IA	WI	IL	IN	OH	MI	PA	ND	SD	NE	KS	MO	KY	TN	WV	SC	NC	GA	VA	MT	AR
MN		0.6	0.9	0.6	0.4	0.5	0.8	0.2	0.9	0.9	0.2	0	0	0	0	0	0	0	0	0	0.2	0
IA	0.6		0.6	0.9	0.9	0.4	0.6	0.2	0.2	0.2	0.4	0.1	0.5	0	0	0	0	0	0	0	0	0
WI	0.9	0.9		0.9	0.7	0.4	0.6	0.2	0.2	0.2	0.4	0.1	0	0	0	0	0	0	0	0	0	0
IL	0.6	0.9	0.8		0.8	0.5	0.6	0.2	0.2	0.2	0.4	0.1	0.4	0	0	0	0	0	0	0	0	0.2
IN	0.6	0.8	0.6	0.8		0.4	0.2	0.1	0.2	0.2	0.4	0.1	0.4	0.1	0.1	0.1	0	0	0	0	0	0.2
OH	0.4	0.6	0.4	0.6	0.6		0.2	0.1	0.2	0.2	0.4	0.1	0.4	0.2	0.2	0.2	0.1	0.1	0.1	0	0	0.2
MI	0.5	0.5	0.5	0.5	0.5	0.5		0.2	0.2	0.2	0.4	0.1	0.2	0	0	0	0	0	0	0	0	0.1
MO	0.4	0.5	0.5	0.5	0.5	0.4	0.4	0	0.1	0.2	0.2	0.5	0	0.2	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.2

State	AR	LA	AL	GA	KY	TN	SC	NC	FL	VA	WV	TX	OK	IL	OH	IN	MO	MS
AR		0.8	0.8	0.5	0.1	0.1	0.1	0.1	0	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.8
LA	0.6		0.9	0.8	0	0	0.8	0	0.8	0	0	0.3	0.1	0	0	0	0	0.6
AL	0.2	0.8		0.9	0.1	0.1	0.8	0.1	0.9	0	0	0	0	0	0	0	0	0.8
GA	0.2	0.8	0.8		0.1	0.1	0.8	0.1	0.9	0	0	0	0	0	0	0	0	0.4
KY	0	0	0.1	0.1		0.9	0.7	0.8	0	0.8	0.8	0	0	0.1	0.1	0.1	0.2	0
TN	0	0	0.1	0.1	0.1		0.7	0.8	0	0.8	0.8	0	0	0	0	0	0	0.7
SC	0.8	0.7	0.7	0.1	0.2	0.2		0.5	0	0.2	0.2	0	0	0	0	0	0	0.5
NC	0.5	0.2	0.2	0.2	0.7	0.7	0.7		0	0.7	0.7	0	0	0	0	0	0	0.5
FL	0.1	0.9	0.9	0.9	0	0	0.5	0		0	0	0	0	0	0	0	0	0.3
VA	0.2	0.2	0.2	0.2	0.2	0.7	0.7	0.7	0		0.8	0	0	0	0	0	0	0
WV	0.2	0.2	0.2	0.2	0.2	0.7	0.7	0.7	0.7		0	0	0	0	0	0	0	0
MS	0.8	0.6	0.9	0.8	0	0.4	0.7	0.1	0.3	0	0	0.2	0.2	0	0	0	0.1	

State	MD	DE	NJ	VA	SC	NC	PA
MD		0.8	0.8	0.4	0.1	0.3	0.2
DE	0.8		0.8	0.4	0.1	0.3	0.2
NJ	0.8	0.8		0.4	0.4	0.4	0.2

Table 1
Continued

State	WA	OR	CA	NV	ID	MT	WY	UT	CO	AZ	NM	KS	TX	NE	SD	ND	MN	OK
WA		0.9	0.3	0.2	0.7	0.1	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
OR	0.8		0.4	0.1	0.6	0.2	0.2	0.2	0.1	0.2	0.2	0	0	0	0	0	0	0
CA	0.1	0.2		0.2	0.2	0.1	0.1	0.2	0.1	0.4	0.2	0	0.2	0	0	0	0	0
NV	0.2	0.2	0.2		0.8	0.2	0.5	0.8	0.6	0.5	0.8	0	0	0	0	0	0	0
ID	0.4	0.5	0.3	0.8		0.2	0.6	0.9	0.6	0.5	0.5	0	0.1	0	0	0	0	0
MT	0.1	0.1	0	0.2	0.2		0.9	0.2	0.2	0.1	0.1	0	0	0.2	0.6	0.8	0.1	0
WY	0.1	0.4	0.2	0.5	0.5	0.2		0.5	0.4	0.4	0.4	0.1	0	0	0	0	0	0
UT	0.1	0.4	0.2	0.9	0.9	0.1	0.6		0.6	0.5	0.6	0	0.1	0	0	0	0	0
CO	0.1	0.4	0.1	0.7	0.7	0.1	0.4	0.7		0.2	0.2	0.2	0.1	0	0	0	0	0.1
AZ	0.1	0.3	0.8	0.5	0.5	0.1	0.3	0.5	0.4		0.8	0	0.1	0	0	0	0	0
NM	0.1	0.3	0.1	0.9	0.9	0.1	0.5	0.9	0.7	0.4		0	0	0	0	0	0	0

State	ND	SD	KS	OK	NE	TX	MN	IA	WI	IL	IN	OH	MI	MO	AR	LA	MT	WY	UT
ND		0.6	0	0	0.2	0	0.2	0	0	0	0	0	0	0	0	0	0.8	0.3	0
SD	0.8		0.2	0	0.9	0	0.5	0	0	0	0	0	0	0	0	0	0.8	0.3	0
KS	0	0		0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.3	0.3
OK	0	0	0.4		0.2	0.2	0	0	0	0	0	0	0	0.2	0.4	0.2	0	0	0
NE	0.3	0.3	0.2	0.2		0	0.3	0.4	0.4	0.4	0.4	0.4	0.2	0	0	0	0.4	0.2	0.1
TX	0	0	0.1	0.4	0.1		0	0	0	0	0	0	0	0	0.4	0.4	0	0	0

State	PA	NY	CT	MA	VT	NH	ME	OH	IN	IL	RI
PA		0.9	0.9	0.9	0.9	0.9	0.9	0.1	0.1	0.1	0.8
NY	0.9		0.9	0.9	0.9	0.9	0.9	0	0	0	0.8
CT	0.9	0.9		0.9	0.9	0.9	0.9	0	0	0	0.9
MA	0.9	0.9	0.9		0.9	0.9	0.9	0	0	0	0.8
VT	0.9	0.9	0.9	0.9		0.9	0.9	0	0	0	0.8
NH	0.9	0.9	0.9	0.9	0.9		0.9	0	0	0	0.8
ME	0.9	0.9	0.9	0.9	0.9	0.9		0	0	0	0.8
RI	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0	0	0	

Table 2. Agricultural TFP in 1996 and Average Annual Growth Rate for Farm Output, Input, TFP and Public Agricultural Research Capital, by State Grouped by ERS Farm Production Regions, 1970-1999 (Rank order is in parentheses)

		Average annual growth rate, 1970-1999 (%)			
Region/State	TFP relative level 1996	Total output	Total input	TFP	Public ag research capital
New England					
Maine	1.059 (20)[a]	0.13	-1.51	1.64 (23)	1.43 (41)
New Hampshire	0.820 (43)	0.07	-1.24	1.30 (40)	0.77 (46)
Vermont	1.006 (28)	0.66	-0.25	0.91 (47)	1.49 (40)
Massachusetts	1.114 (15)	0.24	-1.52	1.75 (17)	0.02 (48)
Connecticut	1.138 (14)	1.19	-0.83	2.02 (5)	0.18 (47)
Rhode Island	1.148 (12)	-0.16	-1.62	1.47 (33)	1.18 (42)
Northeast					
New York	1.009 (27)	0.46	-0.94	1.40 (35)	2.12 (33)
New Jersey	1.143 (12)	0.75	-0.80	1.55 (27)	0.96 (43)
Pennsylvania	0.986 (32)	1.60	0.09	1.51 (28)	2.24 (29)
Delaware	1.293 (6)	2.85	2.01	0.84 (48)	1.57 (38)
Maryland	1.099 (17)	1.52	0.32	1.19 (42)	2.38 (26)
Lake States					
Michigan	0.941 (35)	1.94	-0.60	2.54 (1)	3.38 (10)
Minnesota	1.030 (23)	2.06	0.09	1.97 (7)	2.49 (25)
Wisconsin	0.926 (37)	1.08	0.64	1.72 (19)	2.25 (28)
Corn Belt					
Ohio	0.916 (38)	1.32	-0.60	1.92 (9)	0.79 (45)
Indiana	1.101 (17)	1.63	-0.32	1.94 (8)	1.64 (36)
Illinois	1.193 (10)	1.29	-0.58	1.79 (15)	1.56 (39)
Iowa	1.237 (8)	1.03	-0.50	1.73 (18)	3.19 (15)
Missouri	0.904 (39)	0.89	-0.60	1.48 (31)	3.39 (9)
Northern Plains					
North Dakota	0.979 (33)	2.18	-0.03	2.21 (2)	4.06 (6)
South Dakota	1.054 (20)	2.00	0.01	1.98 (6)	2.60 (21)
Nebraska	1.105 (16)	2.52	0.96	1.57 (26)	4.42 (4)
Kansas	0.990 (31)	2.15	0.81	1.33 (38)	3.35 (12)
Appalachia					
Virginia	0.992 (30)	1.43	-0.27	1.51 (28)	3.25 (14)
West Virginia	0.574 (48)	1.19	-0.28	1.46 (34)	2.15 (31)
Kentucky	1.022 (25)	1.63	-0.06	1.69 (21)	2.23 (30)
North Carolina	1.462 (3)	2.19	0.36	1.83 (14)	4.50 (3)
Tennessee	0.837 (41)	0.66	-0.26	0.93 (46)	2.95 (17)

Table 2, continued

Southeast					
South Carolina	1.088 (19)	1.17	-0.69	1.87 (10)	2.13 (32)
Georgia	1.333 (4)	2.28	0.42	1.87 (10)	5.53 (1)
Florida	1.618 (1)	2.01	0.17	1.84 (13)	3.47 (8)
Alabama	1.000 (29)	1.86	0.38	1.48 (31)	1.63 (37)
Delta States					
Mississippi	1.022 (25)	1.55	0.04	1.51 (28)	2.69 (19)
Arkansas	1.228 84)	2.65	0.60	1.85 (12)	3.30 (13)
Louisiana	1.038 (22)	0.96	-0.02	0.98 (45)	1.69 (34)
Southern Plains					
Oklahoma	0.698 (46)	1.64	0.34	1.29 (41)	1.67 (35)
Texas	0.786 (44)	2.04	0.43	1.61 (24)	2.88 (18)
Mountain States					
Montana	0.736 (45)	1.21	0.17	1.05 (43)	2.49 (23)
Idaho	1.203 (9)	2.41	0.64	1.77 (16)	3.38 (10)
Wyoming	0.576 (47)	1.18	0.19	0.99 (44)	0.92 (44)
Colorado	0.937 (36)	1.76	0.15	1.61 (24)	3.77 (7)
New Mexico	0.875 (40)	2.14	0.43	1.72 (19)	2.49 (24)
Arizona	1.045 (22)	1.47	-0.19	1.66 (22)	4.63 (2)
Utah	0.829 (42)	1.85	0.50	1.35 (36)	2.60 (20)
Nevada	0.904 (39)	1.55	0.21	1.35 (36)	4.17 (5)
Pacific					
Washington	1.306 (5)	3.09	0.92	2.16 (3)	2.35 (27)
Oregon	0.943 (34)	2.63	0.65	2.04 (4)	2.59 (22)
California	1.549 (2)	2.66	1.33	1.33 (38)	3.02 (16)

[a] The TFP level is relative to Alabama.

Source: Data for Input, Output and TFP growth rates for the agriculture sector by state are from the USDA-ERS (2009) and the public agricultural research data are my data.

Table 3. Variable Names and Definitions and Summary Statistics

Name	Symbol	Mean (Sd)	Description
Total factor productivity	*TFP*	-0.208[a] (0.258)	Total factor productivity for the agricultural sector (Ball et al., 2002)
Public agricultural research capital	*RPUB*	16.129[a] (0.870)	The public agricultural research capital for an originating state. The summation of past investments in agricultural research within a state having an agricultural productivity focus in 1984 dollars. Capital stock obtained by summing past real research expenditures with a 2- through 35-year lag and trapezoidal shaped timing weights (similar to Figure 2).
Public agricultural research capital spillin	*RPUBSPILL*	17.763[a] (0.567)	The public agricultural research spillin stock for a state, constructed from state agricultural subregion data (Figure 1).
Public extension capital	*EXT*	1.292[a] (0.594)	A state's stock of public extension, created by summing for a given state the public full-time equivalent staff years in agriculture and natural resource extension, applying a weight of 0.50 to the current year and then 0.025, 0.125, 0.0625, and 0.031 for the following four years. The units are staff-years per 1,000 farms.
Private agricultural capital	*RPRI*	6.076[a] (0.248)	A state's stock of private patents of agricultural technology. Each state's private agricultural research capital in the national total of agricultural patents awarded to U.S. and foreign inventors for each year (Johnson and Brown) obtained by weighting the number of private patents in crops (excluding fruits and vegetables and horticultural and greenhouse products) and crop services, fruits and vegetables, horticultural and greenhouse products, and livestock and livestock services by a state's sales share in crops (excludes fruits, vegetables, horticultural and greenhouse products), fruits and vegetables, horticultural and greenhouse products and livestock and livestock products, respectively. The annual patent totals are 2- thru 18-year lag using trapezoidal timing weights.
Regional indicators	*Northeast*		Dummy variable taking a 1 if state is CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI or VT
	Southeast		Dummy variable taking a 1 if state is AL, FL, GA, KY, NC, SC, TN, VA, or WV
	Central		Dummy variable taking a 1 if state is IN, IL, IA, MI, MO, MN, OH, or WI
	North Plains		Dummy variable taking a 1 if state is KS, NE, ND, or SD
	South Plains		Dummy variable taking a 1 if state is AR, LA, MS, OK, or TX
	Mountains		Dummy variable taking a 1 if state is AZ, CO, ID, MT, NV, NM, UT, or WY
	Pacific		Dummy variable taking a 1 if state is CA, OR, or WA
Trend	*Trend*		Annual time trend

[a] Numbers reported in natural logarithms.

Table 4. Econometric Estimates of State Agricultural Productivity Equation: Contribution of Public Agricultural Research Capital and Other Factors, Forty-Eight U.S. States, 1970-1999 (N x T = 48 x 30 = 1,440)

	Regression (1)		Regression (2)		Regression (3)	
Regressors	**Coefficients**	**z-values**[a]	**Coefficients**	**z-values**	**Coefficients**	**z-values**
Intercept	-30.815	7.68	-33.666	7.78	-12.566	1.96
ln (*Public Ag Res Capital*)$_t$	0.691	3.65	0.910	4.12	-0.439	1.02
ln (*Public Ag Res Capital Spillin*)$_t$	0.079	5.48	0.085	5.84	-1.312	3.97
ln (*Public Extension Capital*)$_t$	0.126	6.03	0.821	3.02	1.179	4.05
ln (*Private Ag Res Capital*)$_t$	1.428	2.75	1.815	3.20	2.122	3.85
ln (*Public Ag Res Capital*)$_t$ x						
ln (*Public Ag Res Capital Spillin*)$_t$					0.085	4.22
ln (*Public Extension Capital*)$_t$			-0.044	2.56	-0.067	3.60
ln (*Private Ag Res Capital*)$_t$	-0.095	2.98	-0.118	3.38	-0.139	4.48
Regional Indicators						
Northeast (= 1)	0.042	0.94	0.080	1.73	0.109	2.27
Southeast (= 1)	0.009	0.26	0.047	1.26	0.072	1.86
Northern Plains (= 1)	0.099	3.40	0.132	4.09	0.147	4.43
Southern Plains (= 1)	-0.041	1.05	-0.021	0.52	0.006	0.15
Mountain (= 1)	-0.061	1.28	-0.021	0.43	0.002	0.03
Pacific (= 1)	0.110	2.44	0.116	2.57	0.157	3.33
Trend	0.009	4.42	0.009	4.16	0.009	4.42
R^2	0.437		0.438		0.449	

Note : The dependent variable is $\ln(TFP)_{ilt}$. The Central region (IN, IL, IA, MI, MO, MN, OH, and WI) is the excluded region in the regression equations. Parameters are estimated by Prais-Winsten estimator where the estimate of the AR(1) parameter ρ for regression (1) is 0.683, for (2) is (0.685) and for (3) is 0.682. The estimation was carried out in STATA9.0 using the panel data routing "xtpcse" and subroutine "ar1." Also, see Beck and Katz (1995).

[a] The *z*-values are constructed from standard errors that are corrected for heteroscedasticity across states and contemporaneous correlation of disturbances across pairs of states.

Table 5. The Marginal Impacts of Agricultural Research and Extension on TFP: State Data[a]

Marginal impact	Regression (1)	Regression (2)	Regression (3)
$\partial \ln(TFP)/\partial \ln(RPUB)$	0.114	0.136	0.140
$\partial \ln(TFP)/\partial \ln(RPUBSPILL)$	0.079	0.085	0.059
$\partial \ln(TFP)/\partial \ln(EXT)$	0.126	0.111	0.098
$\partial \ln(TFP)/\partial \ln(RPRI)$	-0.104	-0.088	-0.140

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[a] Estimated regression coefficients are taken from Table 4. Where interaction terms are involved, marginal impacts are evaluated at the sample mean of the appropriate regressors. These sample means of regressors are taken from Table 3.

Appendix A: Table 1. Public Agricultural Research: Research commodities (or resources) in the Current Research Information System, 1967- (√ denotes commodities included in new data)[14]

PRIME COMM	SUB COMM	COMMODITY NAME
√ 0100		**Soil and Land**
	0110	Soil
	0120	Land
	0199	Soil and Land, General
√ 0200		**Water** (See Special Classification – Table G for Water Resources Research codes)
√ 0300		**Watersheds and River Basins**
	0310	River Basins
	0320	Watersheds
	0330	Irrigation and Drainage Districts
	0399	Watersheds and River Basins, General
√ 0400		**Air and Climate**
0500		**Recreational Resources**
	0510	Wilderness (Roadless Areas)
	0520	Campgrounds and Picnic Areas
	0530	Parks and Urban Greenspace
	0590	Other Recreational Resources
	0599	Recreational Resources, General
0600		**Trees, Forests, and Forest Products** (Excluding Edible Tree Nut Crops 1050)
	0610	Conifers, General
	0611	Christmas Trees
	0612	Douglas Fir
	0613	Other Western Conifers
	0614	Naval Stores
	0615	Ornamental, Shade, and Landscape Conifers
	0616	Southern Pine
	0617	Other Eastern Conifers
	0619	Other Conifers

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[14] [1]The list has evolved over time with additions and modifications. The commodities/resources in the table are the ones in use February 1993.

Table 1. (continued)

PRIME COMM	SUB COMM	
	0620	Hardwoods, General
	0621	Black Walnut
	0622	Other Fine Hardwoods (Ash, Black Cherry, Yellow Birch, Select White and Red Oaks)
	0623	Poplars, Aspen, and Cottonwoods
	0624	Elms (Ornamental, Shade, and Landscape only)
	0625	Other Ornamental, Shade, and Landscape Hardwoods
	0626	Maple (For Syrup and Sugar only)
	0629	Other Hardwoods
	0630	Both Conifers and Hardwoods, General
	0631	Shelterbelts and Windbreaks
	0632	Medicinal (For Agricultural Drug and Chemurgic Crops see 2820)
	0639	Other Conifers and Hardwoods
	0699	Trees, Forests, and Forest Products, General
√ 0700	**Range** (See Also Special Classification – Table J for Range and Pasture Research codes)	
	0710	Sagebrush
	0720	Desert Shrub
	0730	Southwestern Shrub steppe
	0740	Chaparral Mountain Shrub
	0750	Pinyon-Juniper
	0760	Mountain Grassland
	0770	Mountain Meadows and Alpine
	0780	Desert Grassland
	0781	Annual Grassland
	0790	Shinnery
	0791	Texas Savanna
	0792	Plains Grassland
	0793	Prairie
	0798	Other Rangelands
	0799	Range, General
0800	**Fish, Shellfish, Game and Fur-bearing Animals, and other Wildlife and their Habitats**	
	0810	Game Fish Includes: Bass, Bluegill, Muskellunge, Pike, Shad, Trout

Table 1. (continued)

PRIME COMM	SUB COMM	
	0820	Commercial Fish and Shellfish/Aquaculture, General
	0821	Freshwater Fish and Shellfish Includes: Catfish, Carp, Salmon, Trout, Striped Bass, Crayfish
	0822	Saltwater Fish and Shellfish Includes: Clams, Cod, Cusk, flounder, Haddock, Hake, Herring, Lobsters, Menhaden, Oysters, Shrimp, Whiting
	0830	Game Birds Includes: Wild Ducks, Wild Geese, Grouse, Partridges, Pheasants, Quail, Wild Turkeys
	0840	Non-Game Birds Includes: Ostriches, Emus
	0850	Game Animals Includes: Antelopes, Bison, Bobcats, Deer, Elk, Moose
	0860	Fur-Bearing Animals Includes: Beavers, Foxes, Martens, Minks, Muskrats, Nutria, Rabbits
	0870	Fish Habitats
	0880	Wildlife Habitats
	0890	Other Wildlife
	0899	Fish, Shellfish, Game and Fur-Bearing Animals, etc., General
√ 0900	**Citrus and Tropical/Subtropical Fruit**	
	0910	Citrus, General
	0911	Grapefruit
	0913	Oranges
	0914	Lemons
	0919	Other Citrus Includes: Limes, Mandarin Oranges
	0920	Tropical/Subtropical Fruit, General
	0921	Bananas
	0922	Pineapple
	0923	Papayas
	0924	Mangoes
	0925	Dates
	0926	Kiwis
	0929	Other Tropical/Subtropical Fruit Includes: Avocados, Coconuts, Figs, Guavas, Olives, Passion Fruits, Sour sops
	0999	Citrus and Tropical/Subtropical Fruit, General

Table 1. (continued)

PRIME COMM	SUB COMM	
√ 1000		**Deciduous and Small Fruits and Edible Tree Nuts**
	1010	Citrus and Tropical/Subtropical Fruit, General
	1011	Apples
	1012	Apricots
	1013	Cherries
	1014	Nectarines
	1015	Peaches
	1016	Pears
	1017	Plums
	1019	Other Deciduous Tree Fruits
	1030	Berries and Cane Fruits, General
	1031	Blueberries
	1032	Cranberries
	1033	Strawberries
	1034	Raspberries
	1039	Other Berries and Cane Fruits Includes: Blackberries, Boysenberries, Currants, Elderberries
	1040	Grapes, General
	1041	Table Grapes
	1042	Wine Grapes
	1043	Raisin Grapes
	1049	Other Grapes
	1050	Edible Tree Nuts, General
	1051	Filberts
	1052	Pecans
	1054	Almonds
	1055	Walnuts
	1059	Other Edible Tree Nuts Includes: Cashews, Chestnuts, Macadamia Nuts, Pistachios
	1090	Other Deciduous and Small Fruits and Edible Tree Nuts
	1099	Deciduous and Small Fruits and Edible Tree Nuts, General

Table 1. (continued)

PRIME COMM	SUB COMM	
√ **1100**	**Potatoes**	
√ **1200**	**Vegetables**	
	1210	Leguminous Vegetables, General
	1211	Beans (Dry)
	1212	Beans (Fresh, Fresh-Processed)
	1213	Peas (Dry)
	1214	Peas (Fresh, Fresh-Processed)
	1215	Lentils
	1219	Other Leguminous Vegetables
	1220	Melons and Other Cucurbits, General
	1221	Melons Includes Cantaloupes, Muskmelons, Watermelons
	1222	Cucumbers
	1223	Other Cucurbits Includes: Pumpkins, Squash, Gourds
	1230	Greens and Leafy Vegetables Includes: Endive, Lettuce, Spinach, turnip-Greens, Celery, Rhubarb, Parsley, Asparagus
	1240	Cabbage and Other Cole Crops Includes: Cabbage, Kale, Broccoli, Brussels Sprouts, Cauliflower Kohlrabi
	1250	Rhizomes, Tubers, Bulbs, and Root Crops, General (For Potatoes Use 1100)
	1251	Sweet Potatoes
	1252	Onions, Garlic, Leeks, Shallots
	1253	Carrots
	1254	Yams
	1255	Taro
	1256	Cassava (or Manioc)
	1259	Other Rhizomes, Tubers, Bulbs, and Root Crops Includes: Beets, Radishes, Turnips
	1260	Solanaceous and Related Crops, General (For Potatoes use 1100)
	1261	Tomatoes
	1262	Peppers
	1263	Eggplant
	1264	Other Solanaceous and Related Crops

Table 1. (continued)

PRIME COMM	SUB COMM	
	1270	Mushrooms and Other Edible Fungi
	1280	Sweet corn
	1291	Herbs and Spices Includes: Dill, Fennel, Mustard, Basil, Ginger, Sage, Tarragon, Thyme
	1298	Vegetables, General
	1299	Other Vegetables Includes: Okra, Bamboo Shoots
√ **1300**		Ornamentals and Turf (For Shade, Ornamental, and Landscape Trees Use 0600
	1310	Woody Shrubs
	1320	Florist Crops, General
	1321	Perennials (Herbaceous) and Decorative Greens
	1322	Cut Flowers
	1323	Cut Foliage and Greens
	1324	Potted Flowering Plants
	1325	Potted Foliage Plants
	1326	Bedding/Garden Plants
	1330	Lawns and Turf Includes: Bent grass, Bermuda grass, Bluegrass, Dechondra, Fescue, Ryegrass, Zoysia
	1340	Ground Covers
	1350	Aquatic Plants
	1391	Arboreta and Botanical Gardens
	1398	Ornamentals and Turf, General
	1399	Other Ornamentals and Turf Includes: Cacti
√ **1400**		**Corn** (For Sweet corn use 1280)
	1410	Corn
	1430	Popcorn
√ **1500**		**Grain Sorghum**
√ **1600**		**Rice**

Table 1. (continued)

PRIME COMM	SUB COMM	
√ **1700**	**Wheat** (For Wheat as Forage use 2090)	
	1710	Hard Red Winter Wheat
	1720	Hard Red Spring Wheat
	1730	Soft red Winter Wheat
	1740	White Wheat
		Includes: Blub, Western, and Soft White
	1750	Durum Wheat
	1790	Other Wheat
	1799	Wheat, General
√ **1800**	**Other Small Grains**	
	1810	Barley
	1820	Oats
	1830	Rye
	1890	Other Specific Small Grains
		Includes: Buckwheat, Millet, Triticale
	1899	Other Small Grains, General
√ **1900**	**Pasture** (See Special Classification – Table J for Range and Pasture Research Codes)	
√ **2000**	**Forage Crops**	
	2010	Perennial Grasses, General
	2011	Warm Season Perennial Grasses
		Includes: Dallisgrass, Bluestems, Bermuda grass
	2012	Cool Season Perennial Grasses
		Includes: Bluegrass, Brome grass, Fescue, Orchard grass, Perennial Ryegrass, Timothy, Wheatgrass
	2020	Annual Grasses, General
	2021	Summer Annual Grasses
	2022	Winter Annual Grasses
		Includes: Annual Ryegrass
	2030	Legumes, General
	2031	Alfalfa
	2032	Trefoil
	2033	Red Clover
	2034	Crown vetch
	2035	Winter Annual Legumes
		Includes: Subterranean Clover, Arrowleaf Clover

Table 1. (continued)

PRIME COMM	SUB COMM	
	2039	Other legumes Includes: Crimson Clover, Ladino Clover, Sweet Clover, Lespedeza
	2040	Forage Seeds, General
	2041	Grass Seeds
	2042	Legume Seeds
	2090	Other Forage Crops Includes: Cereal Crops used for Forage
	2099	Forage Crops, General
√ **2100**		**Cotton** (Including Cottonseed for Planting Purposes)
	2110	Upland Cotton
	2120	Long Fiber Cotton
	2190	Other Cotton
	2199	Cotton, General
√ **2200**		**Cottonseed (**For Meal, Oil, etc.)
√ **2300**		**Soybeans**
√ **2400**		**Peanuts**
√ **2500**		**Other Oilseed and Oil Crops**
	2510	Castor
	2520	Crambe
	2530	Flax
	2540	Safflower
	2550	Jojoba
	2570	Coconut
	2580	Palm
	2590	Other Specific Oilseed and Oil Crops
	2591	Canola
	2592	Cuphea
	2593	Lesquerella
	2594	Meadowfoam
	2595	Rape
	2596	Sesame
	2597	Chinese Tallow
	2598	Tung
	2599	Other Oilseed and Oil Crops, General

