



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Benefits of Public R&D in U.S. Agriculture: Spill-Ins, Extension, and Roads¹

Sun Ling Wang², Eldon Ball

Economic Research Service, U.S. Department of Agriculture, Washington, DC

Lilyan E. Fulginiti

University of Nebraska at Lincoln

Alejandro Plastina

International Cotton Advisory Committee, Washington, DC

Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

Copyright 2012 by Sun Ling Wang, Eldon Ball, Lilyan Fulginiti, and Alejandro Plastina.

All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

¹ The views expressed herein are those of the authors, and not necessarily those of the U.S. Department of Agriculture.

² Contact author: slwang@ers.usda.gov

Benefits of Public R&D in U.S. Agriculture: Spill-Ins, Extension, and Roads

Abstract

This paper uses panel data for the 1980-2004 period to estimate the contributions of public research to U.S. agricultural productivity growth. Local and social internal rates of return are estimated accounting for the effects of R&D spill-in, extension activities and road density. R&D spill-in proxies were constructed based on both geographic proximity and production profile to examine the sensitivity of the rates of return to these alternatives. We find that extension activities, road density, and R&D spill-ins, play an important role in enhancing the benefit of public R&D investments. We also find that the local internal rates of return, although high, have declined through time along with investments in extension, while the social rates have not. Yet, the social rates of return are not robust to the choice of spill-in proxy.

Key words: productivity, public R&D, R&D spill-ins, extension, road density, internal rate of return, cost function.

JEL code: Q16, O3, O4

Since the pioneering work by Griliches (1958, 1964) and Evenson (1967), several empirical studies have shown that public investment in agricultural research and development (R&D) is a primary driver of productivity growth. Regardless of the methodology used, analysts are in agreement that returns to investments in agricultural research are high, though the rates of return may differ depending on the particular research program or the data used to estimate returns. In a survey of the literature, Alston et al. (2000) found that the median of the estimated rate of return to agricultural research was 48 percent per year. Huffman and Evenson (2006) reviewed studies of the U.S. agricultural sector covering the 1965-2005 period and found that, on average, the social rate of return was more than 50 percent per annum. Fuglie and Heisey (2007) reviewed

studies on Federal-State investment in agricultural research. They reported that the rates of return are in range of 20 to 60 percent for most studies.

Previous studies on the contribution of R&D to productivity growth can be grouped into four main categories. First, there are international studies (Coe and Helpman, 1995; Johnson and Evenson, 1999, Funk, 2001) versus single-country studies (Griliches, 1964, Esposti, 2002, Mullen, 2007); second, there are studies that construct knowledge stocks using patent data (Schimmelpfennig and Thirtle, 1999; Jaffe, 1986; Johnson and Evenson, 1999) versus data on R&D expenditures (Alston et al., 2010, Plastina and Fulginiti, 2011); third, there are those studies that focus on individual commodities or commodity programs (Griliches, 1958; McKinsey and Evenson, 2003, Pardey et al., 2006; Fulginiti, 2010) versus aggregate output (Nin Pratt et al., 2008, Plastina and Fulginiti, 2011); and fourth, there are studies that directly incorporate an R&D stock variable in the estimation of a production or cost function (Esposti and Pierani, 2003; Onofri and Fulginiti, 2008) versus those that use a two-step procedure regressing an index of productivity growth on R&D stocks (Yee et. al, 2002, Alston et. al , 2010).

Methodological differences aside, many of these studies point to significant technology spillovers across geographic boundaries. While the contribution to productivity growth of R&D spill-ins from nearby states is widely recognized, it is less clear why productivity growth in some states with similar characteristics and with similar potential R&D spill-ins is faster than in other states. Nor is it clear through which channels technical knowledge is disseminated. Some studies (Birkhauser et al., 1989, Evenson, 2001; Huffman et al, 2002, Yee et al, 2002, Schimmelpfennig et al., 2006,

among others) have emphasized the important role of the Extension Service in promoting productivity growth. Antle (1983) and Paul et al (2001) suggest that road infrastructure can also be an important contributor to productivity growth. Yet most of these studies fail to address the question of how returns to own R&D are affected by research spill-ins, extension activities, and infrastructure. Nor do they consider alternative measures of potential research spill-ins; measures based on geographic proximity have become the norm.

The objectives of this paper are, first, to study the interaction between local (i.e., own) R&D and research spill-ins, extension activities, and road density. Second, we estimate the own as well as social internal rates of return to investment in research in each state. Third, we develop alternative measures of potential research spill-ins using geographic proximity and production profiles for each state and investigate the sensitivity of the estimated rates of return to these alternative measures. Finally, we investigate how changes in extension activities and in road density affect the estimated internal rates of return.