Table 1. (continued)

PRIME COMM	SUB COMM	
√ 2600	**Tobacco**	
	2610	Flue Cured
	2620	Burley
	2630	Sweet Sorghum
	2790	Other Sugar Crops
	2799	Sugar Crops, General
√ 2700	**Sugar Crops**	
	2710	Sugar Beets
	2720	Sugar Cane
	2730	Sweet Sorghum
	2790	Other Sugar Crops
	2799	Sugar Crops, General
√ 2800	**Miscellaneous and New Crops**	
	2810	Fiber Plants, General
	2811	Kenaf
	2812	Hemp
	2813	Ramie
	2814	Agave
	2819	Other Fiber Plants Includes: Abaca, Roselle, Sansevieria
	2820	Drug and Chemurgic Crops, General Includes: Dioscorea, Saponaria, Senna, Tephrosia
	2821	Narcotic Plants
	2830	Flavoring and beverage Plants, General
	2831	Hops
	2832	Mint
	2833	Coffee
	2834	Cocoa
	2835	Tea
	2839	Other Flavoring and Beverage Plants Includes: Vanilla
	2860	Rubber, Gum, And Resin Plants, General
	2861	Guayule
	2862	Hevea
	2863	Gums Includes: Arabic
	2869	Other Rubber and Resin Plants

Table 1. (continued)

PRIME COMM	SUB COMM	
	2890	Other Miscellaneous and New Crops
	2899	Miscellaneous and New Crops, General
√ **2900**	**Poultry**	
	2910	Egg Type Chickens
	2920	Eggs
	2930	Meat Type Chickens
	2940	Ducks and Geese
	2950	Turkeys
	2960	Poultry Meat
	2990	Other Poultry
	2999	Poultry, General
√ **3000**	**Beef Cattle**	
	3010	Meat
	3020	Hides
	3030	Other Beef Cattle Products
	3040	Beef Cattle, Live Animal
	3090	Beef Cattle, General
√ **3100**	**Dairy Cattle**	
	3110	Butter
	3120	Cheese
	3130	Meat
	3140	Milk
	3150	Ice Cream
	3160	Dairy Cattle, Live Animal
	3190	Other Dairy Cattle Products
	3199	Dairy Cattle, General
√ **3200**	Swine	
	3210	Meat
	3220	Hides
	3230	Other Swine Products
	3240	Swine, Live Animal
	3299	Swine, General

Table 1. (continued)

PRIME COMM	SUB COMM	
√ **3300**	**Sheep and Wool**	
	3310	Meat
	3320	Hides
	3330	Wool Fiber
	3340	Sheep, Live Animal
	3399	Sheep and Wool General
√ **3400**	**Other Animals** (See 0800 for Fish, Shellfish, Game and Fur-Bearing Animals)	
	3410	Horses, Ponies, and Mules
	3420	Goats and Mohair
	3430	Pets Includes: Dogs, Cats
	3440	Laboratory Animals Includes: Guinea Pigs, Mice, Rats, Rabbits
	3490	Other Specific Animals
	3491	Other Animal Fibers
	3499	Other Animals, General
√ **3500**	**Bees and Honey and Other Pollinating Insects**	
	3510	Honey Bees
	3530	Honey and Honey Products
	3550	Non-Honey Apiary Products
	3590	Other Pollinating Insects
	3599	Honey Bees and Other Pollinating Insects, General
		MANMADE RESOURCES
√ **3600**	**General Purpose Supplies** Includes: Machinery, Equipment, Fertilizers, Feedstuffs, and Pesticides	
3700	**Clothing and Textiles**	
3800	**Food** (Not readily associated with specific Plant and Animal Products)	
3900	**Structures and Facilities**	
	3910	Houses (People), Furniture, Household Equipment, and Non-Textile Furnishings
	√ 3920	Other Farm Structures and Related Facilities

Table 1. (continued)

PRIME COMM	SUB COMM	
	3930	Nonfarm Structures and Related Facilities including those used in the Marketing, Storing, Processing, and Distributing Functions, and for Recreation Uses.
	3940	Domestic and Community Water Supply Facilities and Systems
	√ 3950	Drainage and Irrigation Facilities and Systems
	3960	Sewage and Waste Disposal Facilities and Systems
	3990	Other Structures and Facilities (such as Trails, Roads, Telephone, and Electricity)
	3999	Structures and Facilities, General
	HUMAN RESOURCES, ORGANIZATIONS AND INSTITUTIONS	
4000		**People as Individual Workers, Consumers, and Members of Society**
4100		**The Family and its Members**
√ 4200		**The Farm as a Business Enterprise**
4300		**Communities, Areas, and Regions, including Counties and States, and their Institutions and Organizations**
4400		**Agricultural Economy of the United States and Sectors thereof, including interrelationships with the Total Economy**
4500		**Agricultural Economy of Foreign Countries and Sectors thereof, including interrelationships with the Total Economy**
4600		**Famer Cooperatives**
4700		**Marketing, Processing, and Supply Firms other than Cooperatives**
4800		**Marketing Systems and Sectors thereof**
TECHNOLOGY NOT ASSOCIATED WITH SPECIFIC COMMODITIES OR RESOURCES		
√ 6100		**Weeds**
√ 6200		**Seed Research**
6300		**Biological Cell Systems**

Table 1. (continued)

PRIME COMM	SUB COMM	
6400	**Experimental Design and Statistical Methods**	
√ 6500	**Invertebrates**	
	6510	Insects
	6520	Spiders, Mites, Ticks, and other Arthropods
	6530	Nematodes
	6590	Other Invertebrates Includes: Snails, Slugs, Leeches
	6599	Invertebrates, General
6600	**Microorganisms, Viruses, etc.**	
	6620	Bacteria
	6630	Fungi
	6640	Viruses
	6650	Viroids, Mycoplasmas, Spiroplasmas, etc.
	6660	Protozoa
	6690	Other Microorganisms
	6699	Microorganisms, General
√ 6700	**Plants**	
	6710	Cross-Commodity Research—Multiple Crops
	6720	Noncrop Plant Research
	6799	Plant Research, General
√ 6800	**Animals (Vertebrates)**	
	6810	Cross-Commodity Research—Multiple Animal Species
	6899	Animal Research, General
6900	**Research on Research Management** (Not Research Management per se)	
7000	**Research Equipment and Technology**	
	7090	Remote Sensing Equipment and Technology
	7098	Research Equipment and Technology, General
	7099	Other Research Equipment and Technology

Source: U.S. Dept. Agr., CSRS, CRIS. Manual of Classification of Agricultural and Forestry Research. Revision V. Beltsville, MD: USDA-CSRS, Feb. 1993.

Appendix A. Table 2. Public Agricultural Research: Research problem areas (RPAs), 1967 – (√ denotes included PRAs)

RPA No.	Goal/Nature of Research
	GOAL I: INSURE A STABLE AND PRODUCTIVE AGRICULTURE FOR THE FUTURE THROUGH WISE MANAGEMENT OF NATURAL RESOURCES
√ 101	Appraisal of Soil Resources
√ 102	Soil, Plant, Water, Nutrient Relationships
√ 103	Management of Saline and Sodic Soils and Salinity
√ 104	Alternative Uses of Land
√ 105	Conservation and Efficient Use of Water
√ 106	Efficient Drainage and Irrigation Systems and Facilities
√ 107	Watershed Protection and Management
√ 108	Economic and Legal Problems in Management of Water and Watersheds
√ 109	Adaptation to Weather and Weather Modification
√ 110	Appraisal of Forest and Range Resources
√ 111	Biology, Culture, and Management of Forests and Timber-Related Crops
√ 112	Improvement of Range Resources
√ 113	Remote Sensing
114	Research on Management of Research
	GOAL II: PROTECT FORESTS, CROPS, AND LIVESTOCK FROM INSECTS, DISEASES, AND OTHER HAZARDS
√ 201	Control of Insects Affecting Forests
202	Control of Diseases, Parasites, and Nematodes Affecting Forests
203	Prevention and Control of Forest and Range Fires
√ 204	Control of Insects, Mites, Slugs, and Snails on Fruit and Vegetable Crops
√ 205	Control of Diseases and Nematodes of Fruit and Vegetable Crops
√ 206	Control of Weeds and Other Hazards of field Crops and Range
√ 207	Control of Insects, Mites, Snails, and Slugs Affecting Field Crops and Range
√ 208	Control of Diseases and Nematodes of Field Crops and Range
√ 209	Control of Weeds and Other Hazards of Field Crops and Range
√ 210	Control of Insects and External Parasites Affecting Livestock, Poultry, Fish, and other Animals
√ 211	Control of Diseases of Livestock, Poultry, Fish, and other Animals
√ 212	Control of Internal Parasites of Livestock, Poultry, Fish, and Other Animals
√ 213	Protect Livestock, Poultry, Fish, and Other Animals from Toxic Chemicals, Poisonous Plants, and Other Hazards
√ 214	Protection of Plants, Animals, and Man from Harmful Effects of Pollution

Table 2. (continued)

RPA	TITLE
	GOAL III: PRODUCE AN ADEQUATE SUPPLY OF FARM AND FOREST PRODUCTS AT DECREASING REAL PRODUCTION COSTS
301	Genetics and Breeding of Forest Trees
302	New and Improved Forest Engineering Systems
303	Economics of Timber Production
√ 304	Improvement of Biological Efficiency of Fruit and Vegetable Crops
√ 305	Mechanization of Fruit and Vegetable Crop Production
√ 306	Production Management Systems for Fruits and Vegetables
√ 307	Improvement of Biological Efficiency of Field Crops
√ 308	Mechanization of Production of Field Crops
√ 309	Production Management Systems for Field Crops
√ 310	Reproductive Performance of Livestock, Poultry, Fish, and Other Animals
√ 311	Improvement of Biological Efficiency in Production of Livestock, Poultry, Fish, and Other Animals
√ 312	Environmental Stress in Production of Livestock, Poultry, Fish, and Other Animals
√ 313	Production Management Systems for Livestock, Poultry, fish, and Other Animals
√ 314	Bees and Other Pollinating Insects
√ 315	Improvement of Structures, Facilities, and General Purpose Farm Supplies and Equipment
√ 316	Farm Business Management
√ 317	Mechanization and Structures Used in Production of Livestock, Poultry, Fish, And Other Animals
318	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
401	New and Improved Forest Products
√ 402	Production of Fruit and Vegetable Crops with Improved Acceptability
403	New and Improved Fruit and Vegetable Products and Byproducts
404	Quality Maintenance in Storing and Marketing Fruits and Vegetables
√ 405	Production of Field Crops with Improved Acceptability
406	New and Improved Food Products from Field Crops
407	New and Improved Feed, Textile, and Industrial Products from Field Crops
408	Quality Maintenance in Storing and Marketing Field Crops

Table 2. (continued)

RPA	TITLE
	GOAL IV (continued)
409	Production of Animal Products with Improved Acceptability
410	New and Improved Meat, Milk, Eggs, and Other Animal food Products
411	New and Improved Non-food Animal Products
412	Quality Maintenance in Marketing Animal Products
	GOAL V: IMPROVE EFFICIENCY IN THE MARKETING SYSTEM
√ 501	Improvement of Grades and Standards—Crop and Animal Products
√ 502	Development of Markets and Efficient Marketing of Timber and Related Products
√ 503	Efficiency in Marketing Agricultural Products and Production Inputs
√ 506	Supply, Demand, and Price Analysis—Crop and Animal Products
√ 507	Competitive Interrelationships in Agriculture
√ 508	Development of Domestic Markets for Farm Products
√ 509	Performance of Marketing Systems
510	Group Action and Market Power
511	Improvement in Agricultural Statistics
512	Improvement of Grades and Standards—Forest Products
513	Supply, Demand, and Price Analysis—Forest Products
	GOAL VI: EXPAND EXPORT MARKETS AND ASSIT DEVELOPING NATIONS
601	Foreign Market Development
602	Evaluation of Foreign Food Aid Programs
603	Technical Assistance to Developing Countries
604	Product Development and Marketing for Foreign Markets
	GOAL VII: PROTECT CONSUMER HEALTH AND IMPROVE NUTRITION AND WELL-BEING OF THE AMERICAN PEOPLE
701	Insure Food Products Free of Toxic Contaminants, Including Residues from Agricultural and Other Sources
702	Protect Food and Feed Supplies from Harmful Microorganisms and Naturally Occurring Toxins
703	Food Choices, Habits, and Consumption
704	Home and Commercial Food Service
705	Selection and Care of Clothing and Household Textiles
706	Control of Insect Pests of Man and His Belongings
707	Prevent Transmission of Animal Diseases and Parasites to Man
708	Human Nutrition
709	Reduction of Hazards to Health and Safety

Table 2. (continued)

RPA	TITLE
	GOAL VIII: ASSIST RURAL AMERICANS TO IMPROVE THEIR LEVEL OF LIVING
801	Housing
802	Individual and Family Decision Making and Resource Use and Family Functioning
803	Causes of Poverty Among Rural People
804	Improvement of Economic Potential of Rural People
805	Communication and Education Processes
806	Individual and Family Adjustment to Change
807	Structural Changes in Agriculture
808	Government Programs to Balance Farm Output and Market Demand
	GOAL IX: PROMOTE COMMUNITY IMPROVEMENT INCLUDING DEVELOPMENT OF BEAUTY, RECREATION, ENVIRONMENT, ECONOMIC OPPORTUNITY, AND PUBLIC SERVICES
901	Alleviation of Soil, Water, and Air Pollution and Disposal of Wastes
902	Outdoor Recreation
903	Multiple Use Potential of Forest Land and Evaluation of Forestry Programs
904	Fish and Other Aquatic Life, Fur-Bearing Animals, and Other Wildlife
905	Trees to Enhance rural and Urban Environment
906	Culture and Protection of Ornamentals and Turf
907	Improved Income Opportunities in Rural Communities
908	Improvement of rural Community Institutions and Services

Source: U.S. Dept. Agr., CSRS, CRIS. Manual of Classification of Agricultural and Forestry Research. Revision V. Beltsville, MD: USDA-CSRS, Feb. 1993.

Appendix A Table3. Fields of science in the Current Research Information (CRIS) Classification of Public Agricultural Research, 1967-

Biological

0110	Biochemistry and biophysics - animal
0112	Biochemistry and biophysics – plant
0113	Biochemistry and biophysics – human
0114	Biochemistry and biophysics – other
0210	Biology – Environmental, systematic, Applied – animal
0212	Biology – Environmental, systematic, Applied – plant
0213	Biology – Environmental, systematic, Applied – human
0214	Biology – Environmental, systematic, Applied – other
0310	Biology – Molecular – animal
0312	Biology – Molecular – plant
0313	Biology – Molecular – other
0410	Entomology – animal
0412	Entomology – plant
0413	Entomology – human
0414	Entomology – other
0510	Animal Genetics and Breeding
0512	Plant Genetics and Breeding
0513	Genetics – other
0610	Immunology – animal
0612	Immunology – plant
0613	Immunology – human
0710	Microbiology – animal
0712	Microbiology – plant
0713	Microbiology – human
0714	Microbiology – soils
0790	Microbiology – other
0810	Nematology – animal
0812	Nematology – plant
0813	Nematology – other
0910	Nutrition and Metabolism - animal
0912	Nutrition and Metabolism – plant
0913	Nutrition and Metabolism – human
0914	Nutrition and Metabolism – other
1010	Parasitology – animal
1012	Parasitology – plant
1013	Parasitology – other
1110	Pathology – animal
1112	Pathology - plant
1113	Pathology – human
1114	Pathology – other
1210	Pharmacology
1310	Physiology – animal
1312	Physiology – plant
1313	Physiology – other
1410	Virology – animal
1412	Virology – plant
1413	Virology – human
1414	Virology – other

Physical

1524	Chemistry – analytical
1525	Chemistry – inorganic
1526	Chemistry – organic
1527	Chemistry – physical
1528	Chemistry –soils
1529	Chemistry – other
1920	Engineering – agricultural
1924	Engineering – mechanical
1925	Engineering – electrical
1926	Engineering – civil
1927	Engineering – chemical
1928	Engineering – industrial
1928	Engineering -- other

Table 3. (continued)

Physical (Cont'd)

Code	Field
2020	Geology and geography
2120	Hydrology
2220	Mathematics
2230	Statistics and biometry
2320	Meteorology and climatology
2420	Physics
2421	Physics – soils

Social and Behavioral

Code	Field
2530	Anthropology
2630	Economics
2730	Education
2740	Information and Communication
2830	History
2930	Law
3030	Political Science
3130	Psychology
3230	Sociology
3310	Art and Architecture

Source: U.S. Dept. Agr., CSRS, CRIS. Manual of Classification of Agricultural and Forestry Research. Revision V. Beltsville, MD: USDA-CSRS, Feb. 1993.

Appendix B: Derivation Expenditures on Research Commodities or Subject Matter Areas, 1929-1969

The procedure for deriving research expenditures on 20 research commodities or subject matter areas is one of deriving predicted research commodity shares for 20 research commodities for each year 1929-1969 and each state and then multiplying each of these shares by our estimate of public agricultural research expenditures on direct productivity research for each state and year 1929-1969. This is another application of the methodology of interpolation of a time series by a related series (Friedman 1962).

Given that the CRIS data were noisy for the first few years after it was initiated in 1967, we decided to use CRIS data for 1970 and value of agricultural production data for 1969 as the set of research shares are for the following 20 commodities (subject areas): vegetables, fruit, corn, wheat, oats, soybean, peanut, flax, cotton, tobacco, potato, sugar, rice, poultry, sheep, beef, swine, dairy, hay and structures. Our regression model is:

(B1) $SR_{i\ell} = \beta_{1\ell} + \beta_{2\ell} SP_{i\ell} + \Sigma\, \delta_{k\ell} D_{ik} + \mu_{i\ell}$, i = states 1-48, ℓ = commodities 1-20.

where $SR_{i\ell}$ is the research expenditure share for the i-th state and ℓ-th research commodity, $SP_{i\ell}$ is the value of farm production share in the i-th state for the ℓ-commodity produced, D_{ik} takes a value of 1 if the i-th state is in the k-th geo-climate region (k = 1, …16; see Figure 1). Equation (7) was first fitted data for research commodity shares (created from CRIS data) in 1970 and value of farm production shares for 1969 from the *Census of Agriculture* 1969. Each share equation was pooled across the 48 states in fitting. Using the estimated coefficients from these fitted OLS regions and the value of farm production commodity shares constructed for1929, 1939, 1949, and 1959 taken from Censuses of Agriculture, predicted research commodity shares were created for 1930, 1940, 1950 and 1960 for each state. Predicted negative shares were set to zero, and all of the positive shares for a given state and year were summed together and then normalized so that the summation across research commodity shares equaled one. Research commodity shares for inter-decade years were obtained by simple linear interpolation.

Appendix C. Plots of Public Agricultural Research Capital by State

Figure 1. Public Agricultural Research Capital, 1970-1999: Alabama

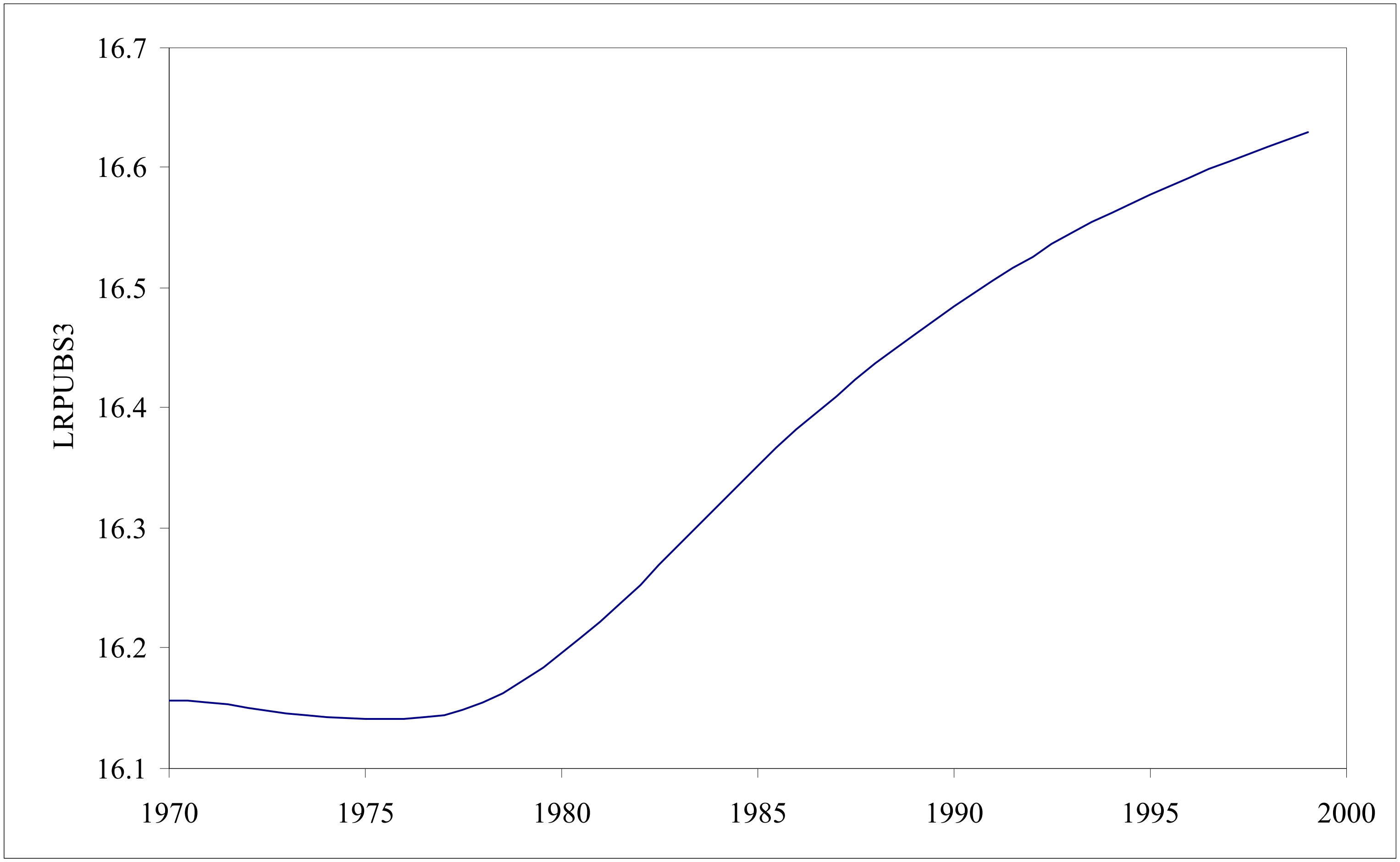

Figure 2. Public Agricultural Research Capital, 1970-1999: Arkansas

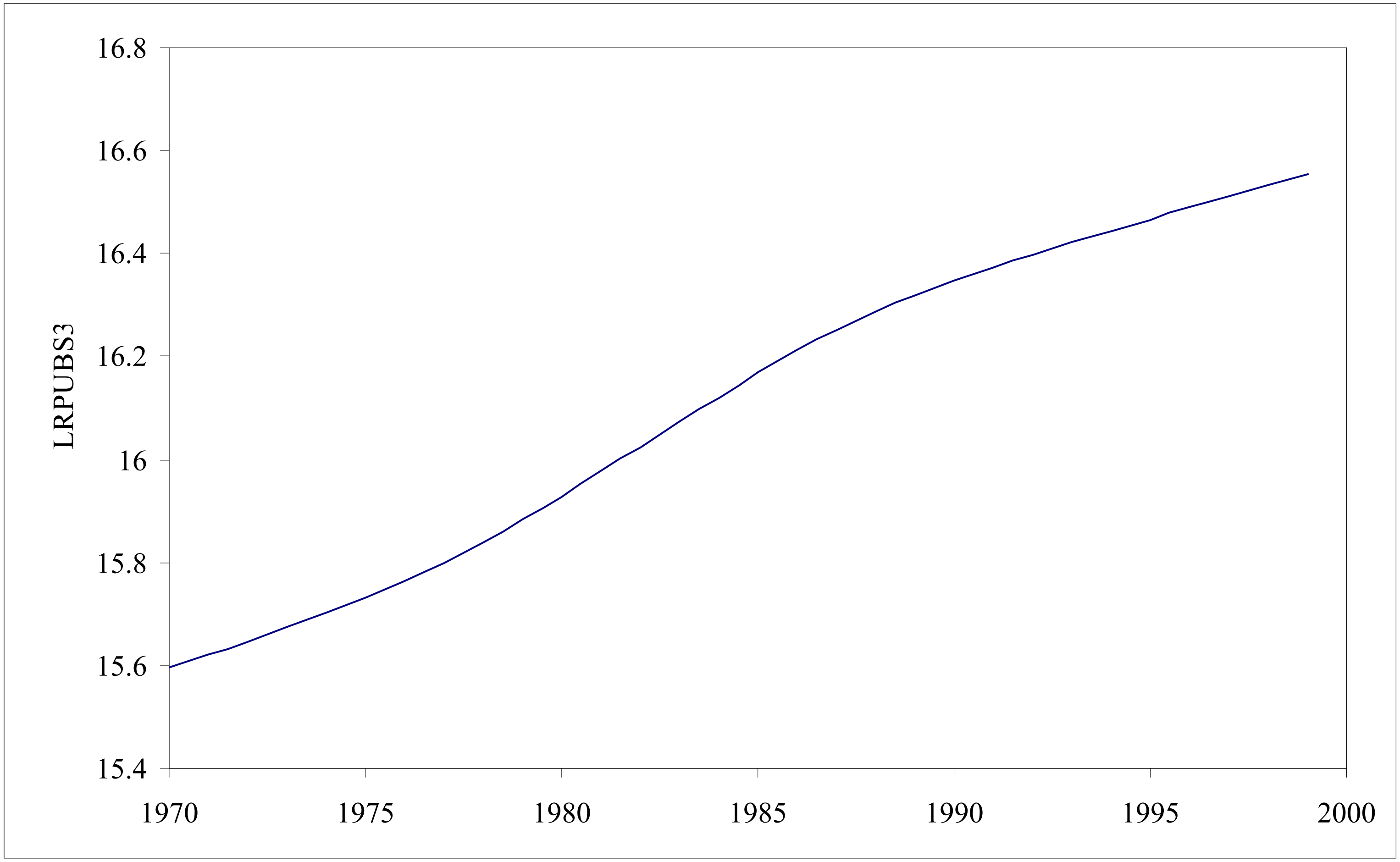

Figure 3. Public Agricultural Research Stock, 1970-1999: Arizona

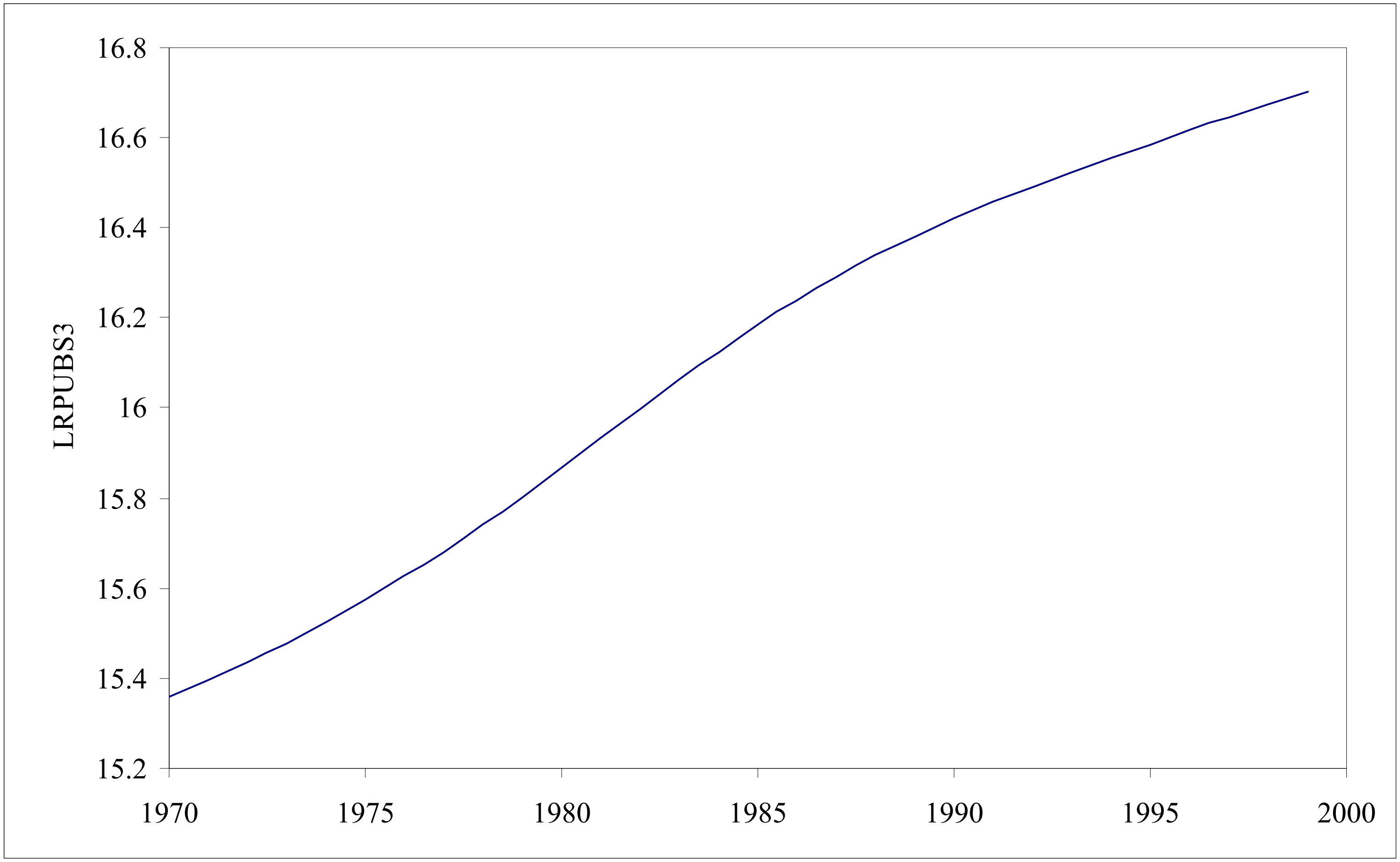

Figure 4. Public Agricultural Research Capital, 1970-1999: California

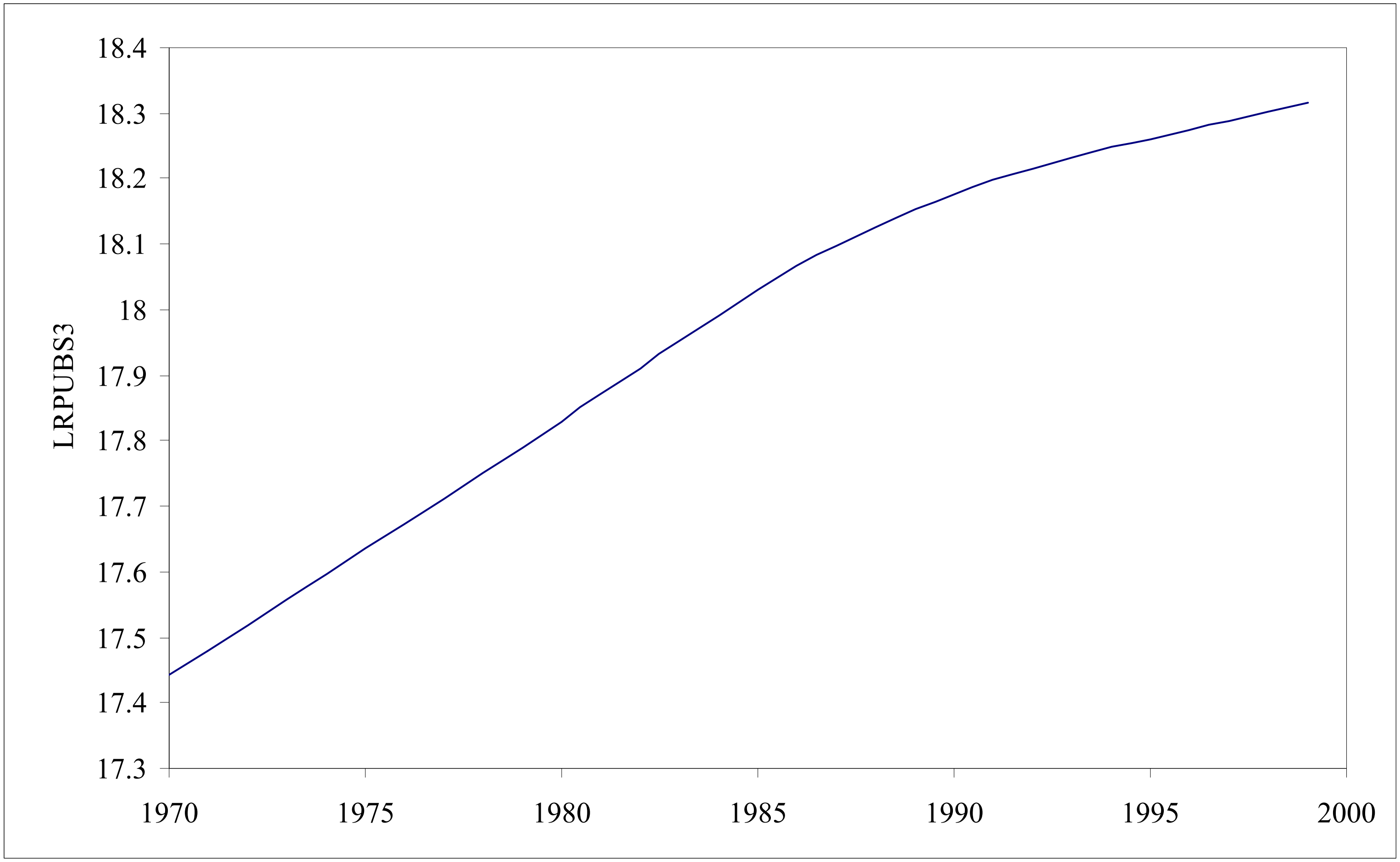

Figure 5. Public Agricultural Research Capital, 1970-1999: Colorado

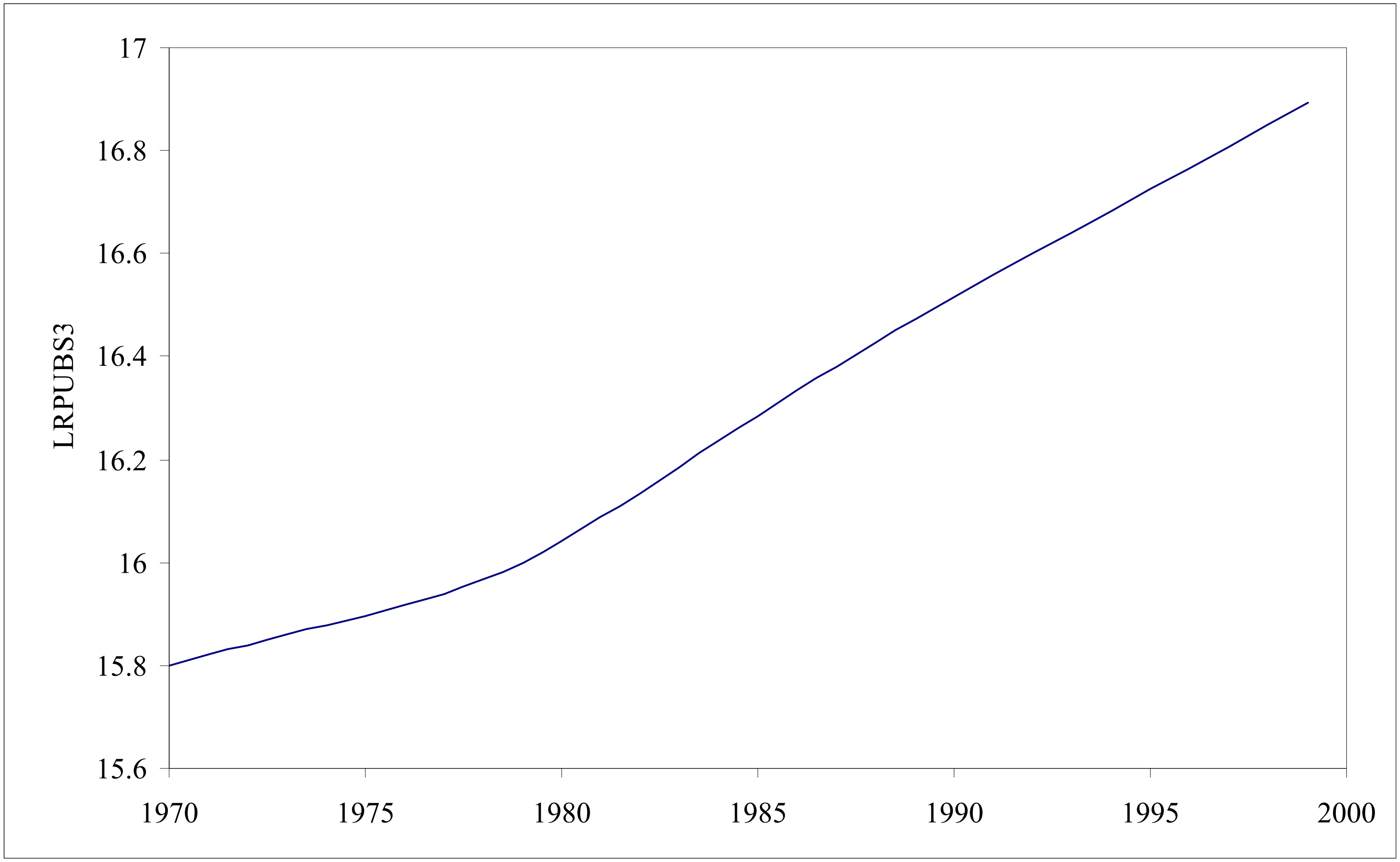

Figure 6. Public Agricultural Research Capital, 1970-1999: Connecticut

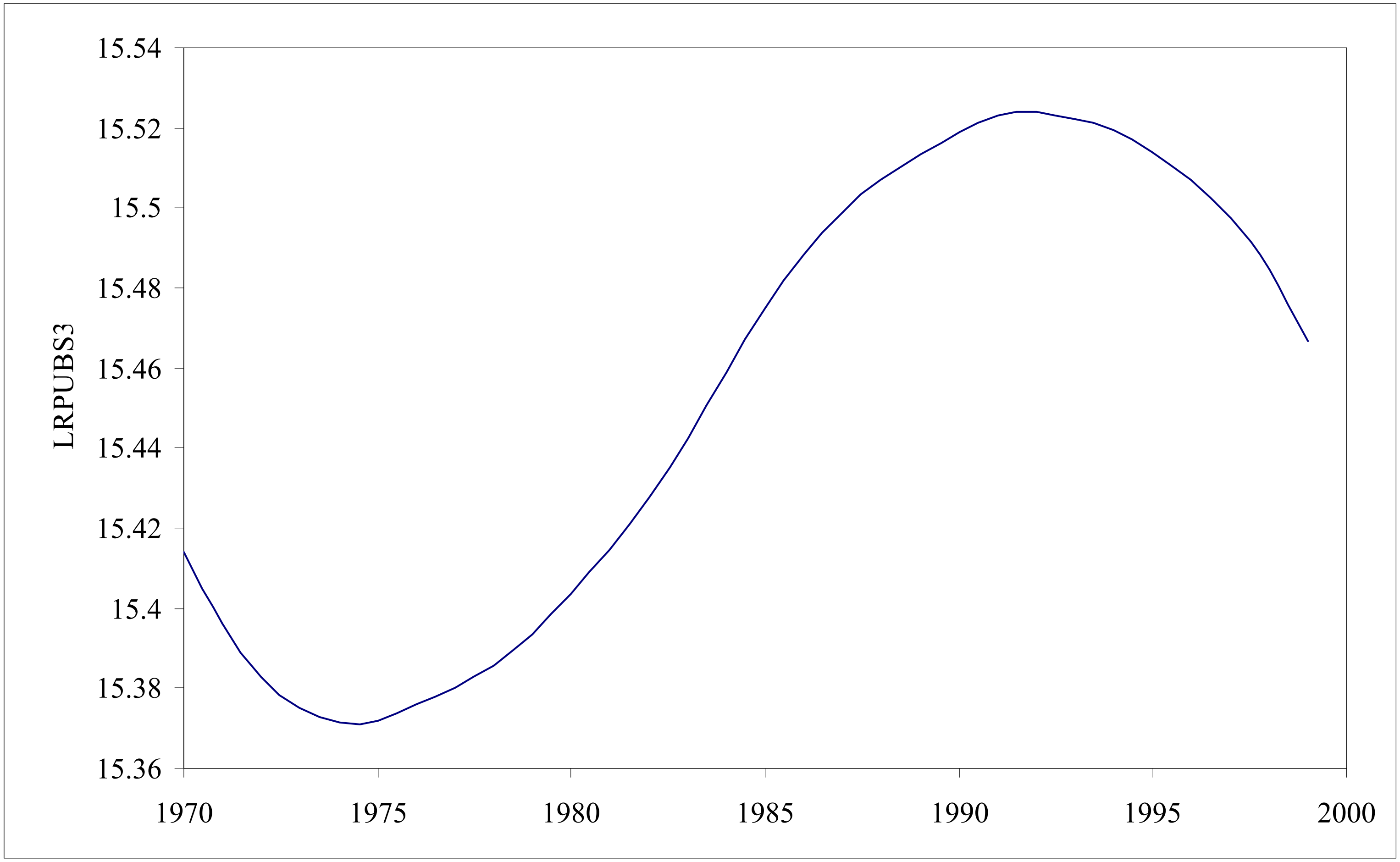

Figure 7. Public Agricultural Research Capital, 1970-1999: Delaware

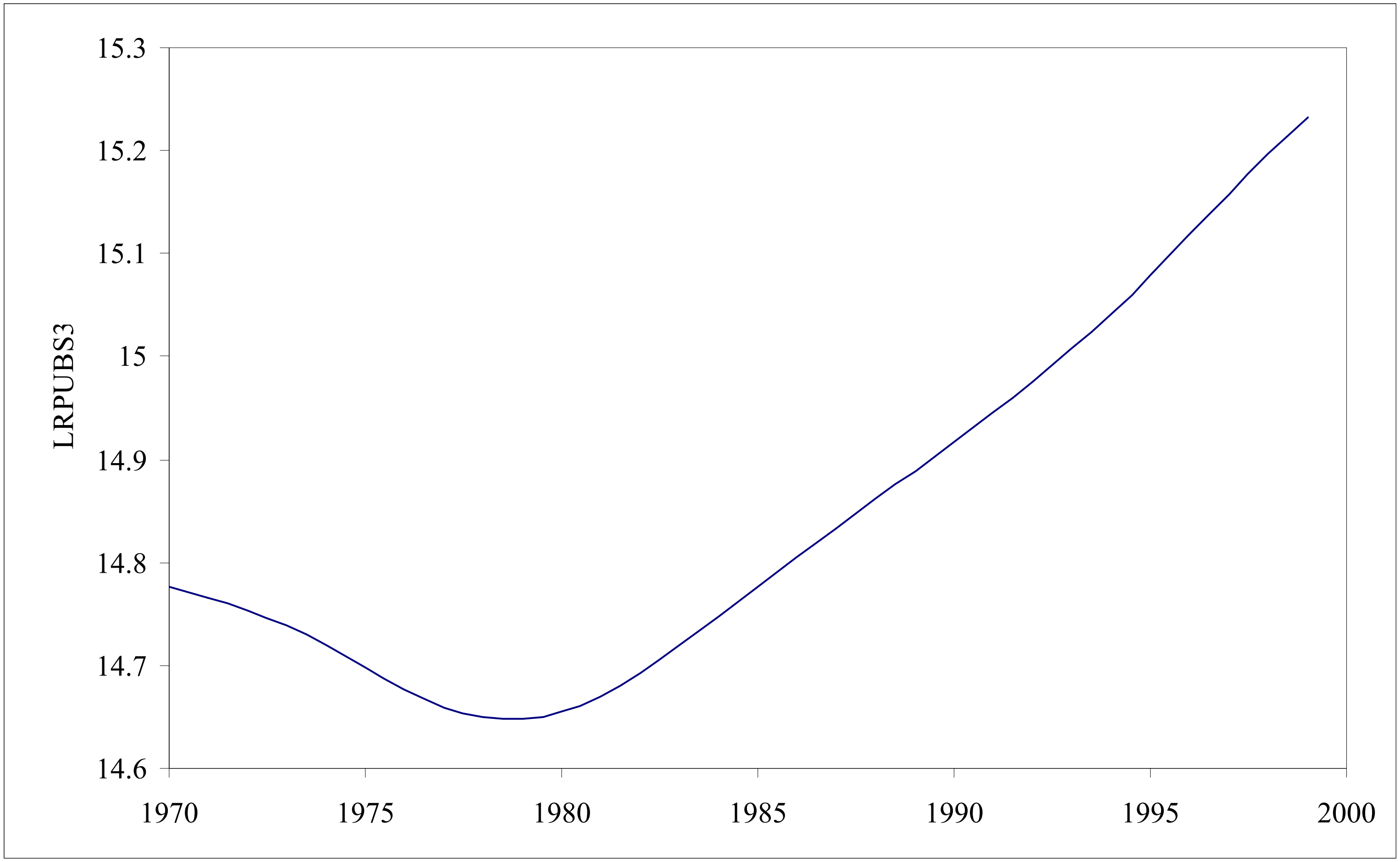

Figure 8. Public Agricultural Research Capital, 1970-1999: Florida