We model technology in agriculture by a dual cost function using a panel of U.S. states. Knowledge stocks, measured as the cumulation of past research expenditures, are treated as a public (i.e., exogenous) capital input. We treat R&D spill-ins, extension, and infrastructure differently from own R&D because we think that while own R&D is fully usable by the state these “efficiency” variables are only partially usable and enter the cost function through interaction terms with local R&D stock.

We find that, although sensitive to the alternative proxies for knowledge spill-ins, the internal rates of return to investment in R&D in U.S. agriculture have been persistently high. Moreover, the rates of return are enhanced through the interaction of own R&D with extension activities, knowledge spill-ins, and road density.

Model

A number of model specifications have been used to assess the contribution of public R&D to U.S. agricultural productivity. Some have first constructed an index of productivity growth and, in a two-step procedure, related this index to R&D investments (Alston et al., 2010; Yee et al., 2002). Still others have estimated the production or dual cost function to obtain simultaneously a measure of productivity growth of the sector and R&D's contribution to that growth (Paul et al., 2001; Huffman et al., 2002; Plastina and Fulginiti, 2011). In this study, we specify a dual cost function and incorporate own R&D stock, as well as its interactions with R&D spill-ins from other states, extension activities, and road density.

While local investment in public agricultural research is viewed as a major driver of technological advancement, investment in research in other states, especially those with similar production characteristics, also contributes to local productivity growth. This effect is generally referred to as a research “spill-in” from other states. We assume that research spill-ins, along with extension activities and road infrastructure, interact with local public research to enhance the diffusion and absorption of technical information. An extensive road network can provide farmers with an easier and less costly way to acquire new technologies by attending workshops or other extension activities. It can also save on

the time it takes the extension staff to contact producers around the state. Given the development of internet technology and broadband investment, extension staff now have more ways to directly strengthen and speed the dissemination and absorption of technical information. Similarly, research spill-ins from nearby states, or from states with similar production profiles could provide a “cluster” effect and generate a multipliable impact with local R&D on productivity growth. In this way, these factors may act as catalysts in stimulating diffusion and utilization of technical information.

We proceed by estimating a translog cost function using state-by-year panel data. We then derive estimates of productivity growth that capture the impact of local R&D investments as well as the magnifying effects of R&D spill-ins, extension activities, and infrastructure. Given its importance, we pay particular attention to construction of the R&D spill-in variable. Finally, we estimate state-level internal rates of return to public agricultural research.

We assume that each state produces three outputs, livestock (V), crops (C) and other farm related goods and services (O), using four variable inputs including land (A), labor (L), materials (M), and capital (K), and one fixed input, own agricultural R&D stock (RD). We include interactions between own R&D and extension activities (ET), road density (RO), and R&D spill-ins (SR), which we term “efficiency variables” (E). These variables have the potential of increasing the marginal productivity of local R&D capital. The translog variable cost function is:

$$(1) \ln TVC = \alpha_0 + \sum_{n=1}^{10} \sum_{i=1}^4 \alpha_{ni} D_n \ln w_i + \sum_{l=1}^3 \beta_l \ln y_l + \gamma_{RD} \ln RD + \frac{1}{2} \gamma_{RDRD} \ln RD \ln RD + \frac{1}{2} \sum_{i=1}^4 \sum_{j=1}^4 \alpha_{ij} \ln w_i \ln w_j +$$

$$\frac{1}{2} \sum_{l=1}^3 \sum_{k=1}^3 \beta_{lk} \ln y_l \ln y_k + \sum_{i=1}^4 \sum_{l=1}^3 \delta_{il} \ln w_i \ln y_l + \sum_{i=1}^4 \theta_{iRD} \ln w_i \ln RD + \sum_{l=1}^3 \phi_{lRD} \ln y_l \ln RD + \sum_{h=1}^3 \xi_{hRD} \ln E_h \ln RD +$$

$$\sum_{h=1}^3 \sum_{i=1}^4 \rho_{ih} \ln E_h \ln w_i + \sum_{i=1}^4 \rho_{iW} \ln W \ln w_i$$

where the w 's are input prices, the y 's are output quantities, RD is the own-state R&D stock, the E 's are efficiency variables, the D 's are regional dummy variables, and W is a measure of rainfall. We introduce regional dummies in the first-order terms to allow for differences in cost shares across the production regions. The regions are the USDA's farm production regions defined in table 1. While the coefficient on rainfall may have an interpretation, its inclusion in the estimation is to remove noise that could affect the estimation of the other parameters.