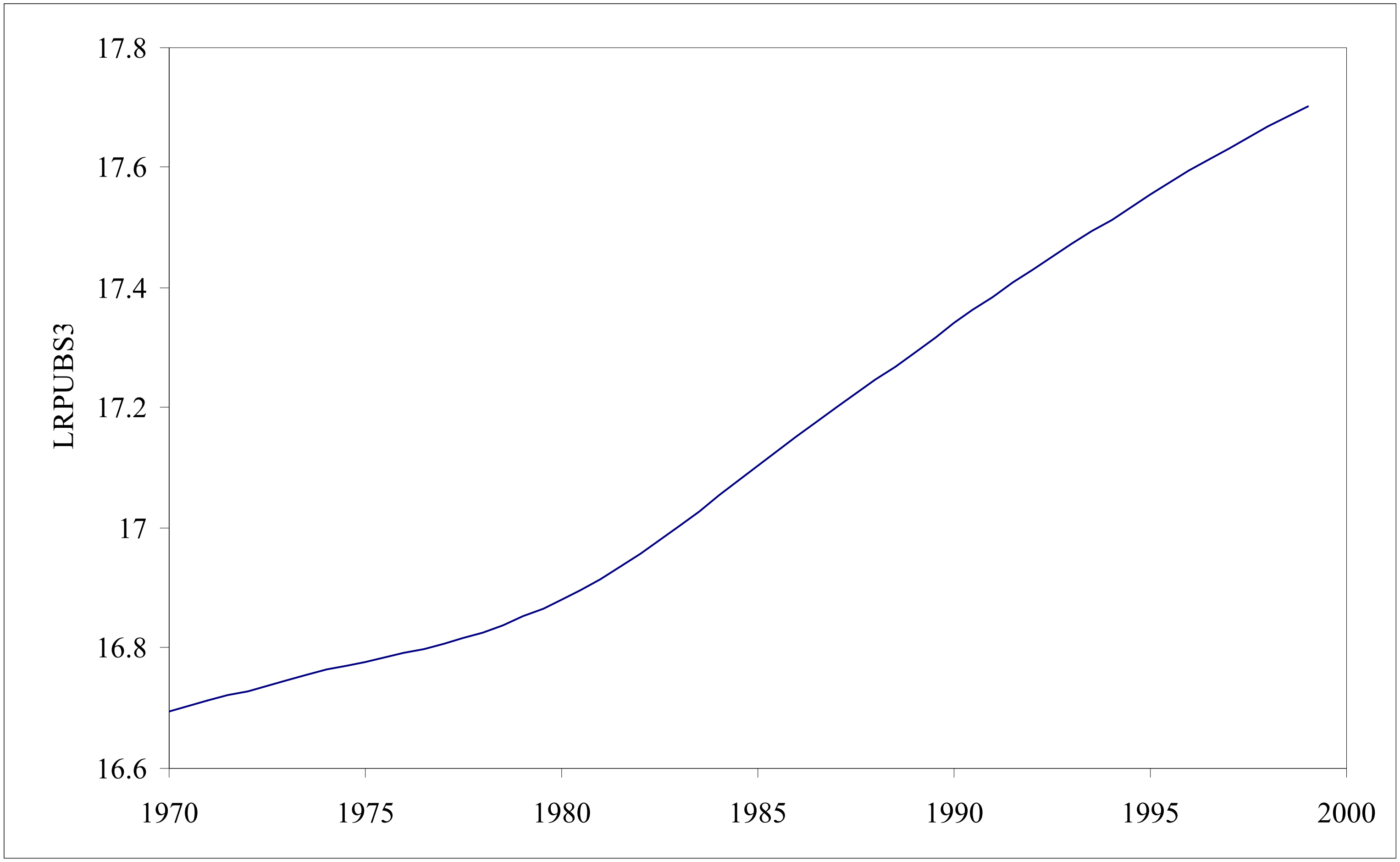

Figure 9. Public Agricultural Research Capital, 1970-1999: Georgia

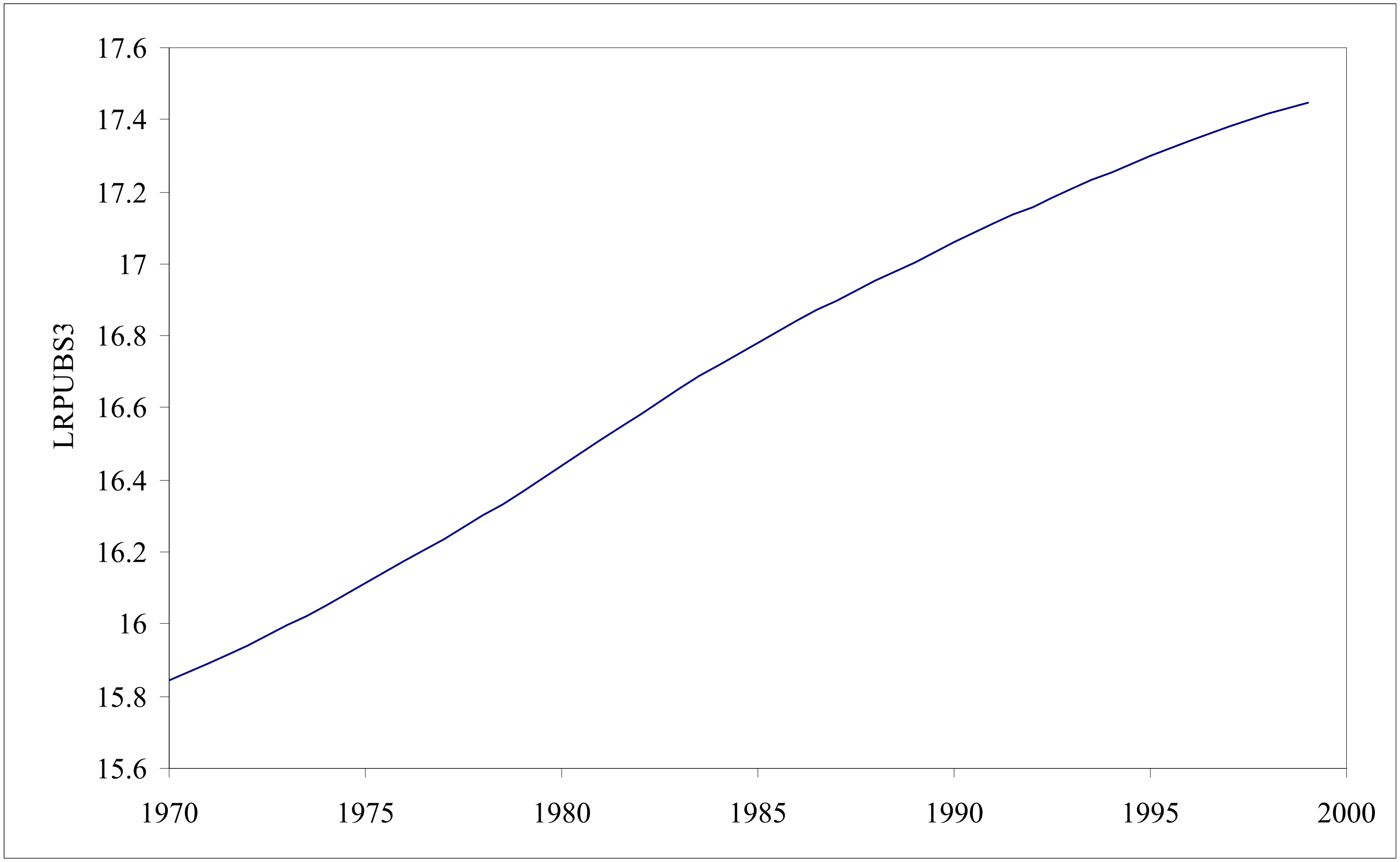

Figure 10. Public Agricultural Research Capital, 1970-1999: Iowa

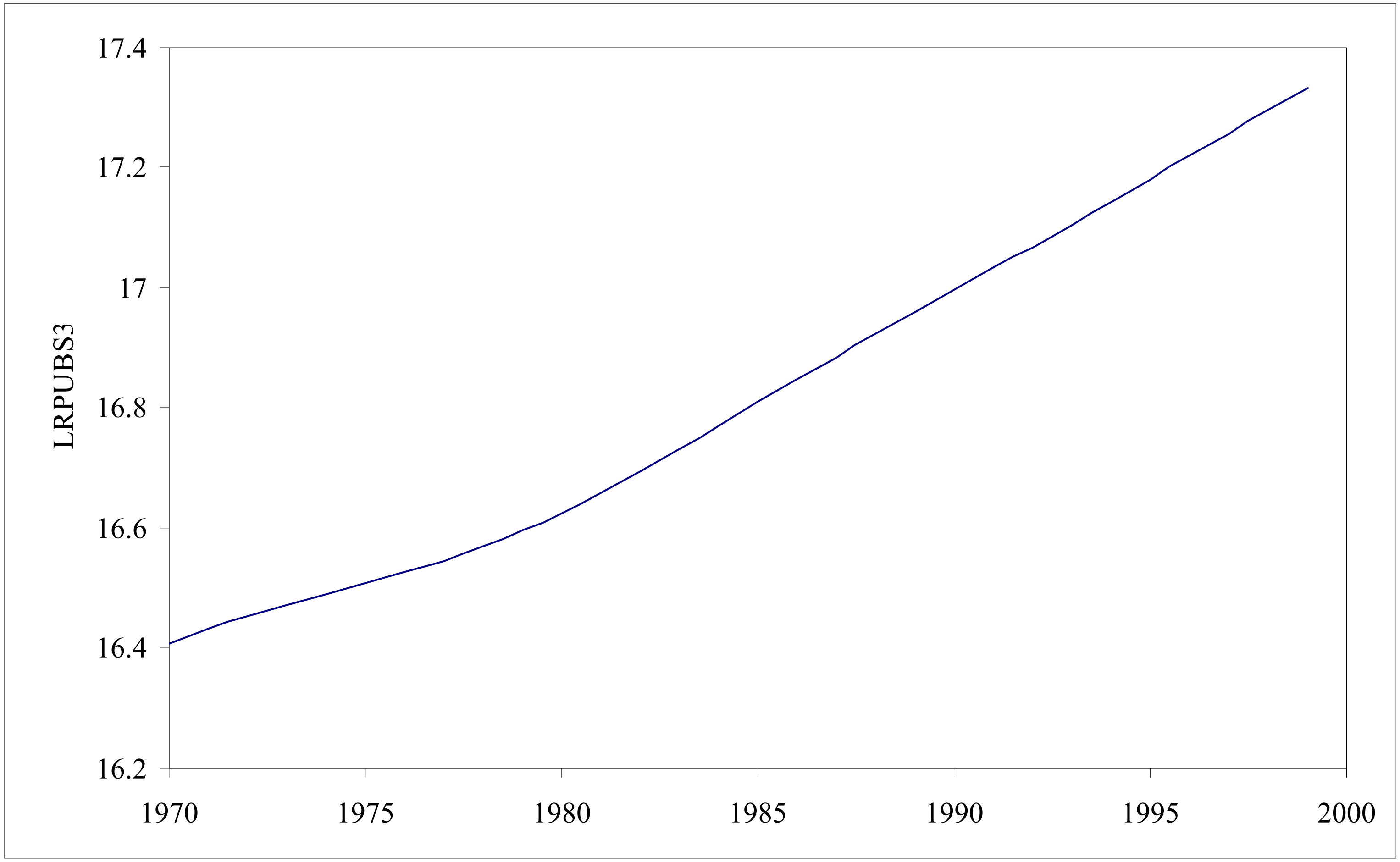

Figure 11. Public Agricultural Research Capital, 1970-1999: Idaho

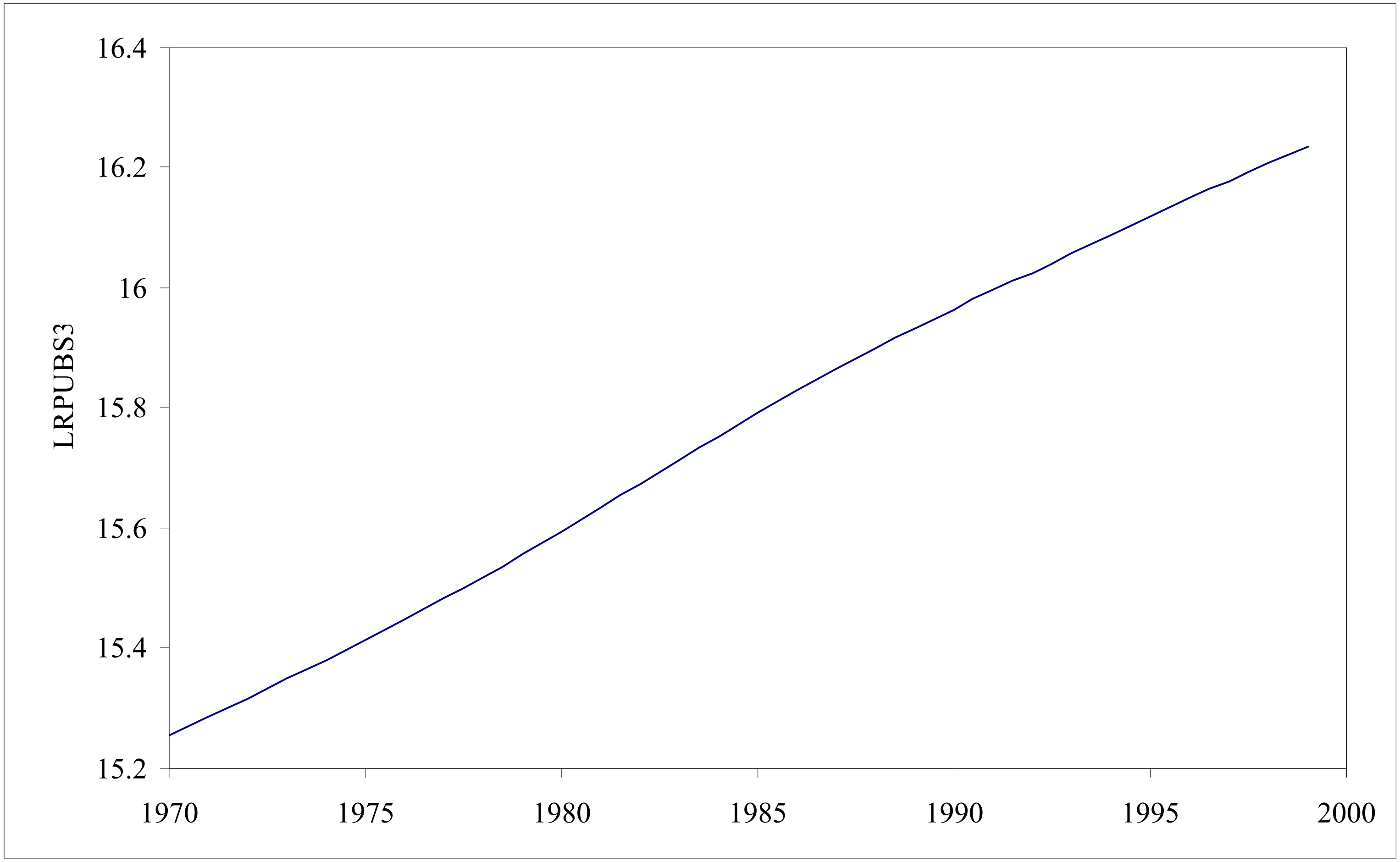

Figure 12. Public Agricultural Research Capital, 1970-1999: Illinois

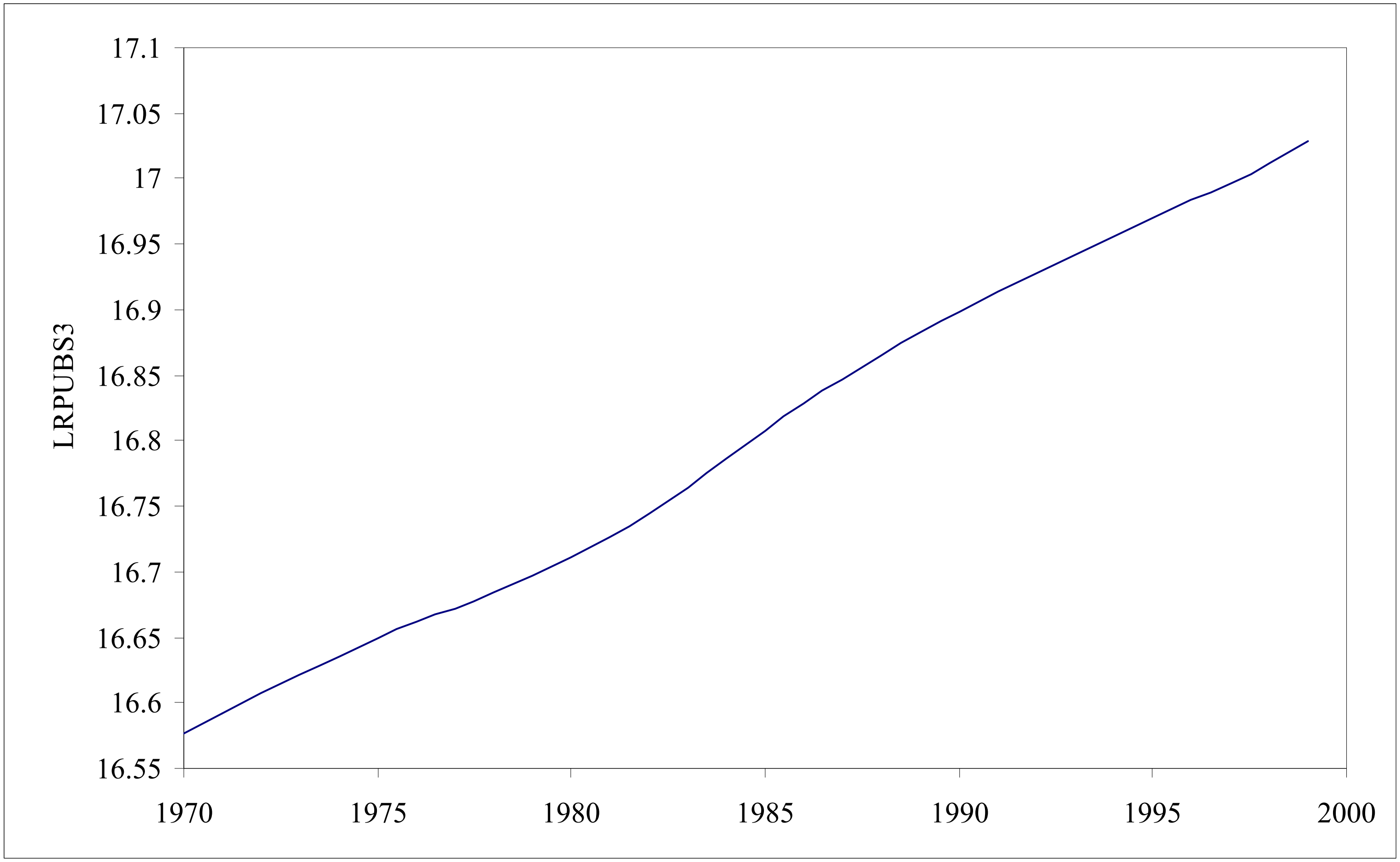

Figure 13. Public Agricultural Research Capital, 1970-1999: Indiana

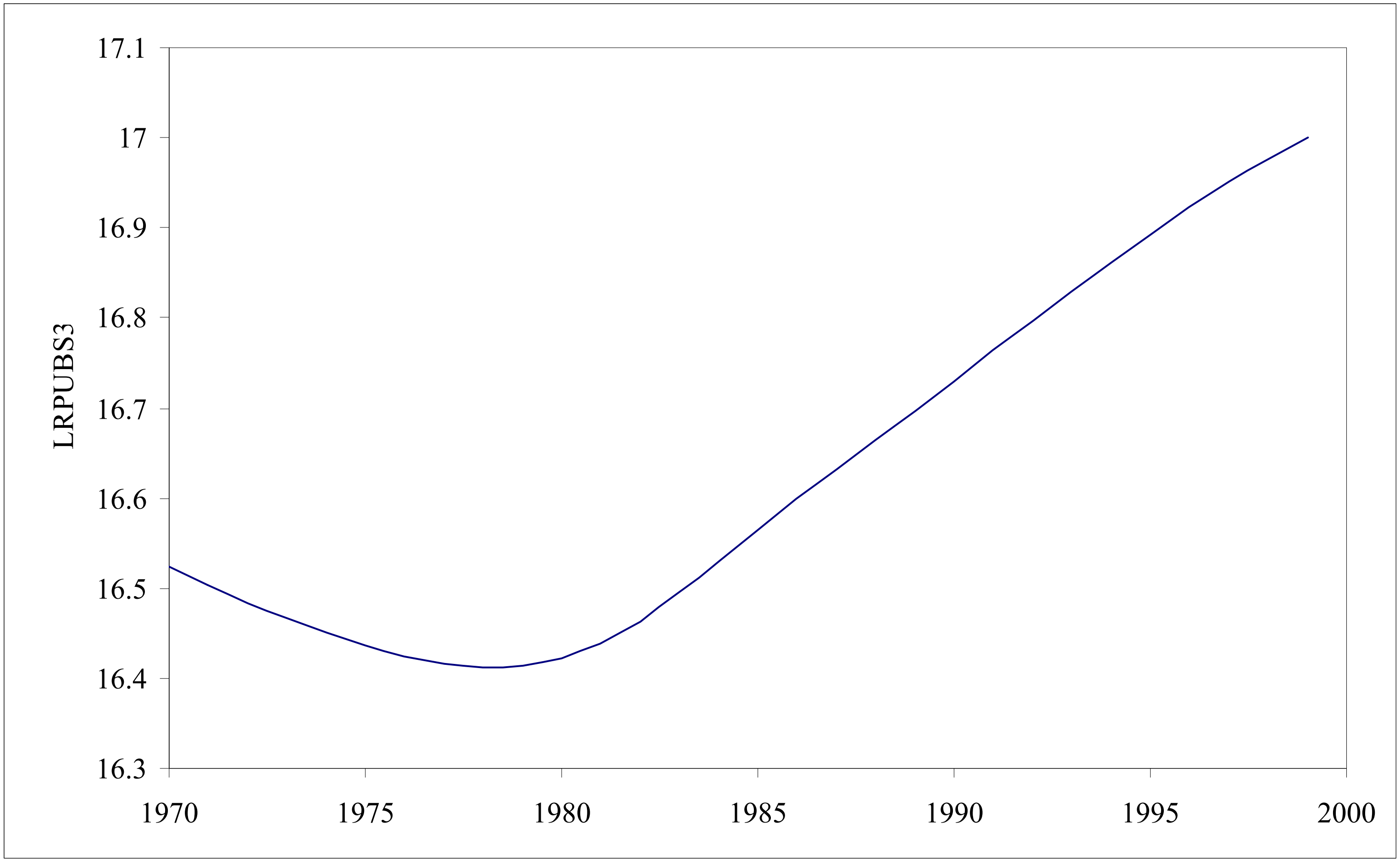

Figure 14. Public Agricultural Research Capital, 1970-1999: Kansas

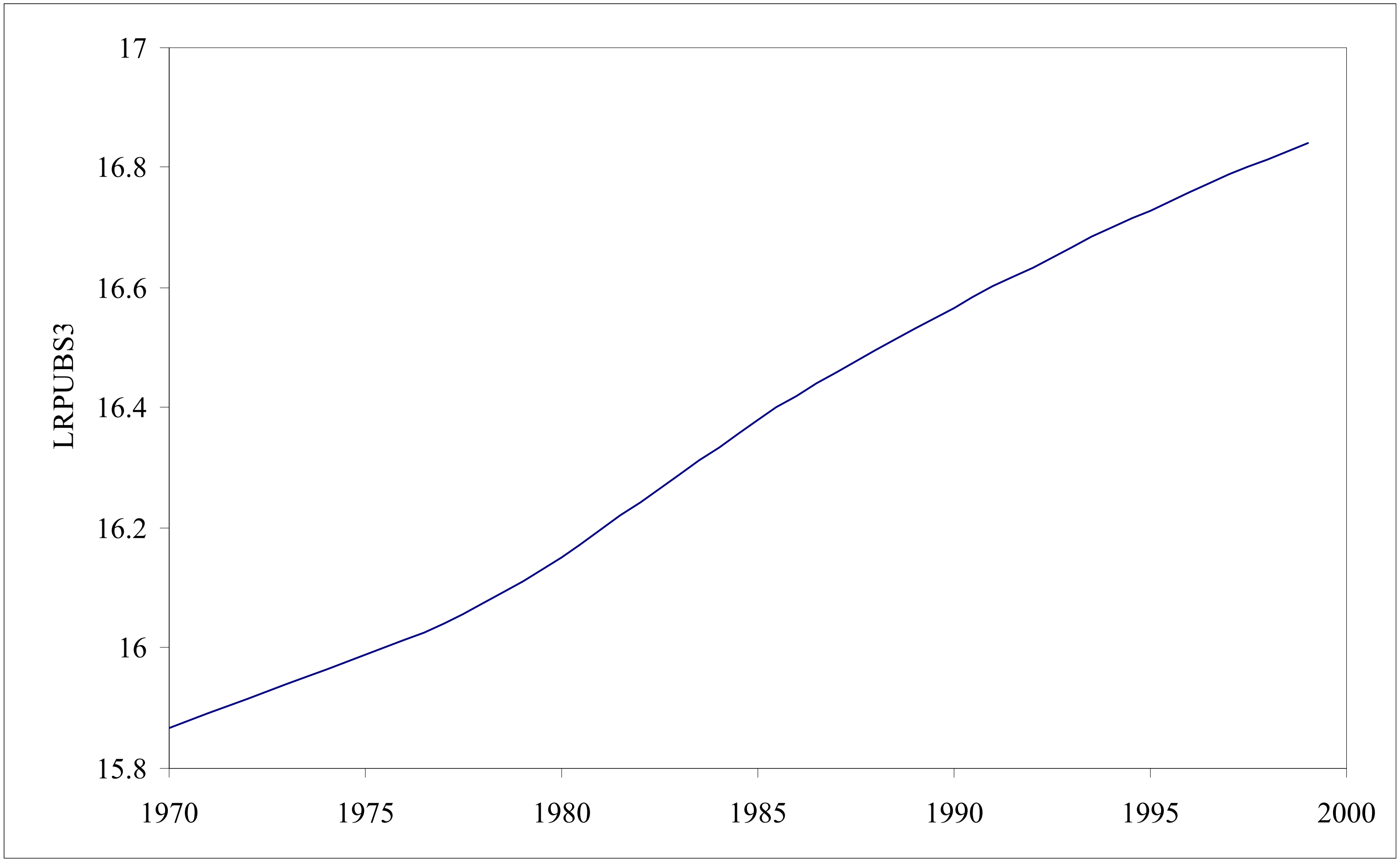

Figure 15. Public Agricultural Research Capital, 1970-1999: Kentucky

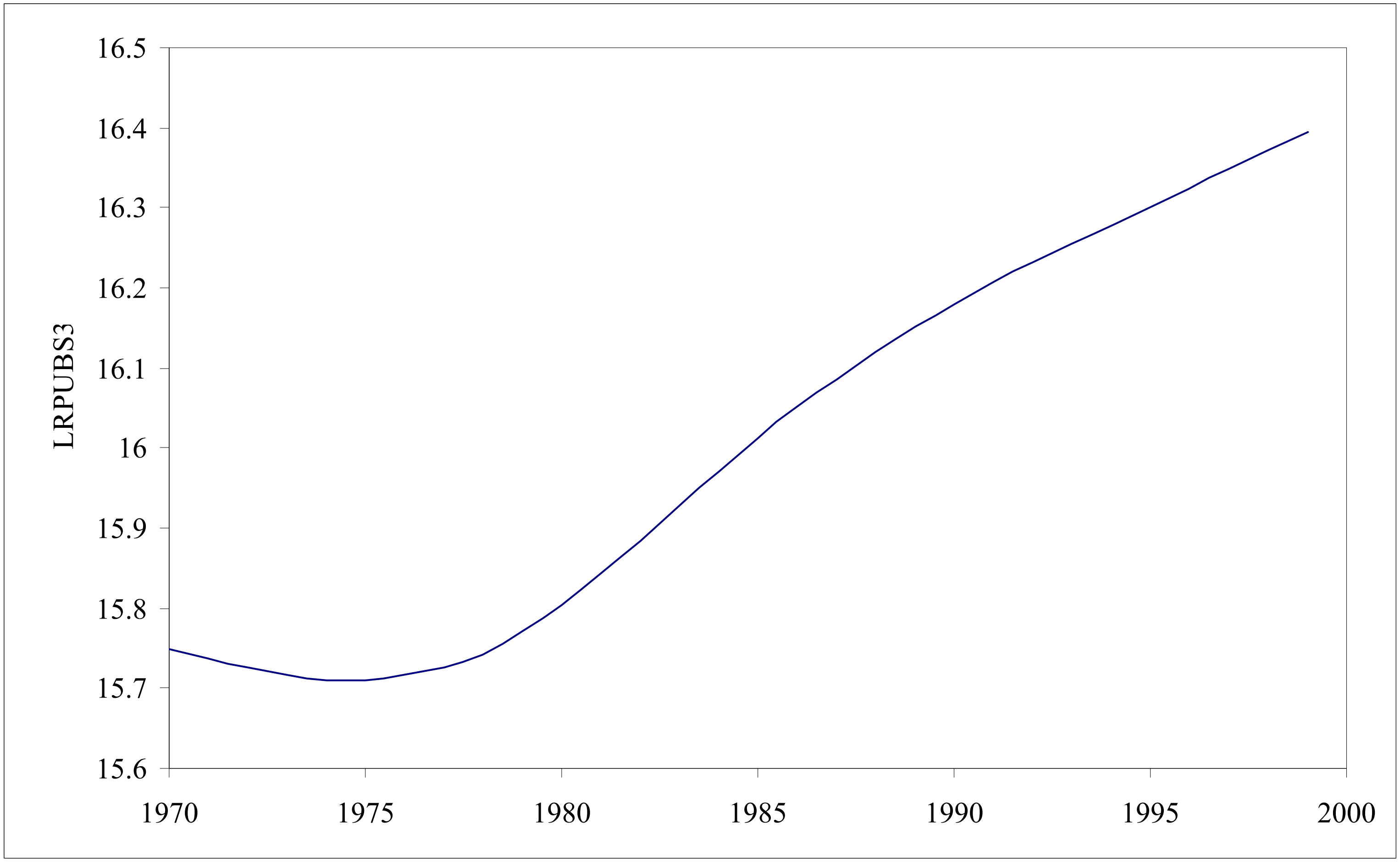

Figure 16. Public Agricultural Research Capital, 1970-1999: Louisiana

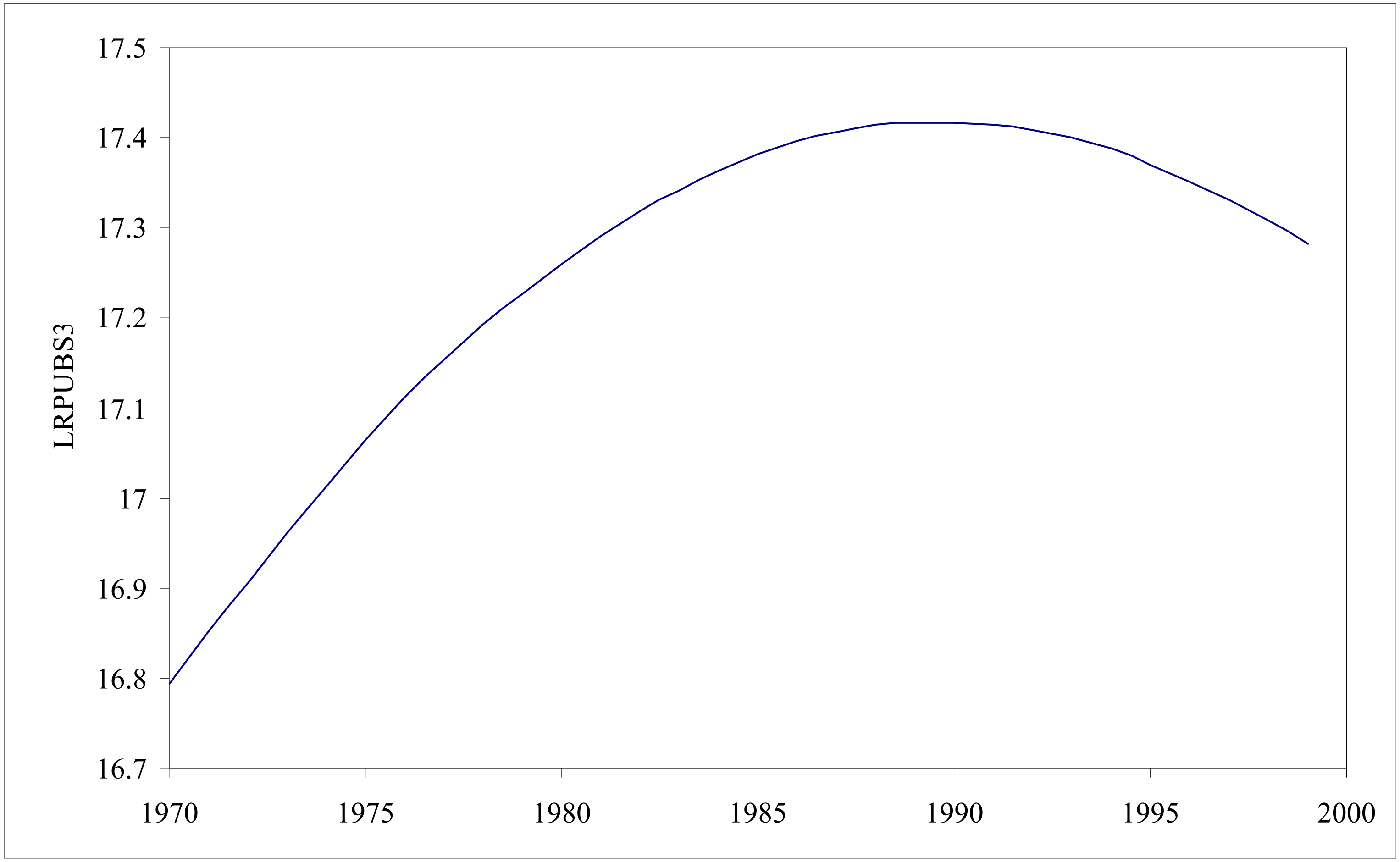

Figure 17. Public Agricultural Research Capital, 1970-1999: Massachusetts

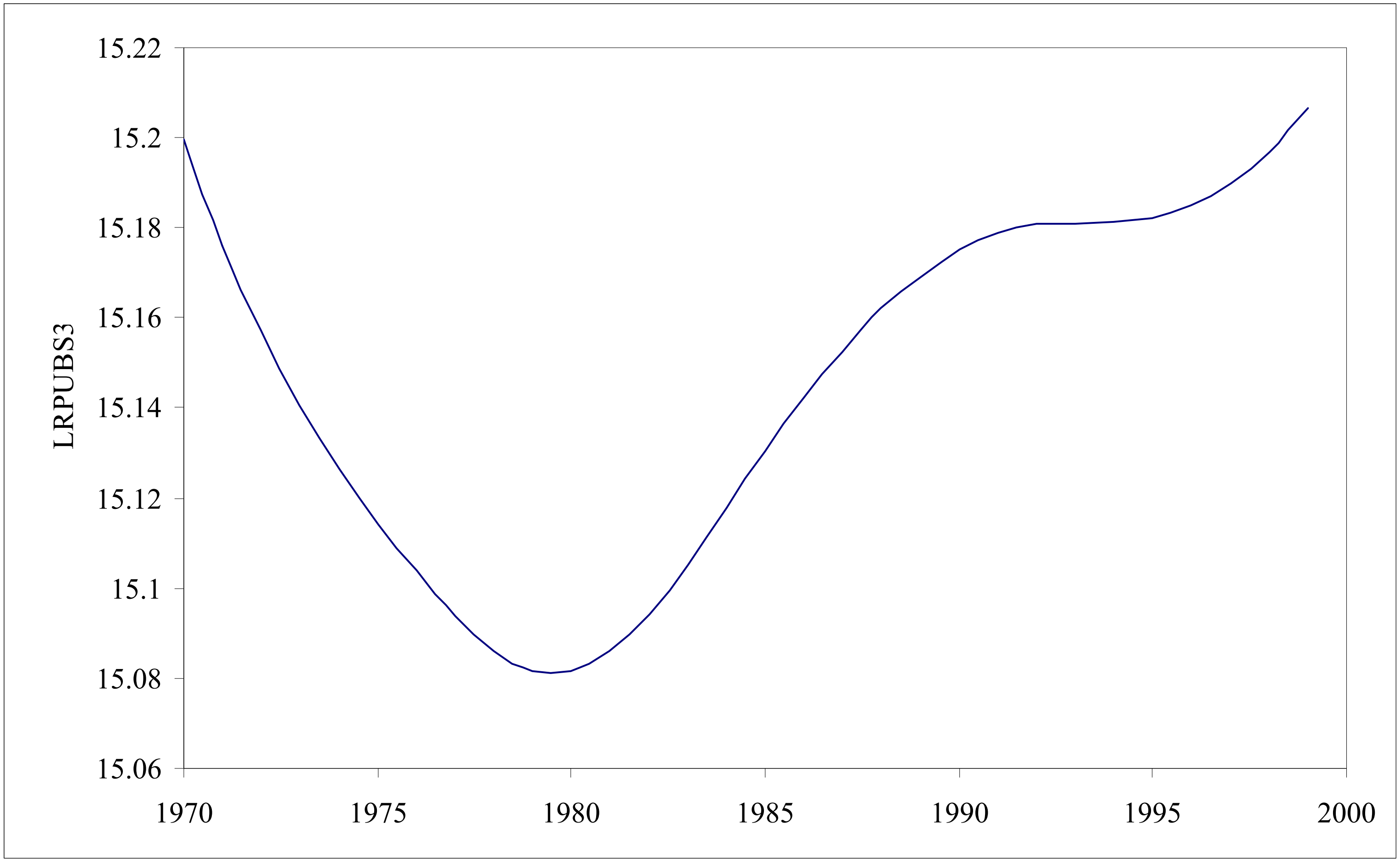

Figure 18. Public Agricultural Research Capital, 1970-1999: Maryland

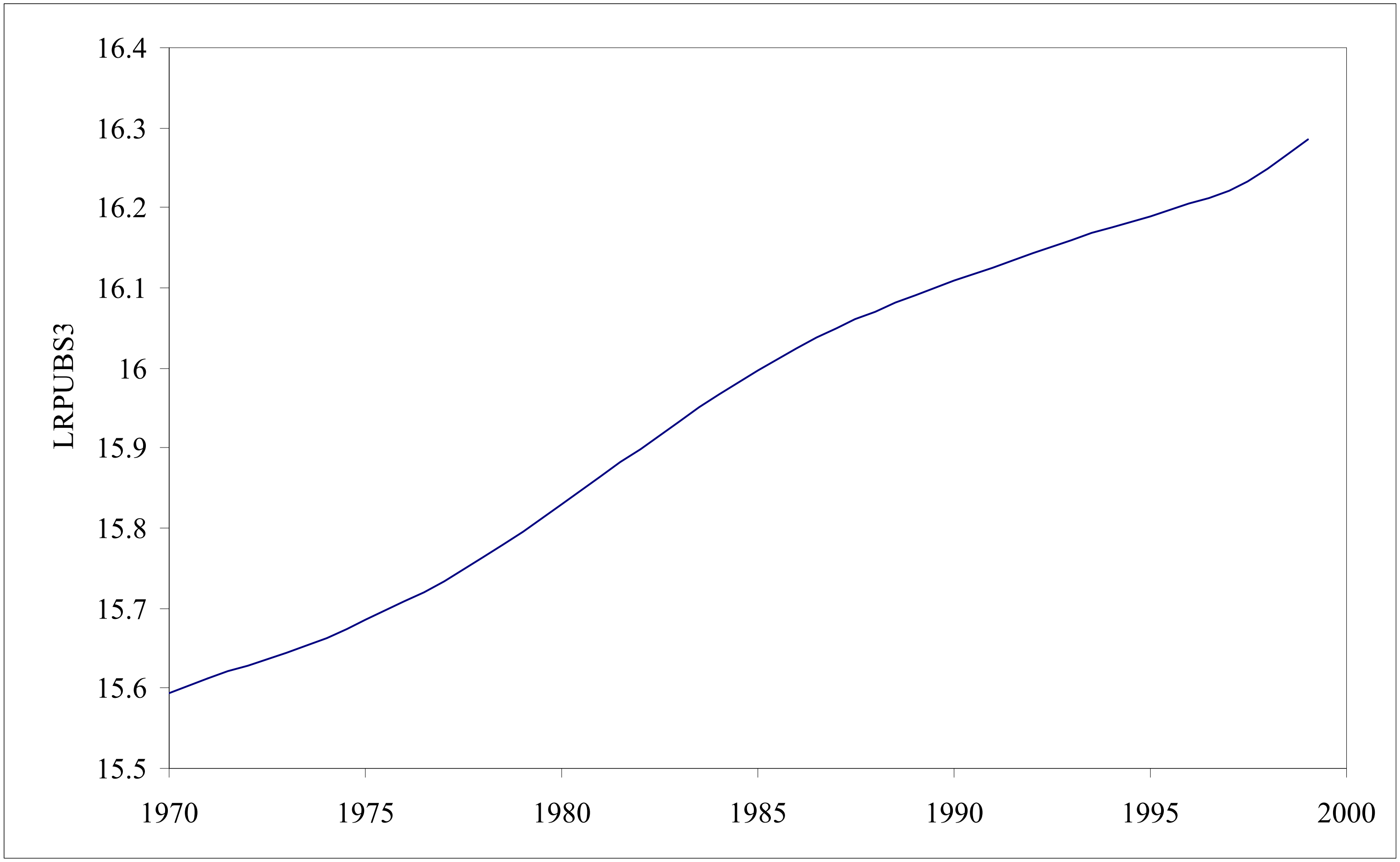

Figure 19. Public Agricultural Research Capital, 1970-1999: Maine

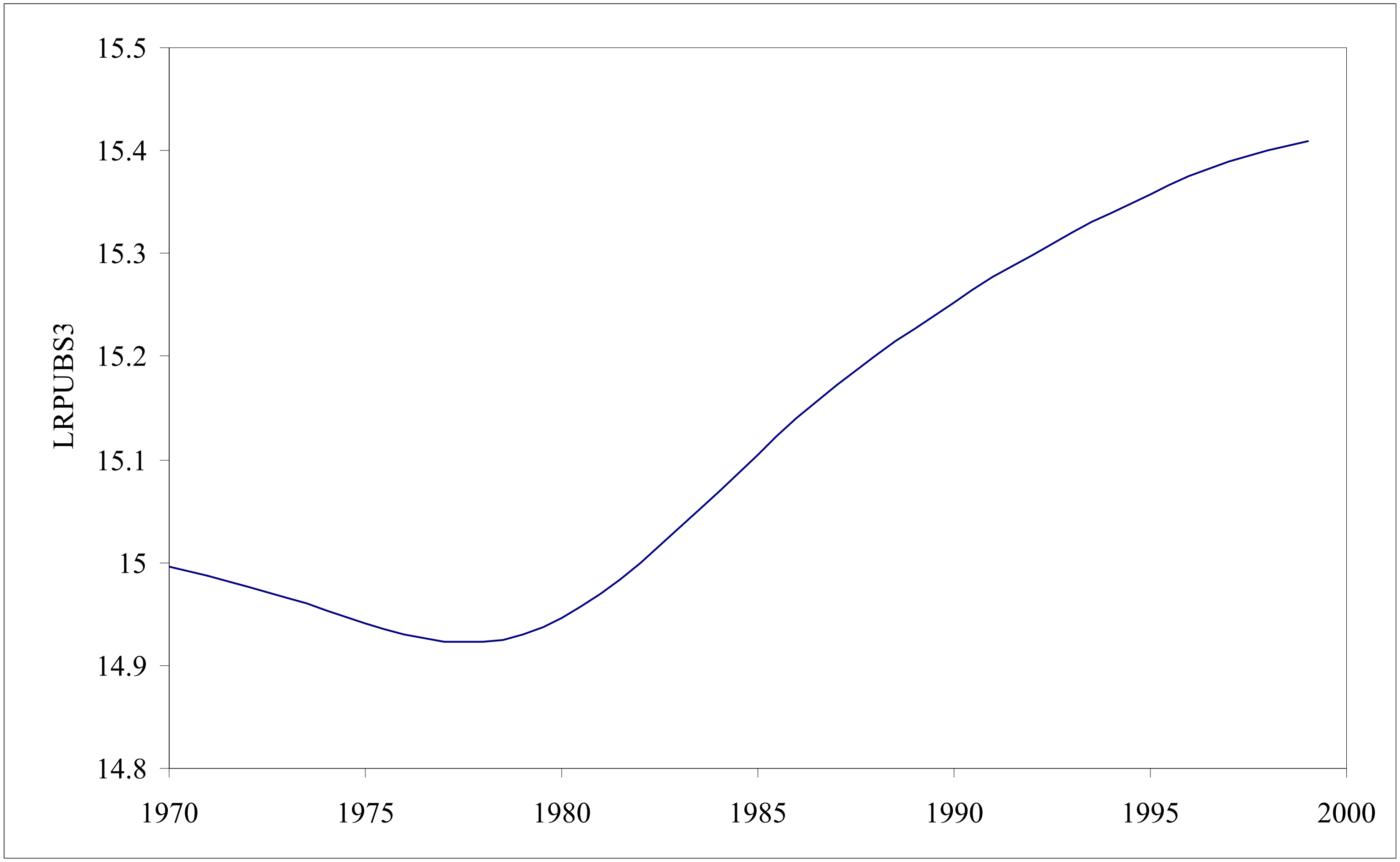

Figure 20. Public Agricultural Research Capital, 1970-1999: Michigan

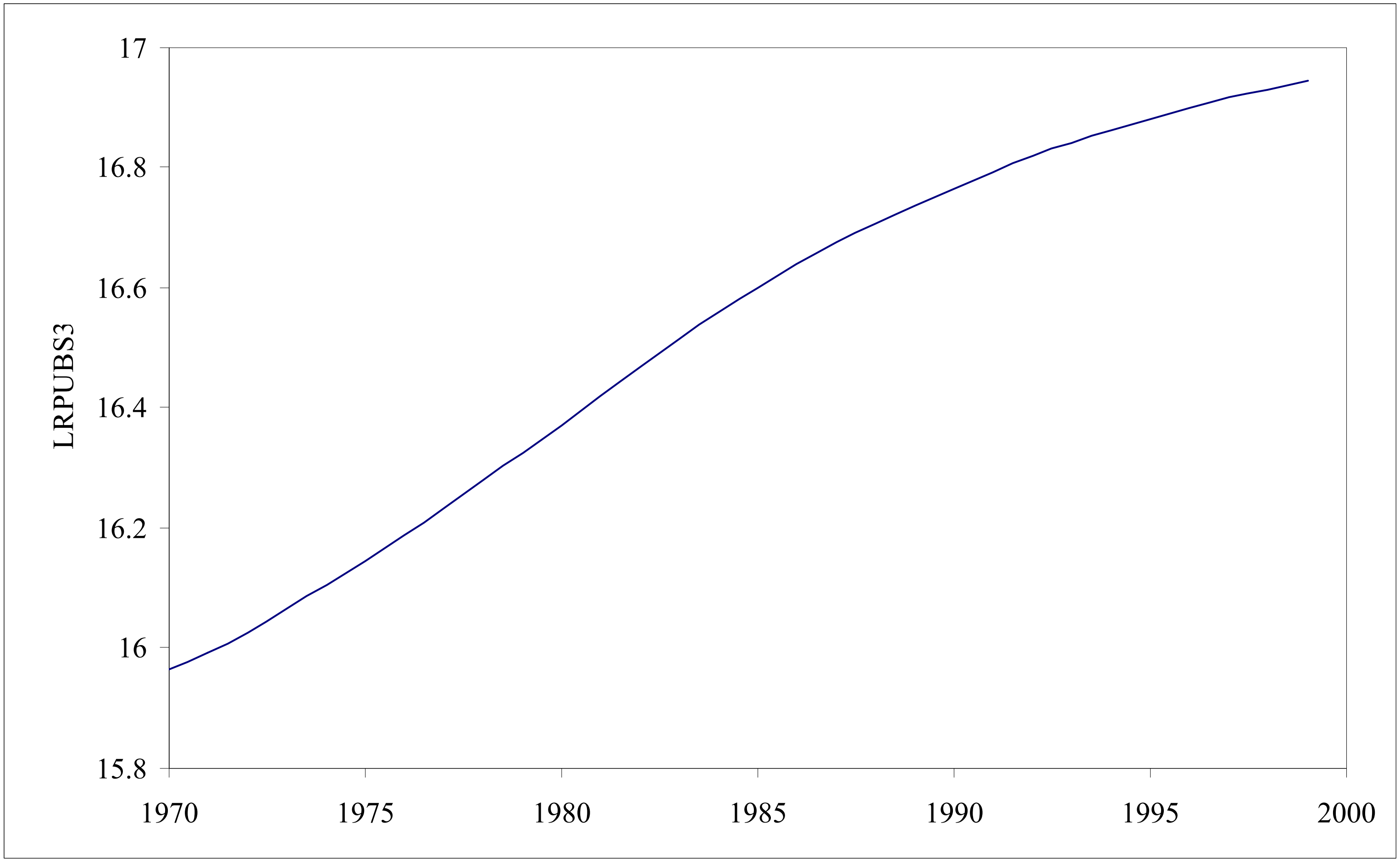

Figure 21. Public Agricultural Research Capital, 1970-1999: Minnesota

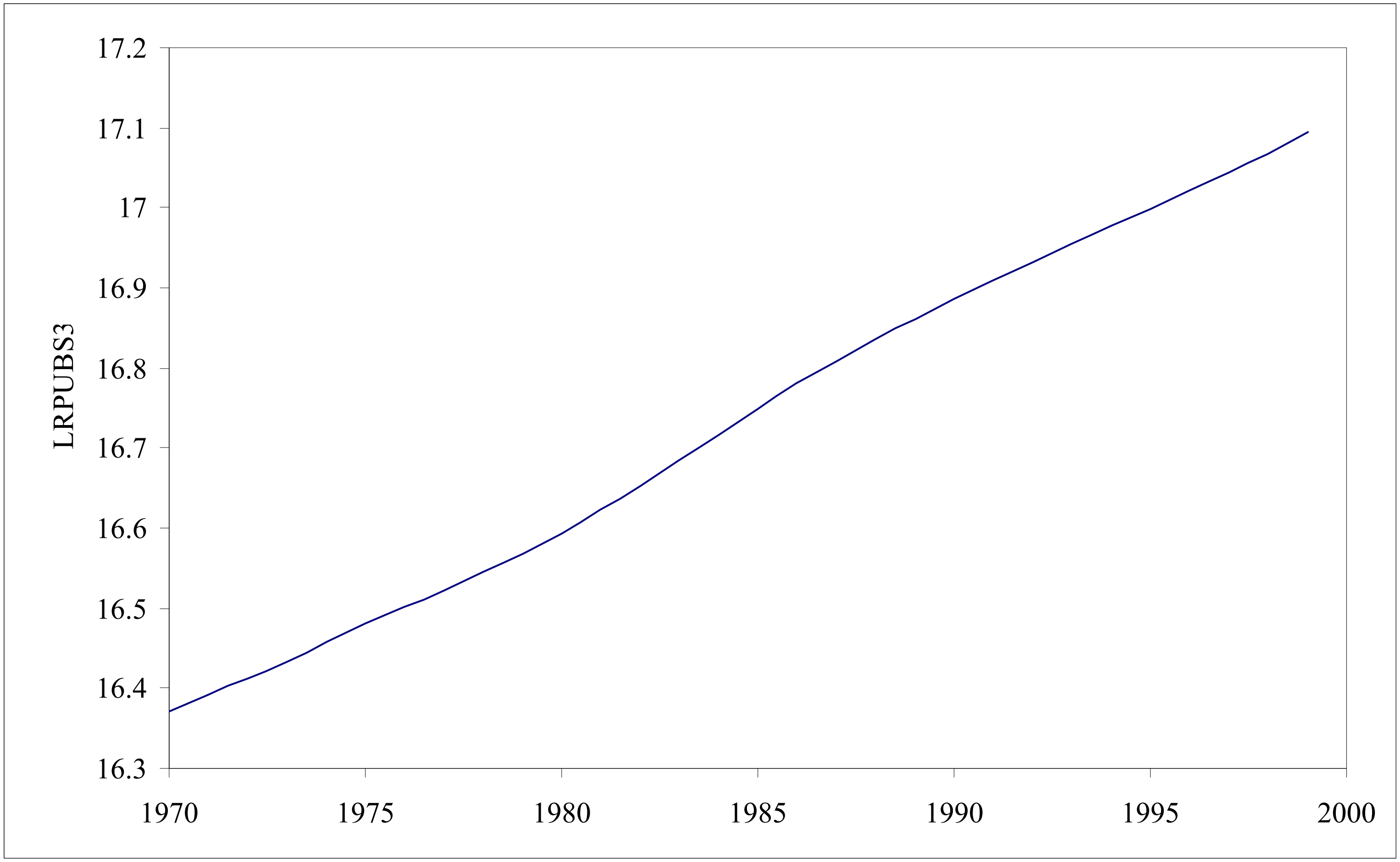

Figure 22. Public Agricultural Research Capital, 1970-1999: Missouri

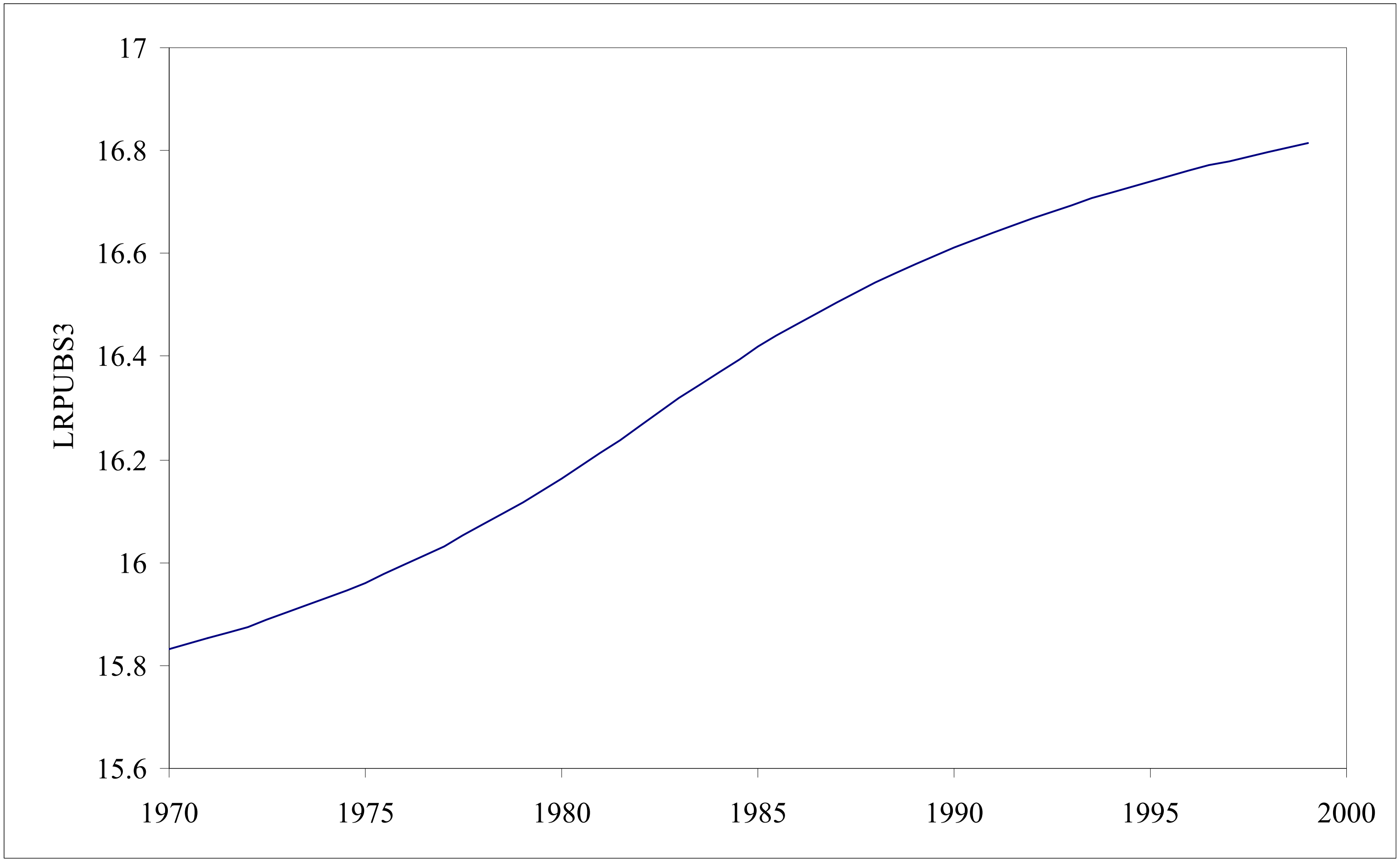

Figure 23. Public Agricultural Research Capital, 1970-1999: Mississippi

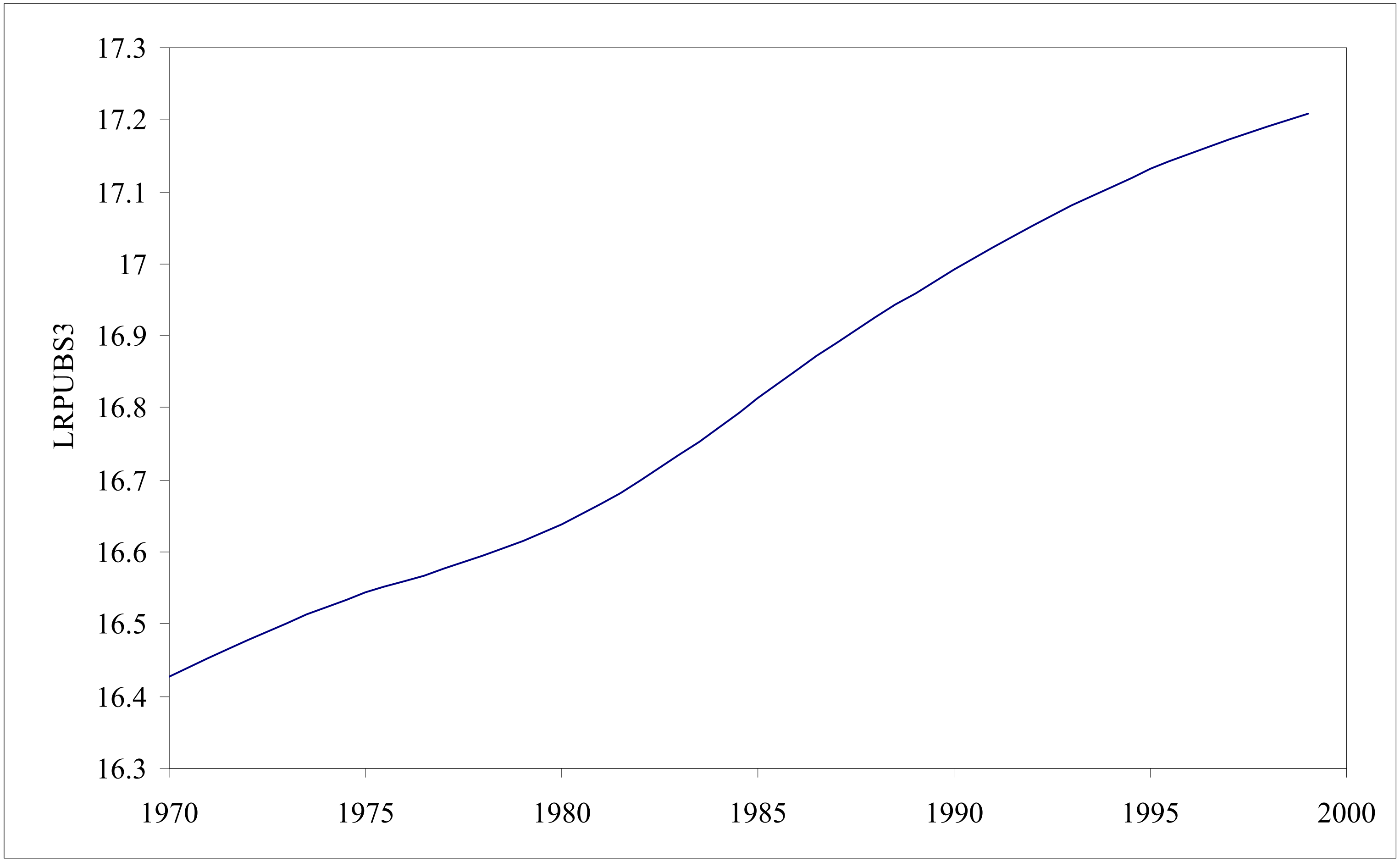

Figure 24. Public Agricultural Research Capital, 1970-1999: Montana

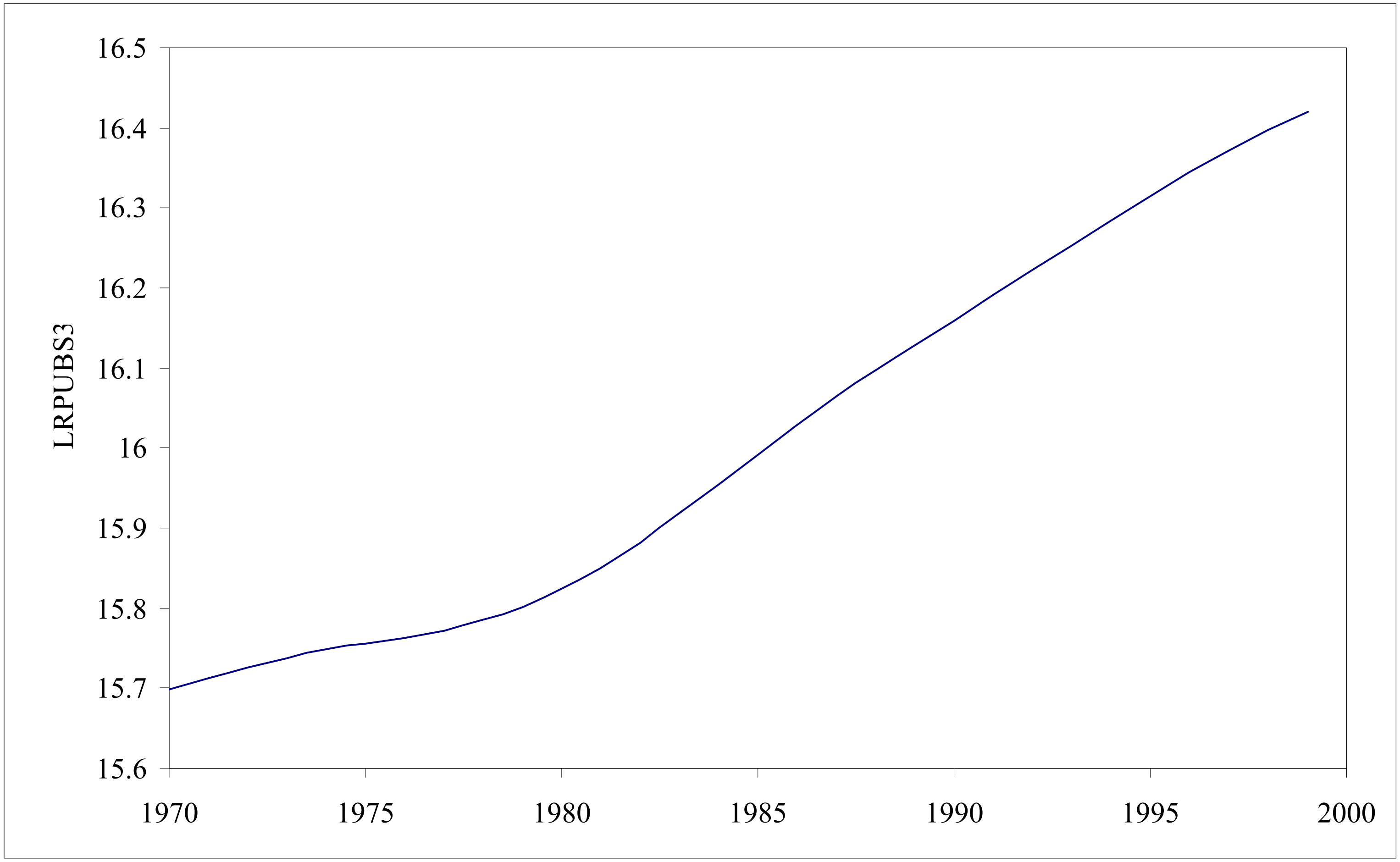

Figure 25. Public Agricultural Research Capital, 1970-1999: North Carolina

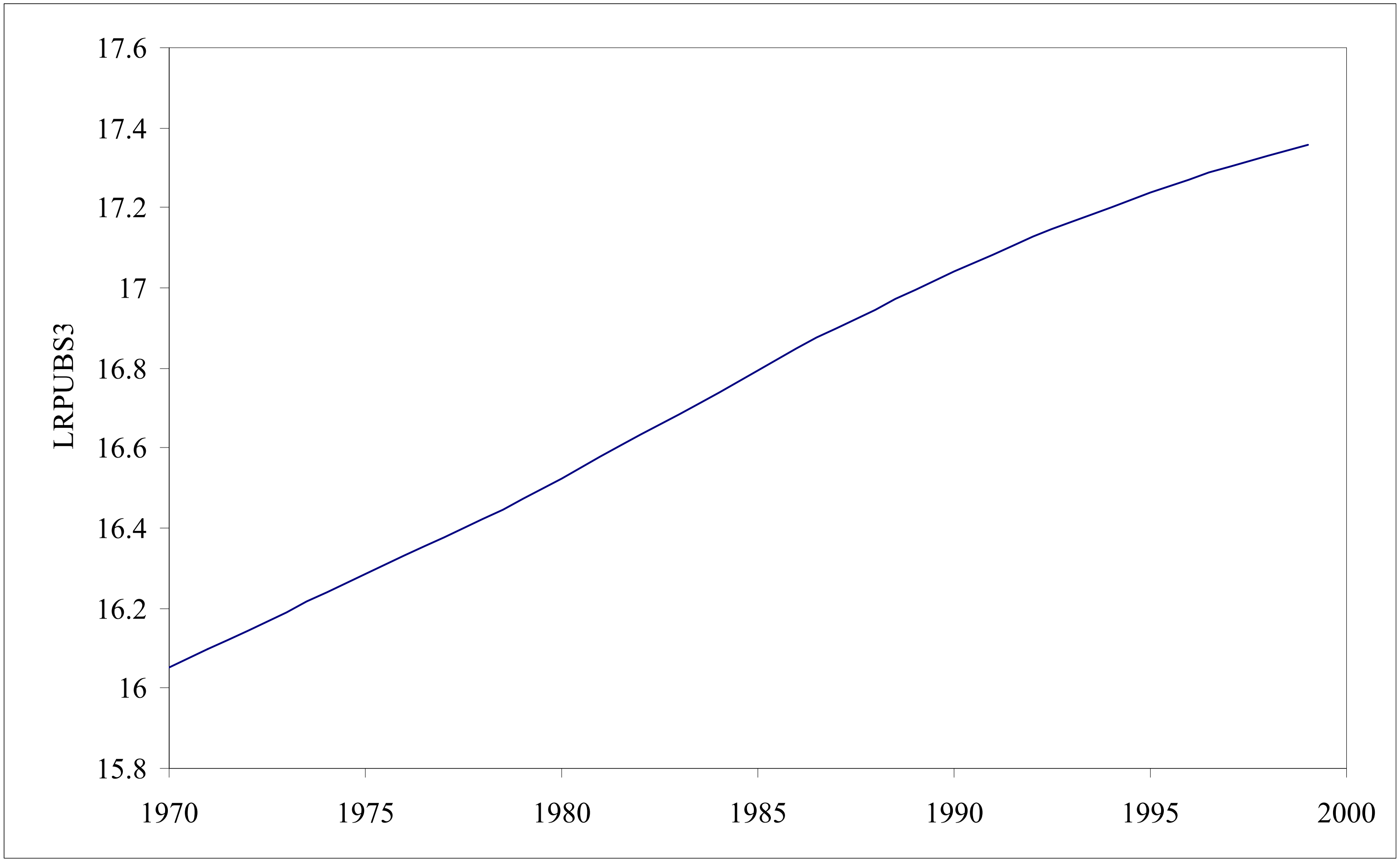

Figure 26. Public Agricultural Research Capital, 1970-1999: North Dakota

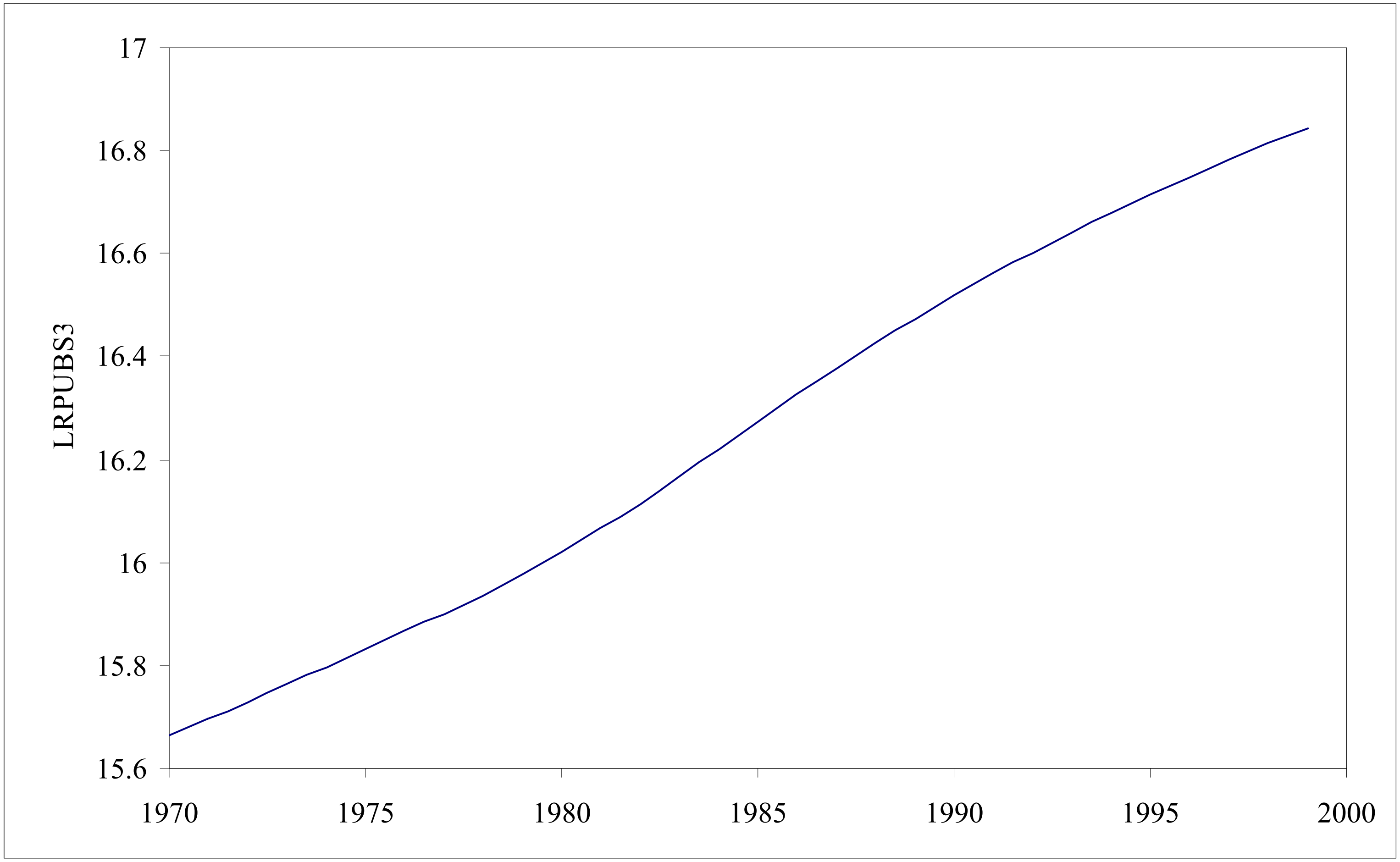

Figure 27. Public Agricultural Research Capital, 1970-1999: Nebraska

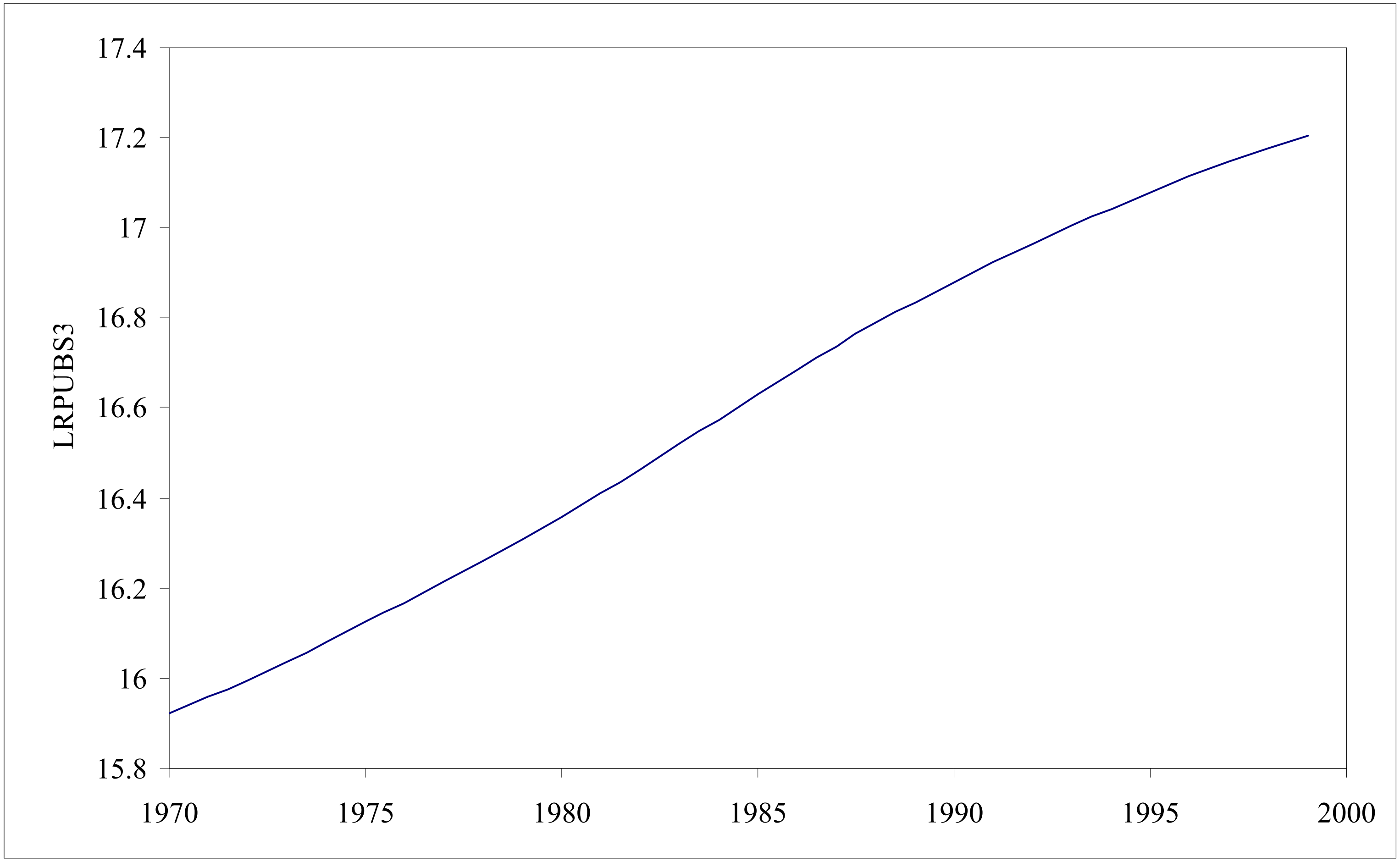

Figure 28. Public Agricultural Research Capital, 1970-1999: New Hampshire

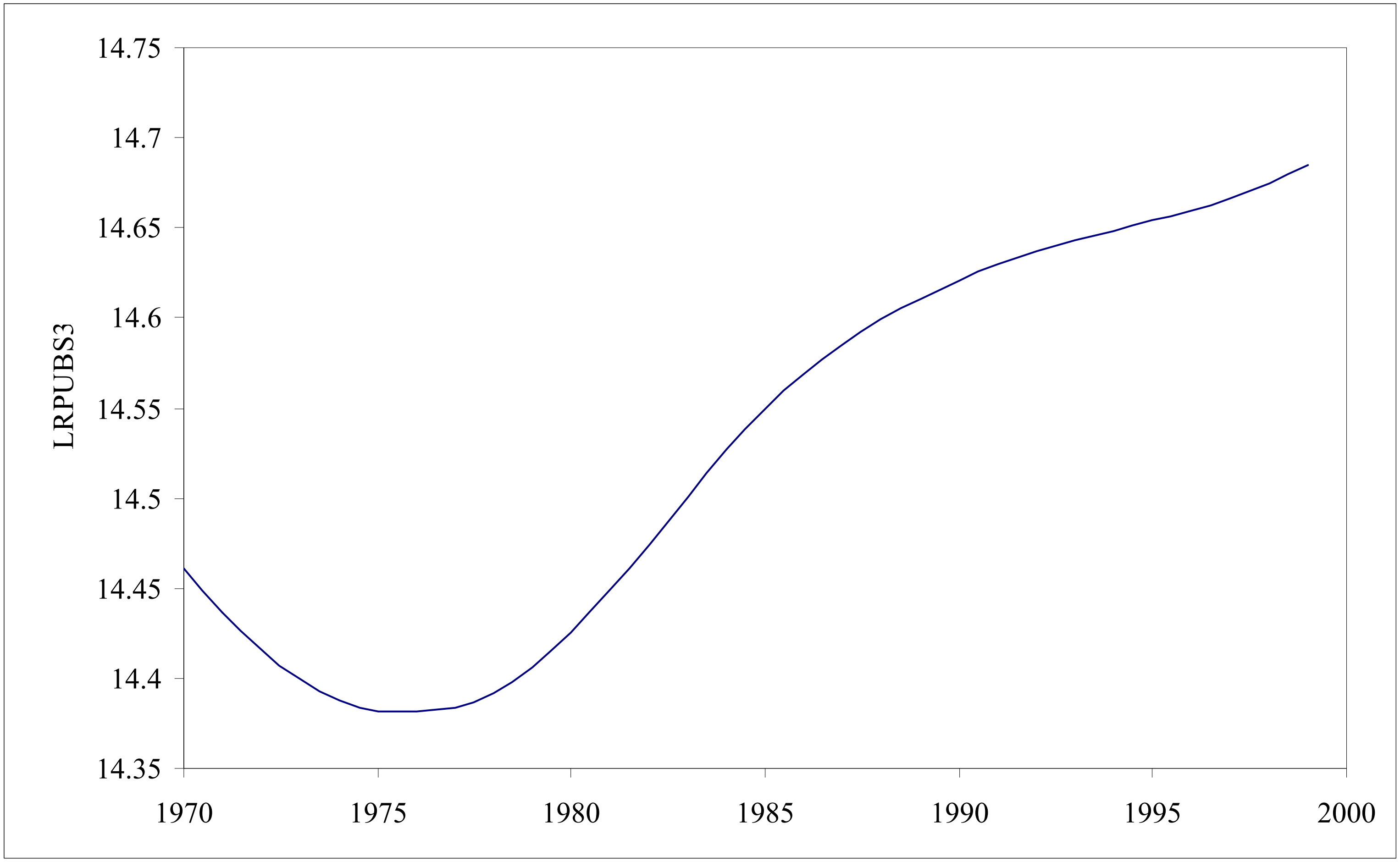

Figure 29. Public Agricultural Research Capital, 1970-1999: New Jersey

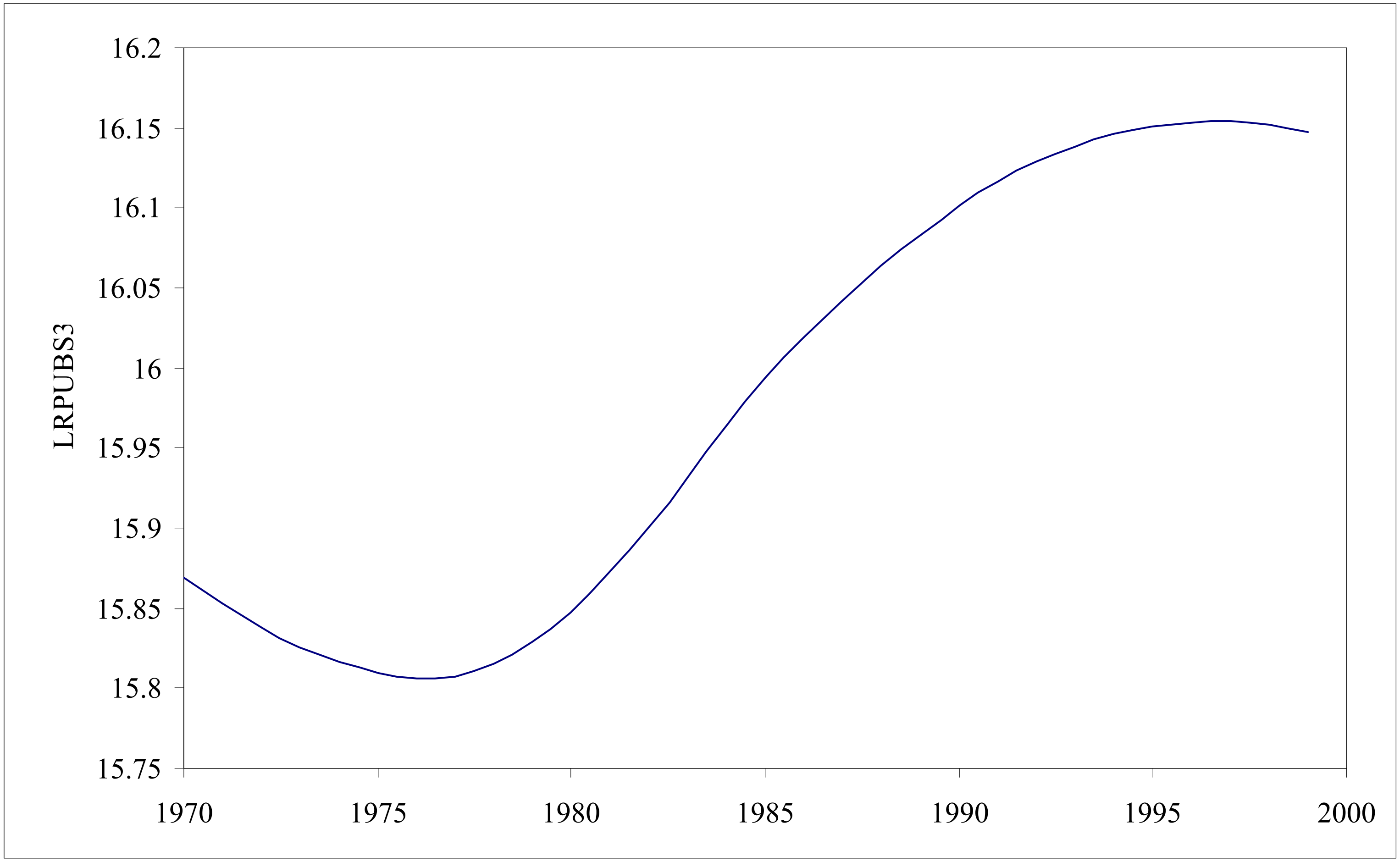

Figure 30. Public Agricultural Research Capital, 1970-1999: New Mexico

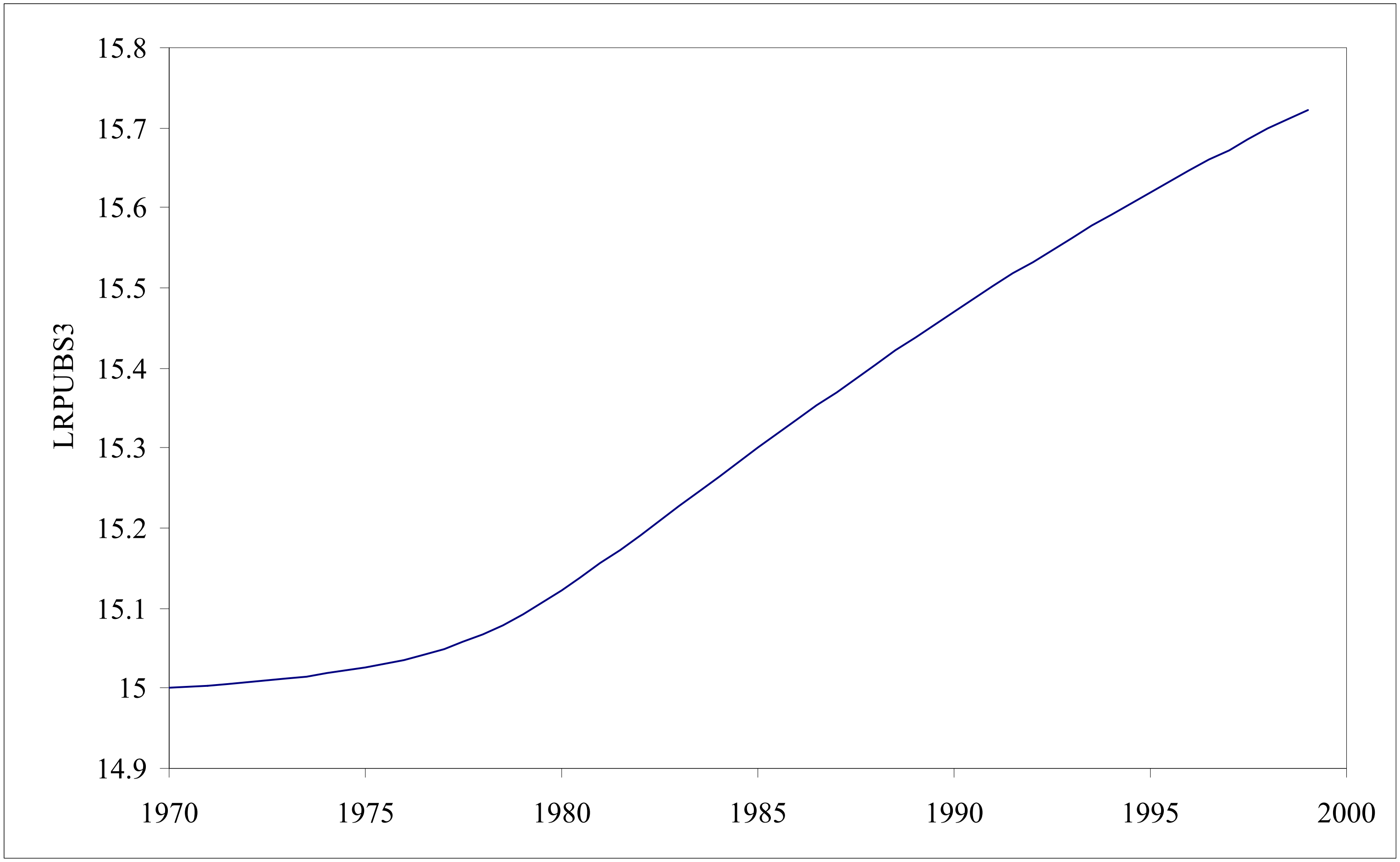

Figure 31. Public Agricultural Research Capital, 1970-1999: Nevada

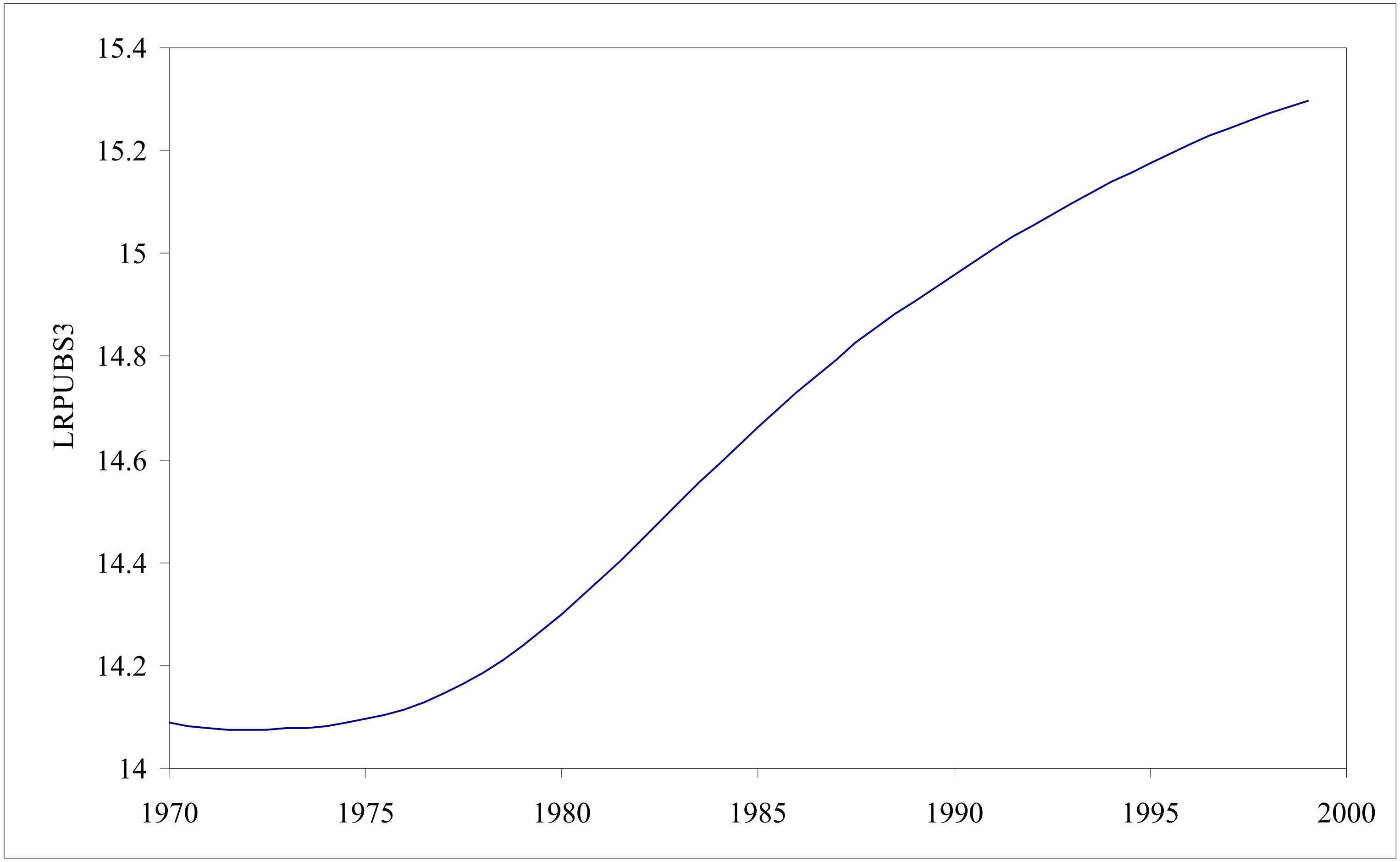

Figure 32. Public Agricultural Research Capital, 1970-1999: New York

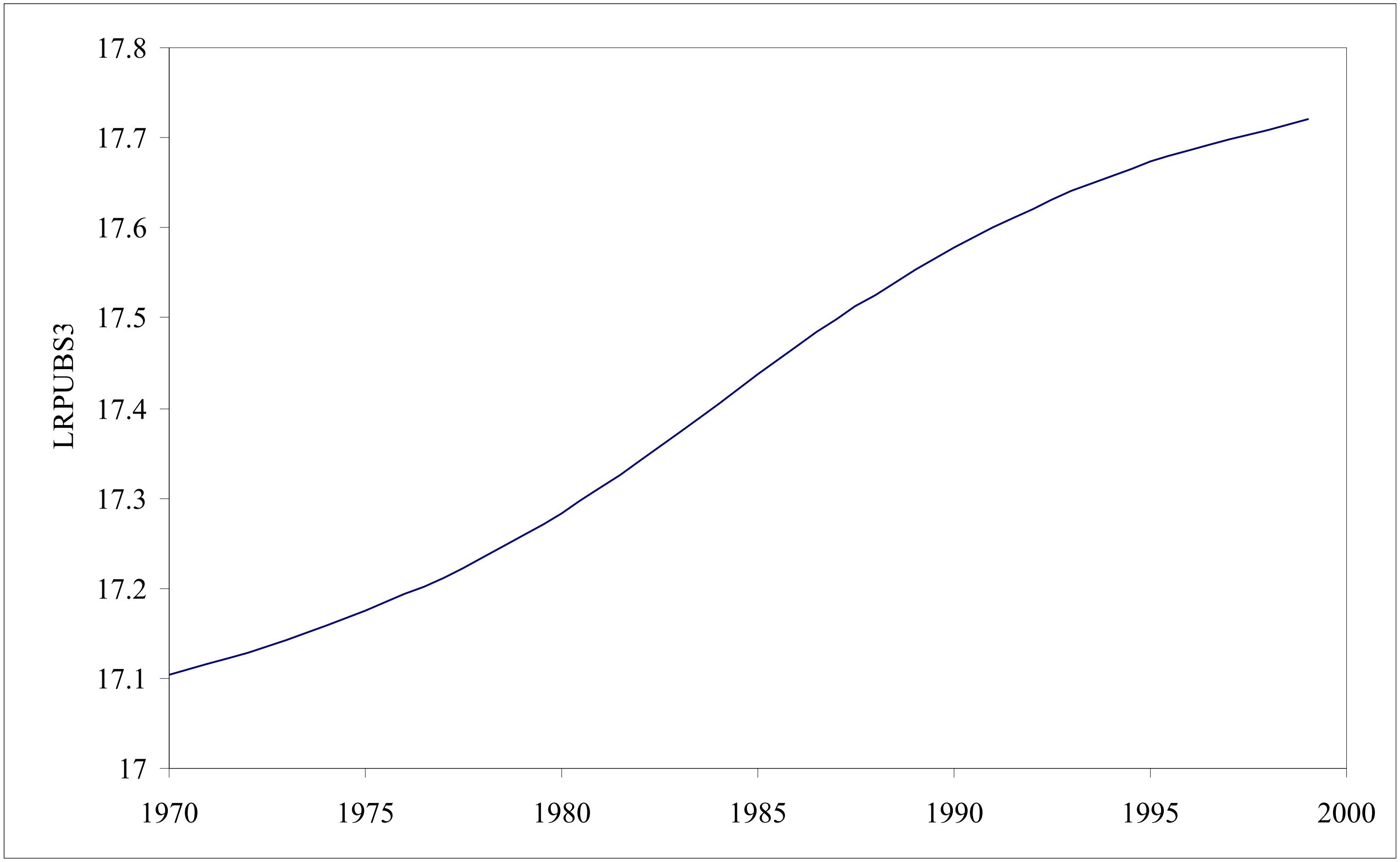

Figure 33. Public Agricultural Research Capital, 1970-1999: Ohio

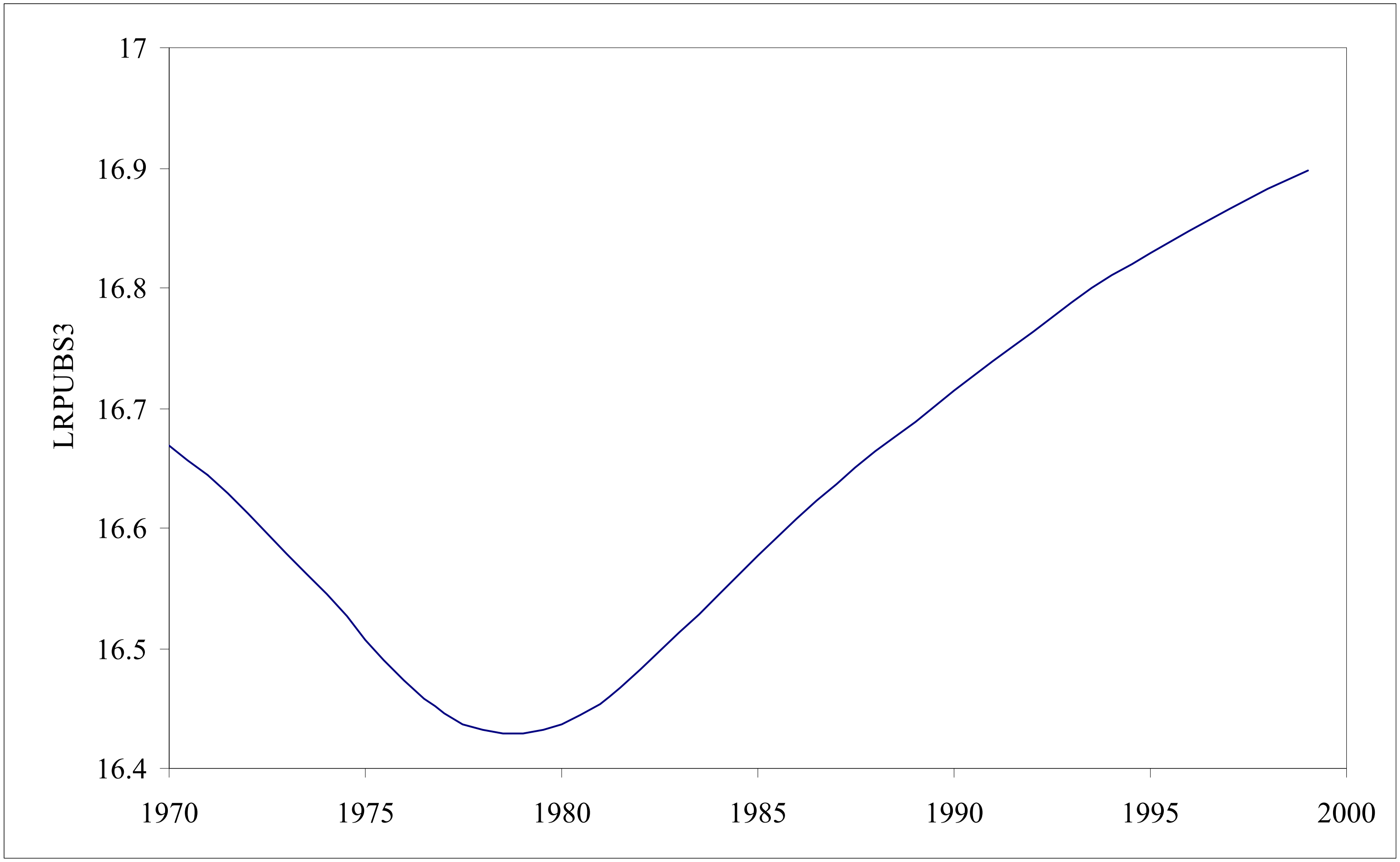

Figure 34. Public Agricultural Research Capital, 1970-1999: Oklahoma

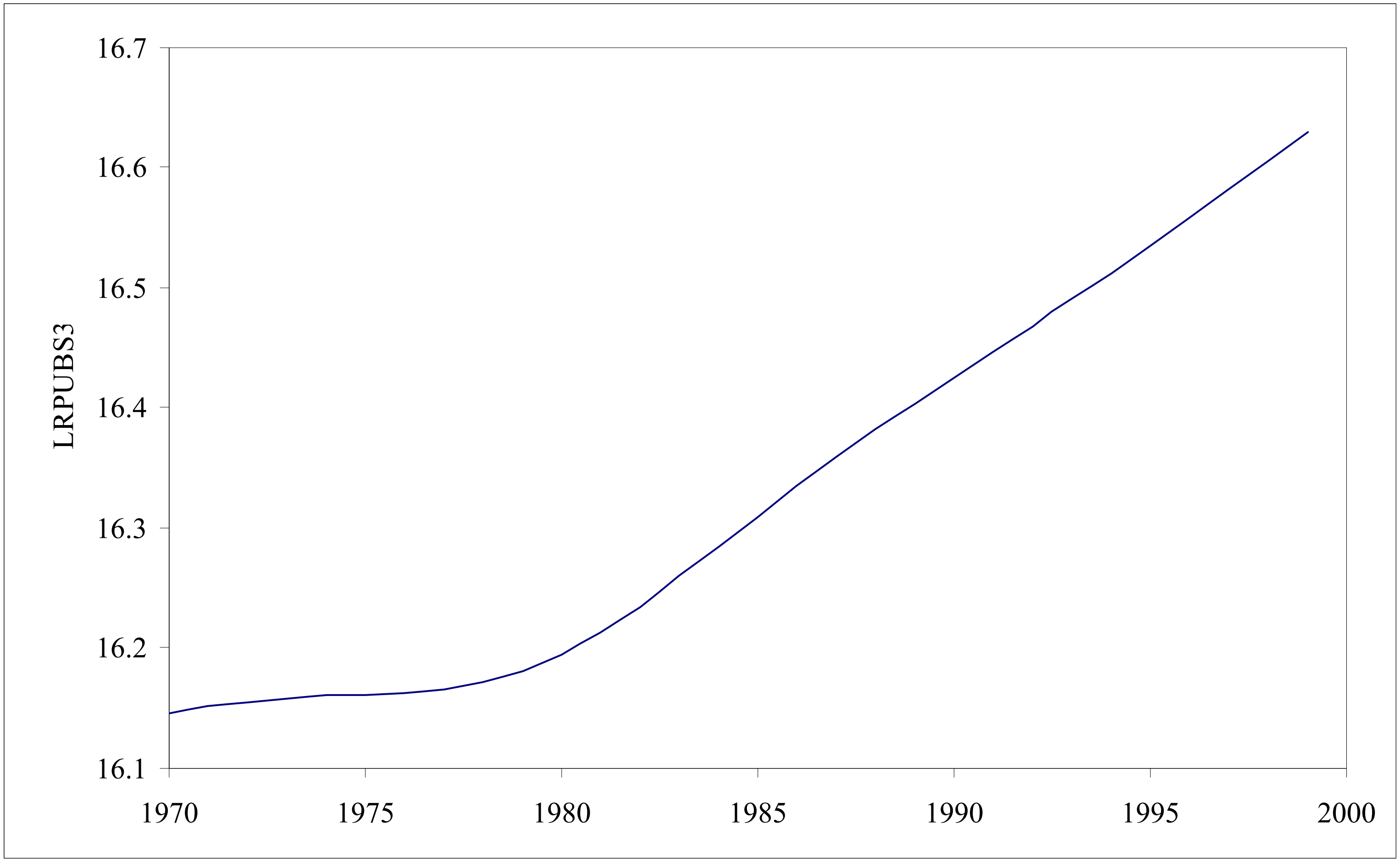

Figure 35. Public Agricultural Research Capital, 1970-1999: Oregon

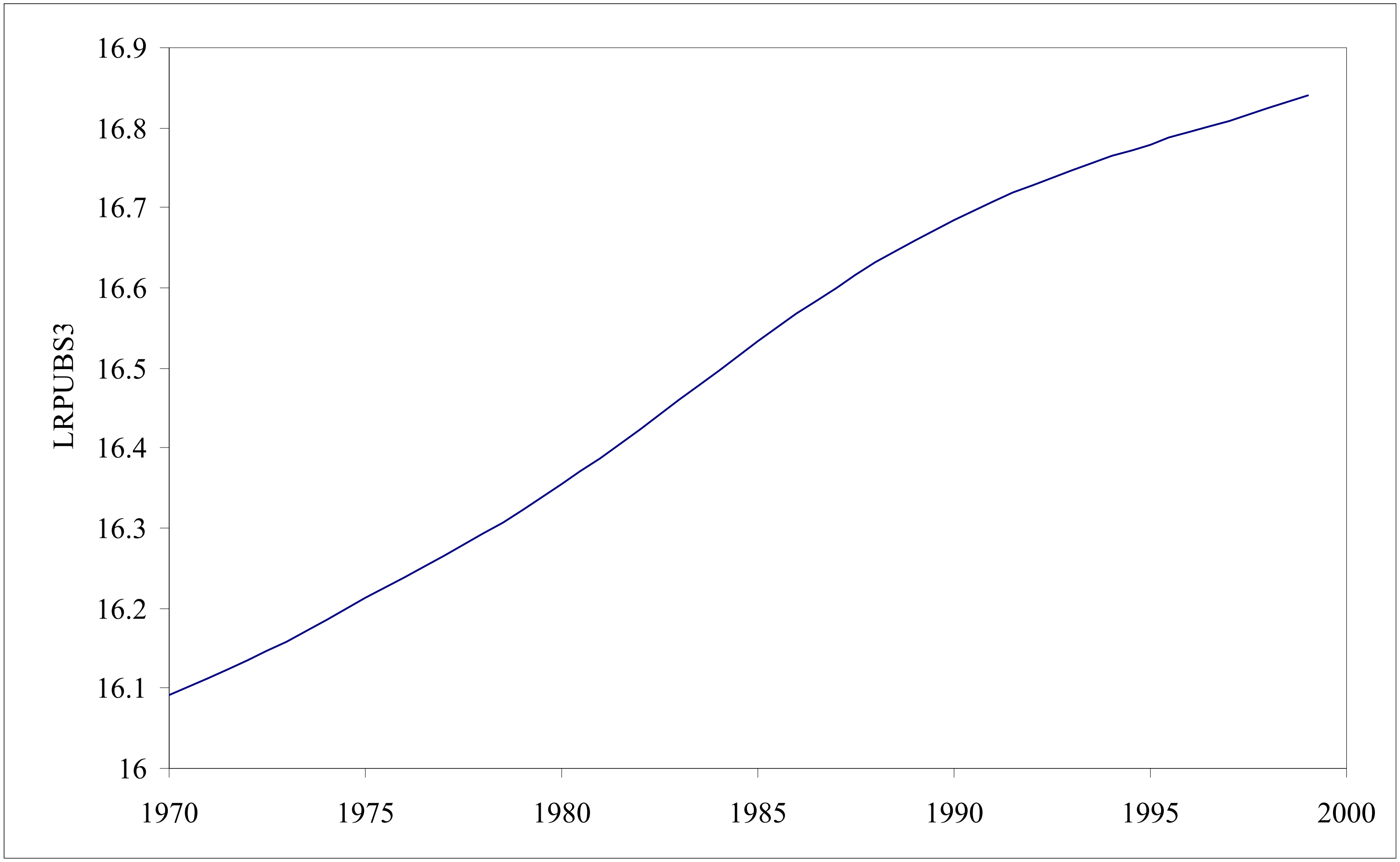

Figure 36. Public Agricultural Research Capital, 1970-1999: Pennsylvania

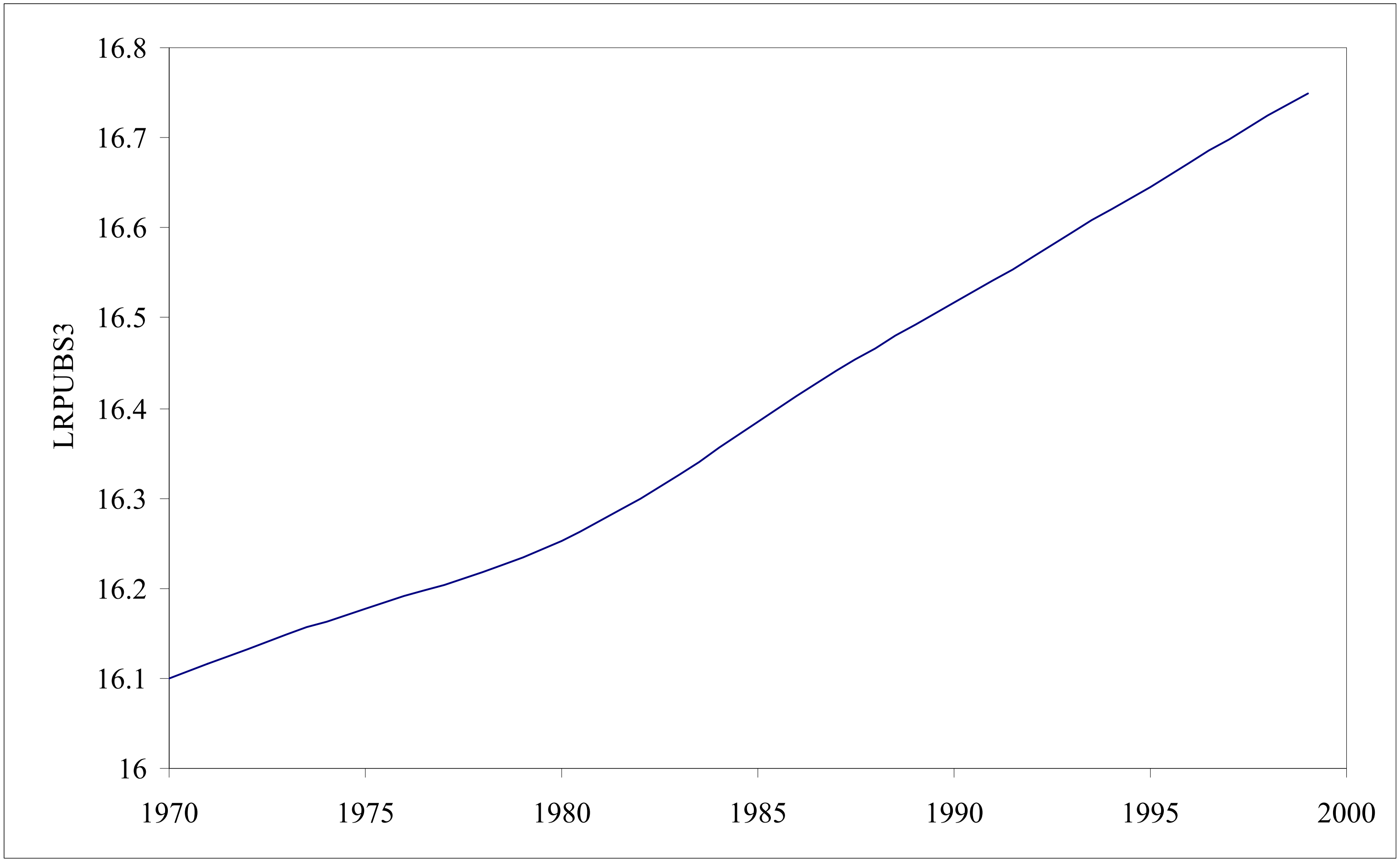

Figure 37. Public Agricultural Research Capital, 1970-1999: Rhode Island

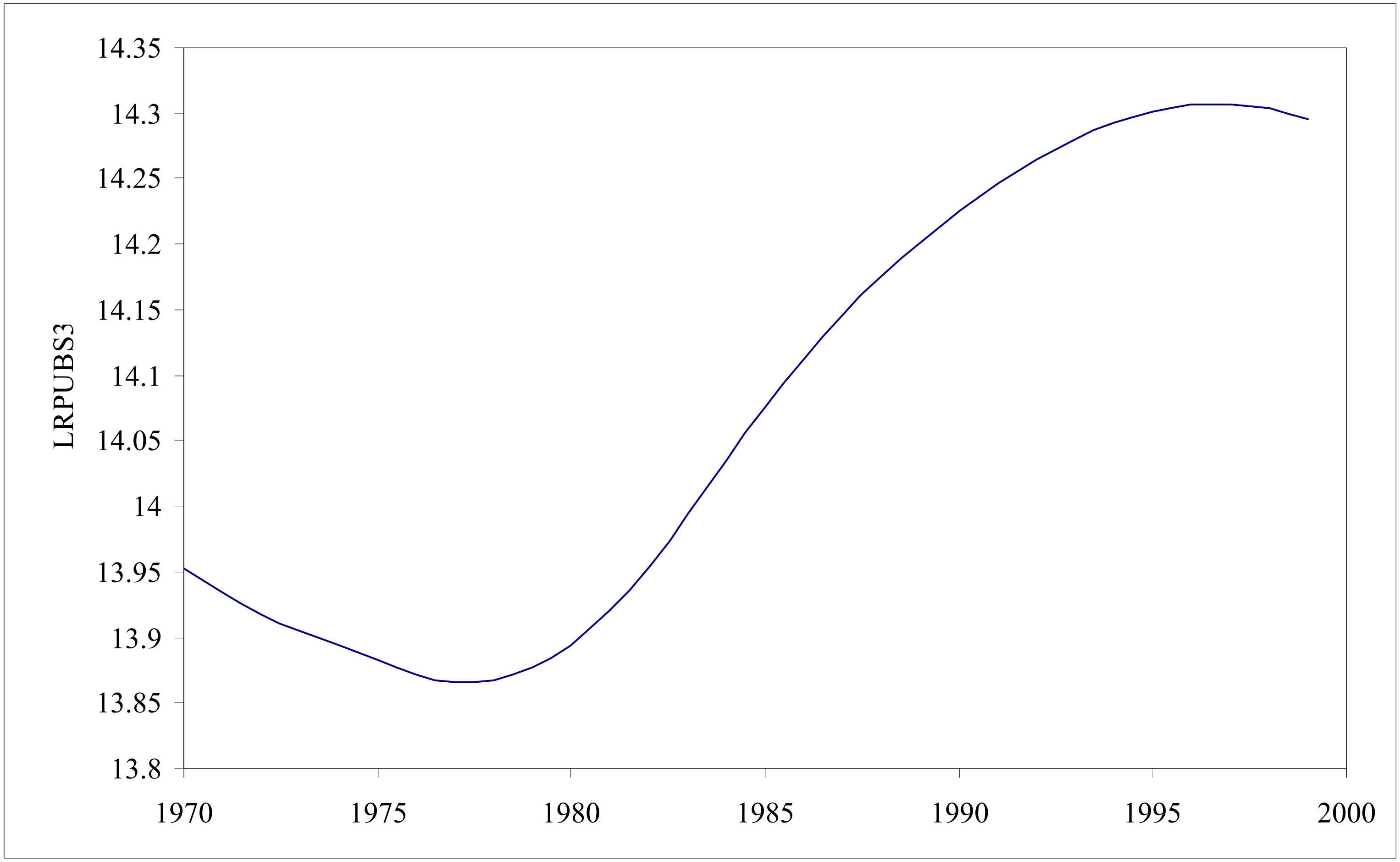

Figure 38. Public Agricultural Research Capital, 1970-1999: South Carolina

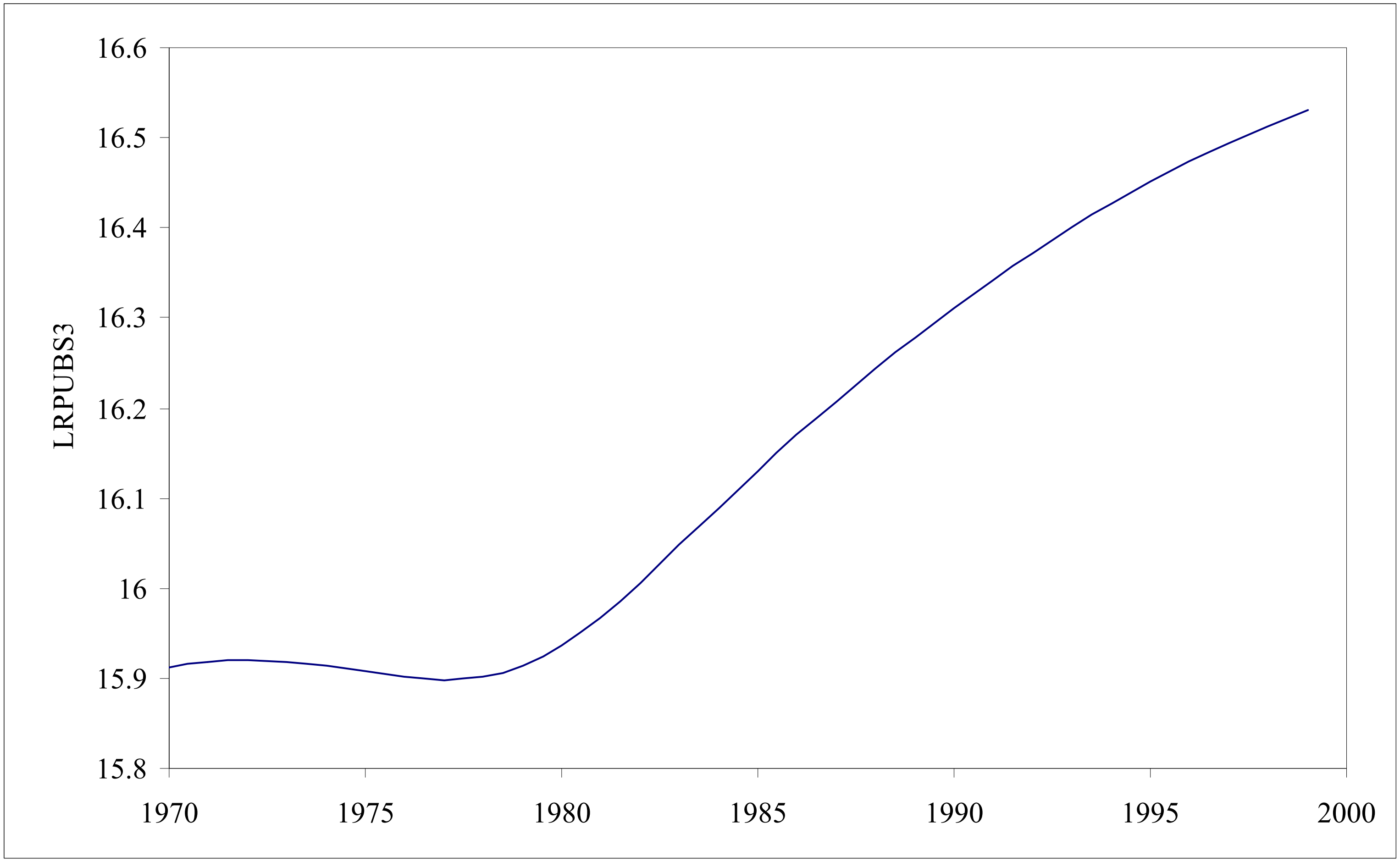

Figure 39. Public Agricultural Research Capital, 1970-1999: South Dakota

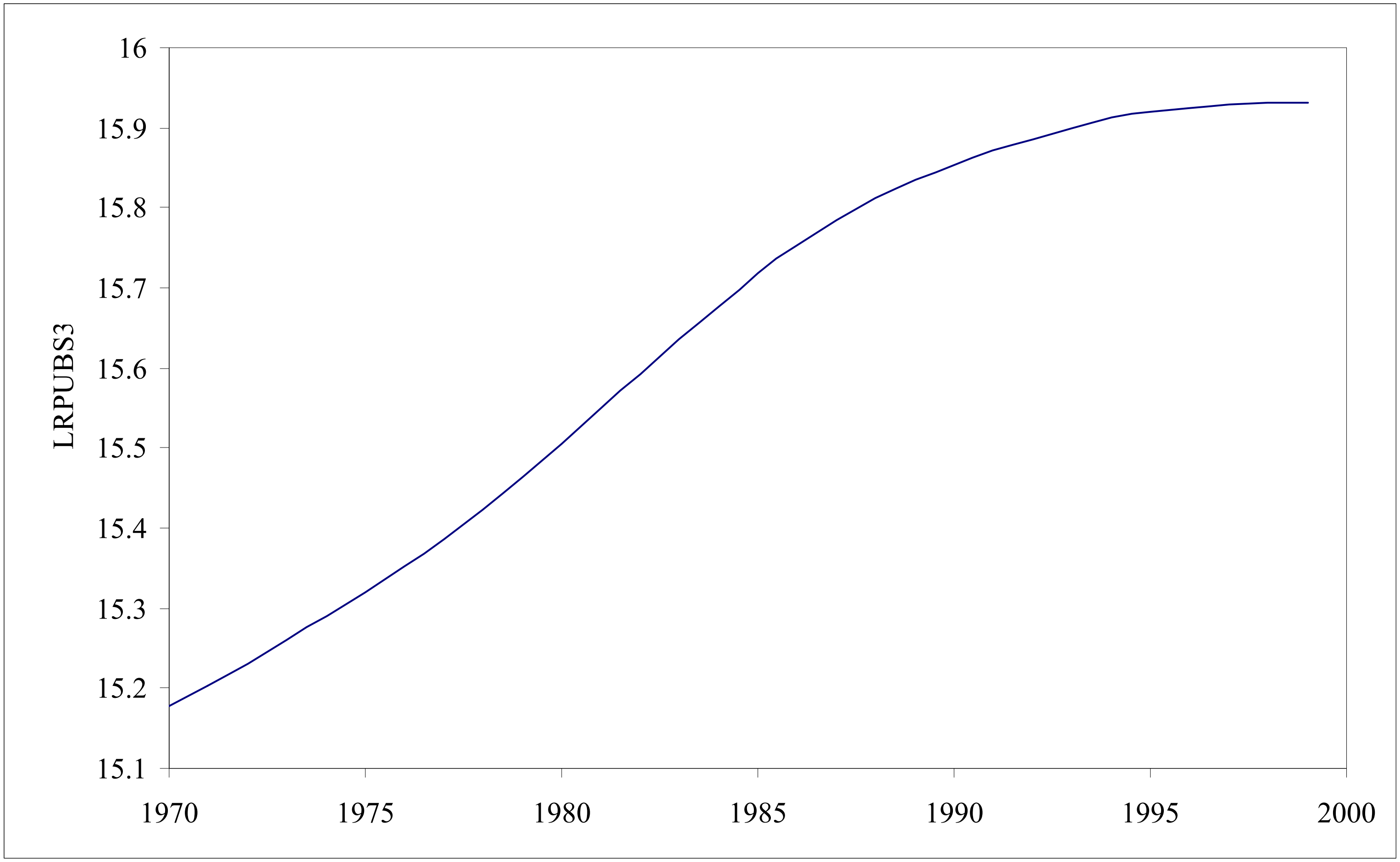

Figure 40. Public Agricultural Research Capital, 1970-1999: Tennessee

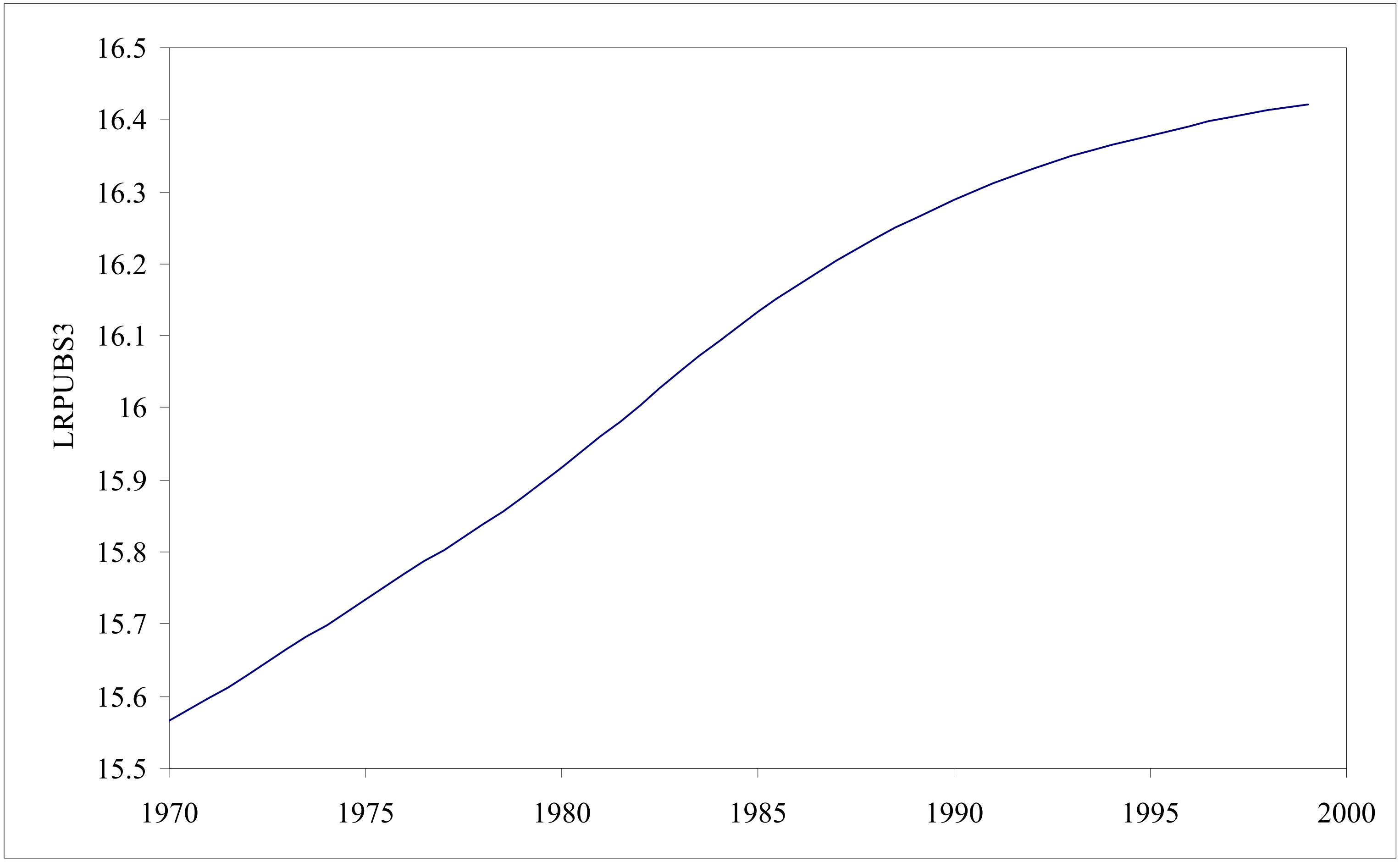

Figure 41. Public Agricultural Research Capital, 1970-1999: Texas

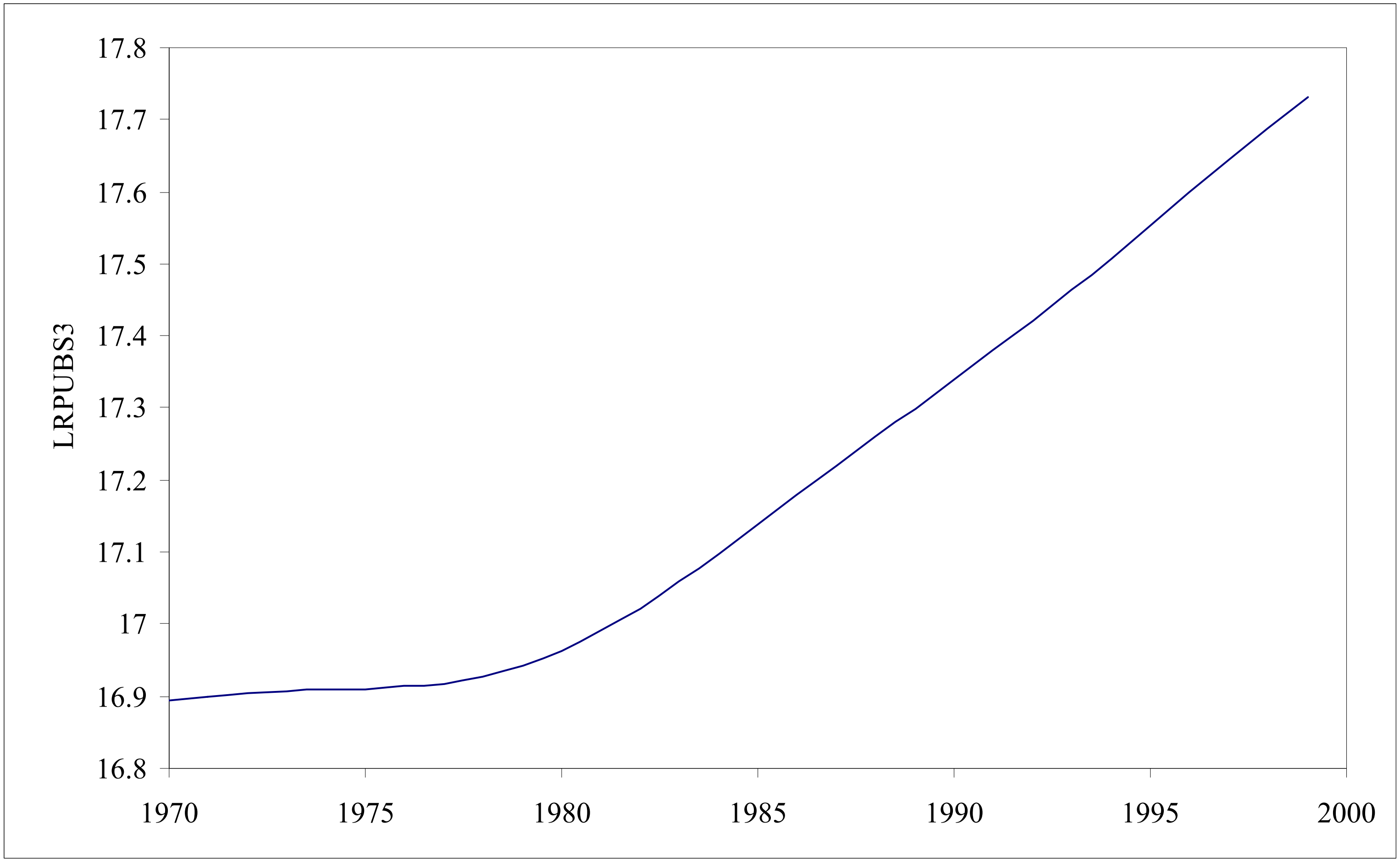

Figure 42. Public Agricultural Research Capital, 1970-1999: Utah

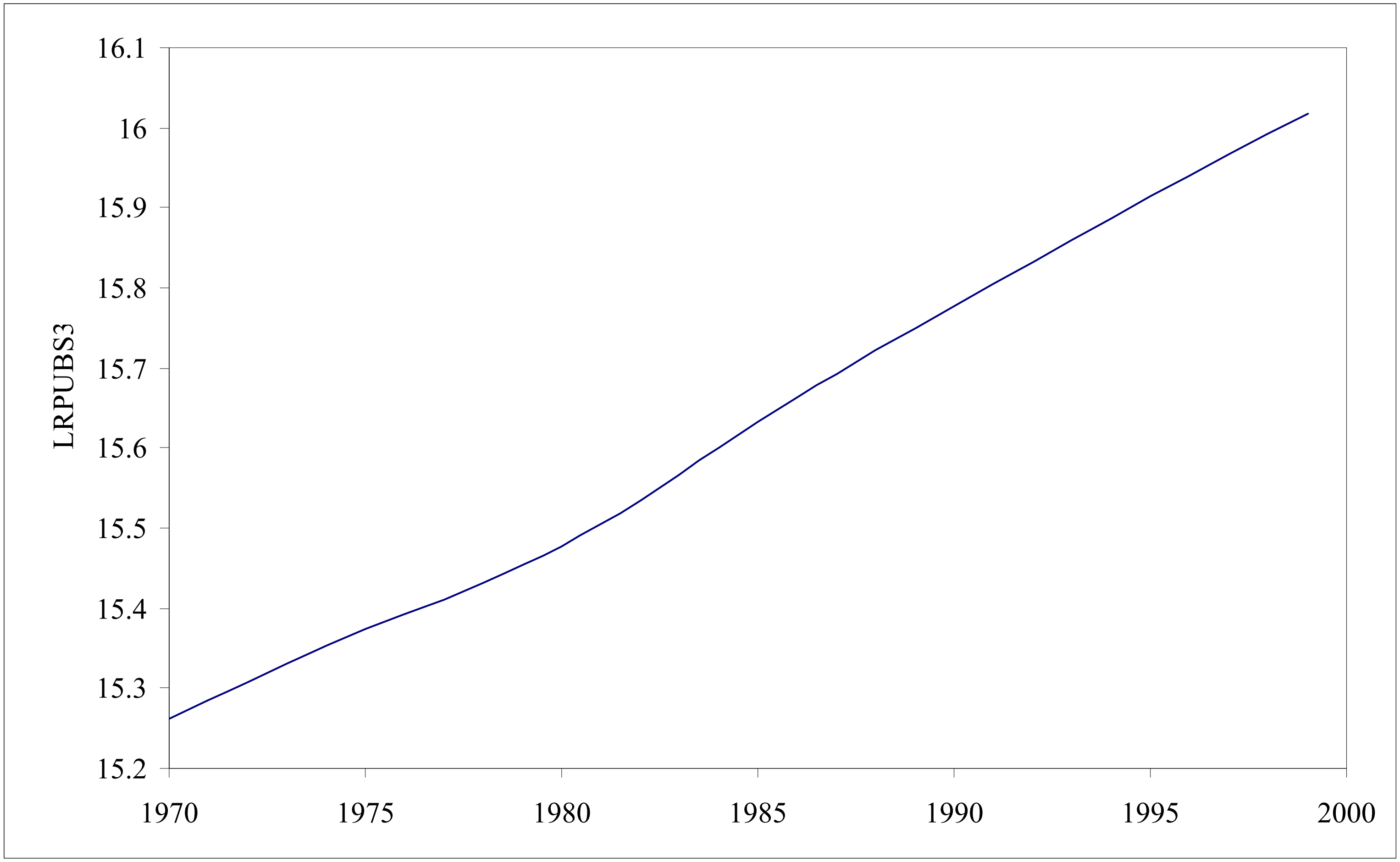

Figure 43. Public Agricultural Research Capital, 1970-1999: Virginia

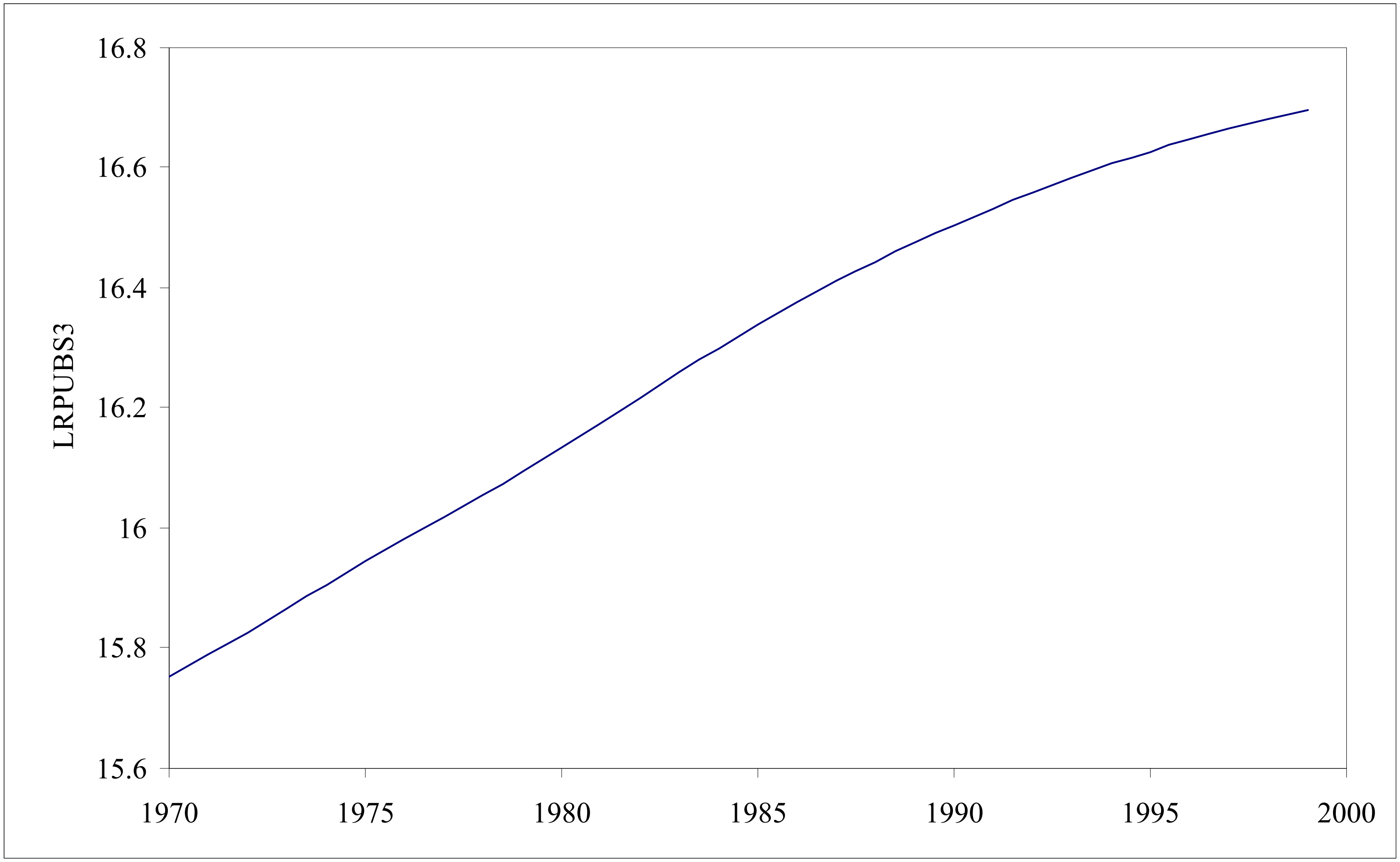

Figure 44. Public Agricultural Research Capital, 1970-1999: Vermont

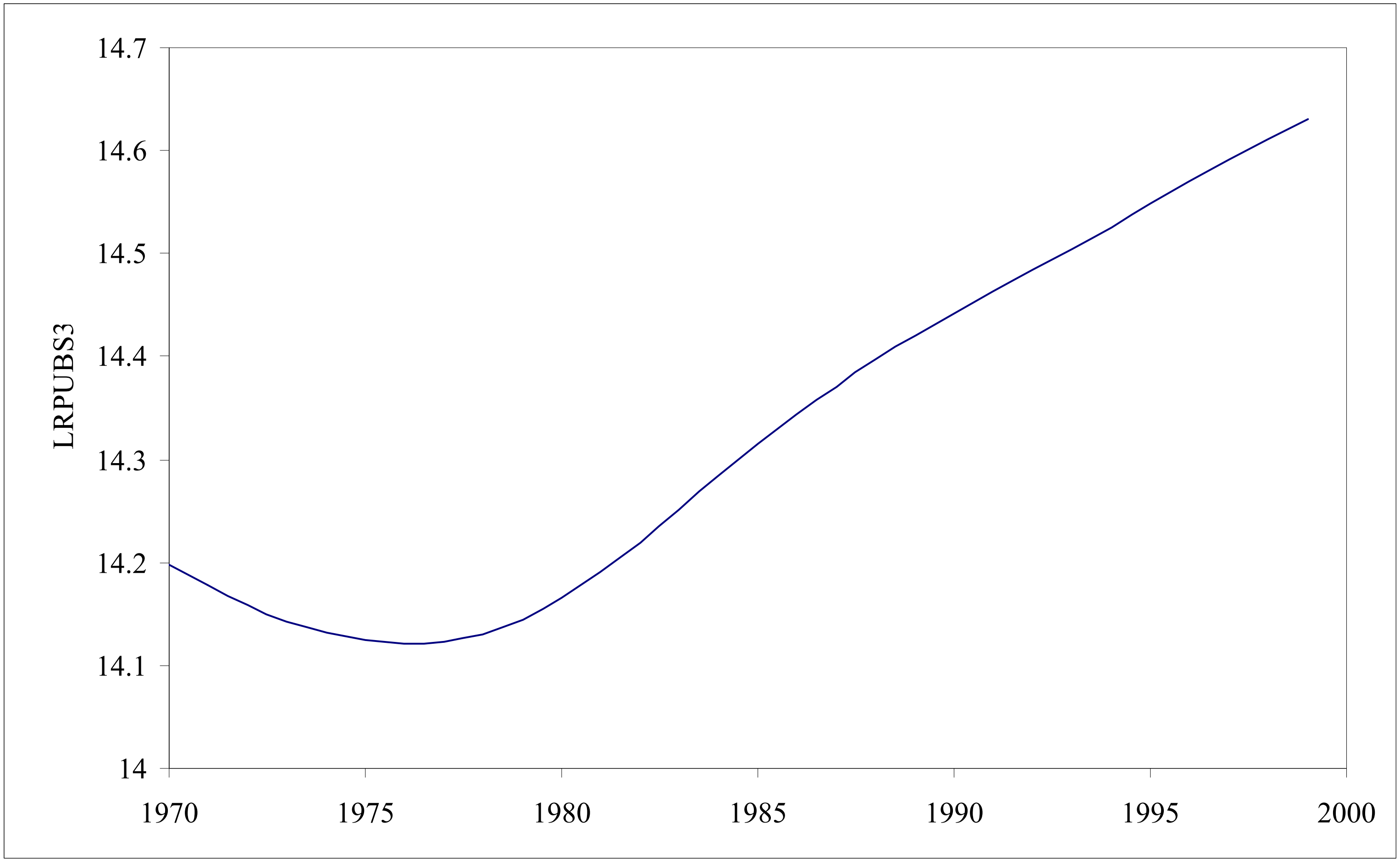

Figure 45. Public Agricultural Research Capital, 1970-1999: Washington

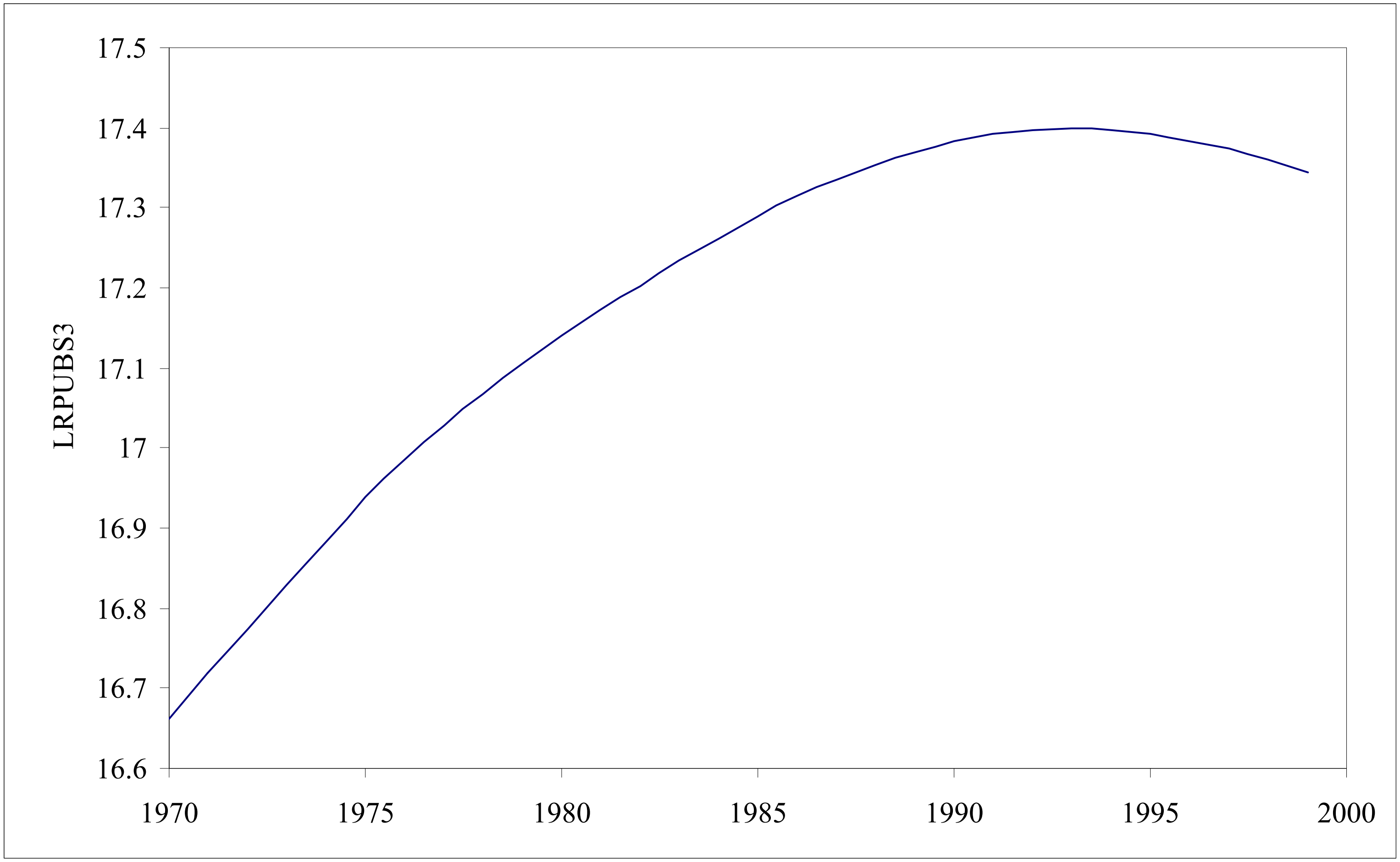

Figure 46. Public Agricultural Research Capital, 1970-1999: Wisconsin

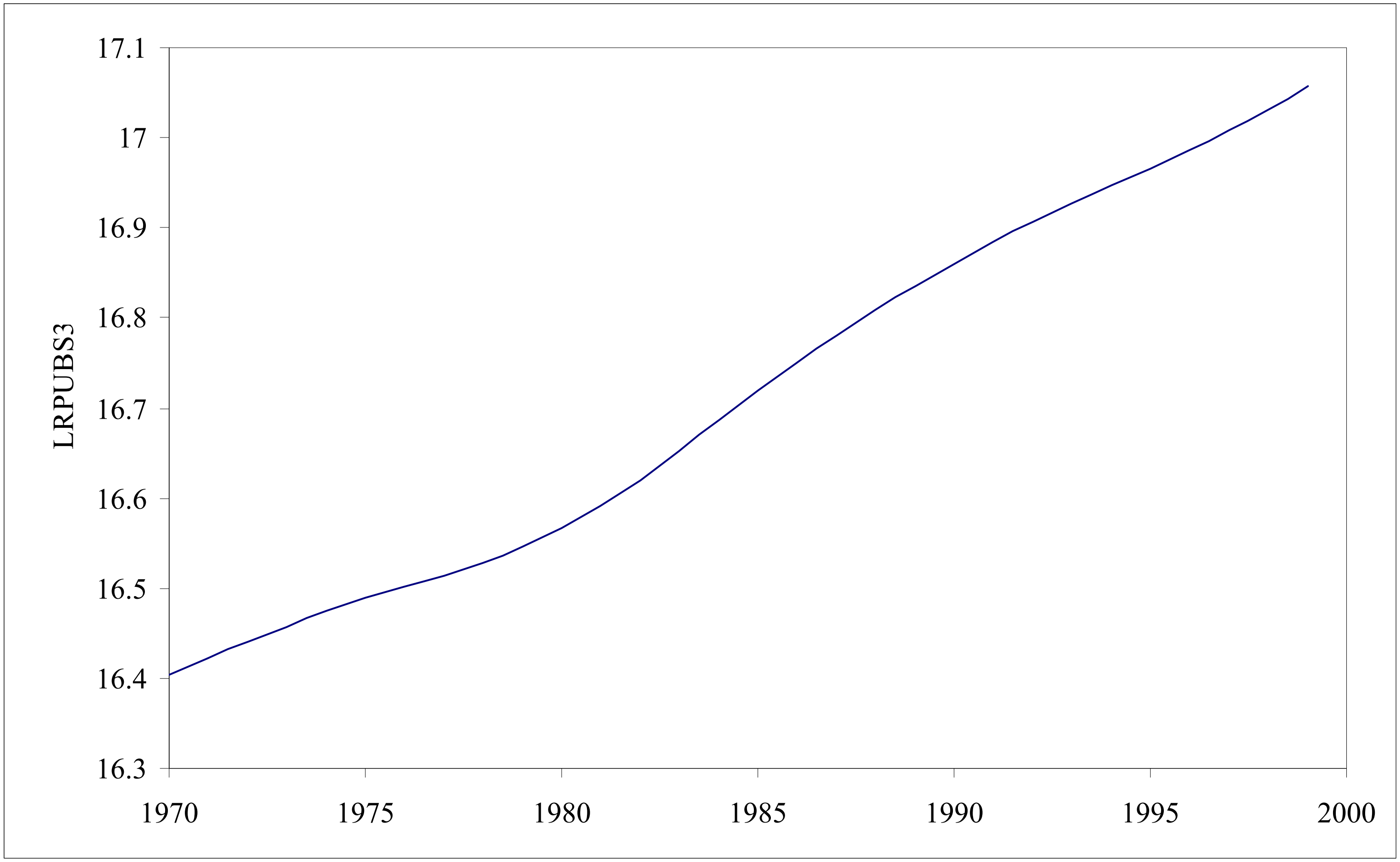

Figure 47. Public Agricultural Research Capital, 1970-1999: West Virginia

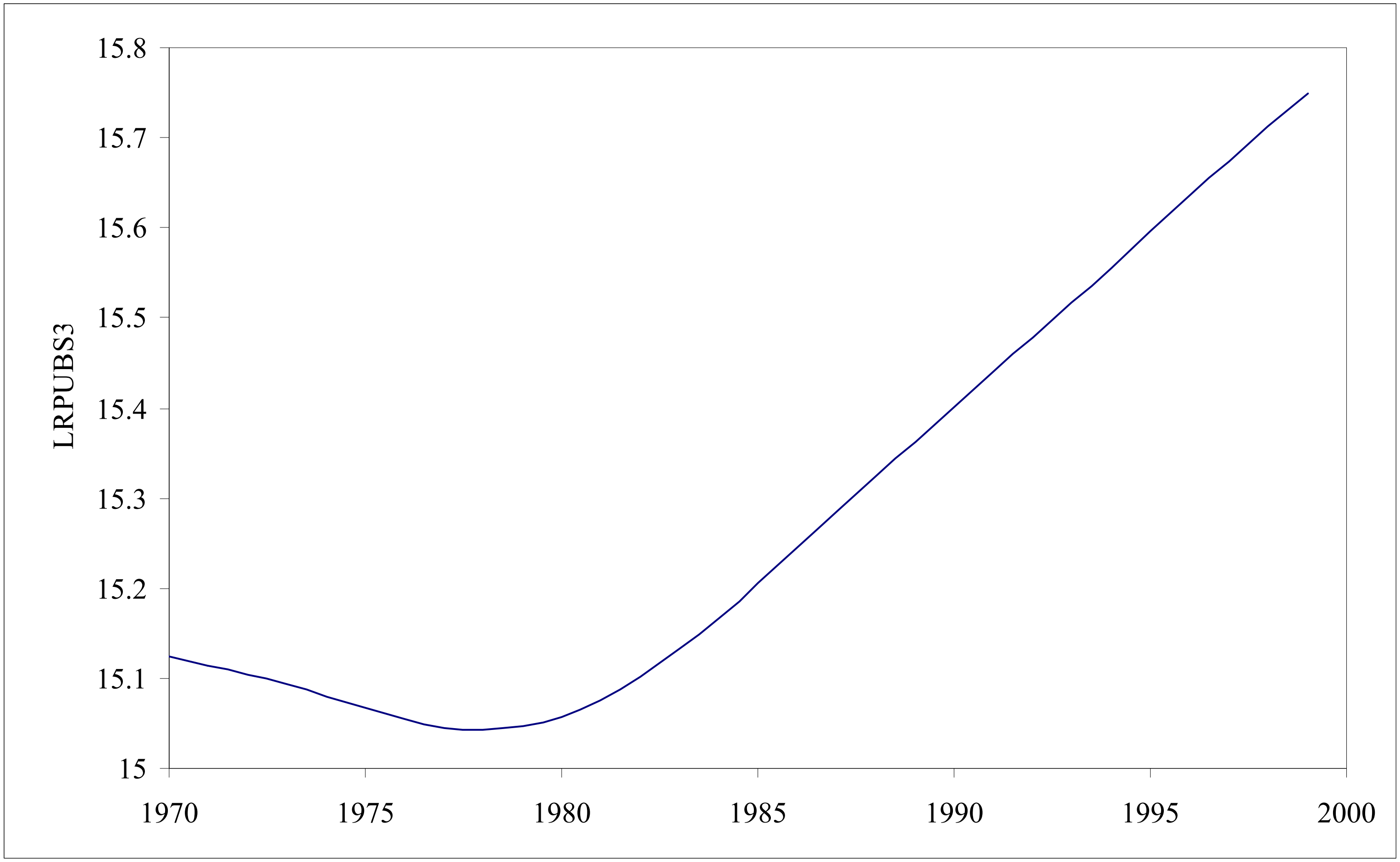

Figure 48. Public Agricultural Research Capital, 1970-1999: Wyoming