Symmetry and linear homogeneity in prices are imposed during estimation. Using Shephard's lemma, the cost share for input i is:

$$(2) \quad S_i = \sum_{n=1}^{10} \alpha_{ni} D_n + \sum_{j=1}^4 \alpha_{ij} \ln w_j + \sum_{l=1}^3 \delta_{il} \ln y_l + \theta_{iRD} \ln RD + \sum_{h=1}^3 \rho_{ih} \ln E_h + \rho_{iW} \ln W$$

The estimated system of equations includes the total variable cost equation (1) and the input cost share equations (2). Additive disturbances are appended to each share equation and the variable cost function. These disturbances are presumed intertemporally independent, multivariate normal with zero mean and nonzero contemporaneous covariances. The contemporaneous covariance matrix of the disturbance terms is singular since the cost shares must sum to unity at every sample point. Hence, a single share equation is dropped in estimation. The system of equations is estimated using the Iterative Seemingly Unrelated Regression (ITSUR) algorithm in SAS. The estimation

results are independent of the equation dropped under the maintained assumptions on the error structure.

The cost elasticities (ε) with respect to local R&D stocks and the efficiency variables (E_h) — spill-in stocks (SR), extension activities (ET), and road density (RO) are estimated:

$$(3) \quad \varepsilon_{RD} = \frac{\partial \ln TVC}{\partial \ln RD} = \gamma_{RD} + \gamma_{RDRD} \ln RD + \sum_{i=1}^4 \theta_{iRD} \ln w_i + \sum_{l=1}^3 \phi_{lRD} \ln y_l + \sum_{h=1}^3 \xi_{E_h RD} \ln E_h$$

$$(4) \quad \varepsilon_{E_h} = \frac{\partial \ln TVC}{\partial \ln E_h} = \xi_{E_h RD} \ln RD + \sum_{i=1}^4 \rho_{iE_h} \ln w_i$$

As noted above, one of the effects that we would like to highlight in this study is the interaction between local R&D stocks and the efficiency variables. This cross effect is:

$$(5) \quad ME_{E_h RD} = \frac{\partial \varepsilon_{RD}}{\partial \ln E_h} = \xi_{E_h RD}$$

If ε_{RD} or ε_E is negative, then an increase in local R&D stock or any of the efficiency variables E_h reduces total variable cost, given input prices and output levels. If $ME_{E_h RD}$ is negative then the efficiency variables have a further cost reducing effect; they magnify the cost-reducing impact of own R&D, as hypothesized.

Internal Rate of Return to Agricultural Research

To evaluate the benefits of public research, we proceed to calculate the internal rate of return (IRR). The internal rate of return is the discount rate that makes the net present value (NPV) of all cash flows (including both inflows and outflows) from a particular investment equal to zero. In other words, the IRR of an investment is the discount rate at which the present value of future cash flows equals the current market

price of the investment. The benefit from one dollar of R&D invested by a state in its own agricultural sector, referred to as local or own-state investment, is the discounted value of all future cost savings in that particular state's agriculture. The local internal rate of return, r_l , is obtained by solving the following equation:

$$(6) \quad 1 = \sum_{\tau=0}^s \frac{-\Delta TVC_{t+\tau}}{\Delta R_t} \cdot \frac{1}{(1+r_l)^\tau} = \sum_{\tau=0}^s \frac{-\Delta TVC_{t+\tau}}{\Delta RD_{t+\tau}} \cdot \frac{\Delta RD_{t+\tau}}{\Delta R_t} \cdot \frac{1}{(1+r_l)^\tau}$$

where s is the total number of periods used in the construction of the R&D stock, R_t is the own-state research investment at time t , and $RD_{t+\tau}$ is the own-state knowledge stock at time period $t+\tau$. $\frac{\Delta RD_{t+\tau}}{\Delta R_t}$ is the change in R&D stock at time period $t+\tau$ resulting from

one dollar of own-state research investment at time t . In this study, $\frac{\Delta RD_{t+\tau}}{\Delta R_t}$ are the weights used at each point in time to construct the R&D stocks from research expenditures:

$$(7) \quad \frac{\Delta RD_{t+\tau}}{\Delta R_t} = \omega_\tau$$

The impact on total variable cost of a one-dollar increase in a state's agricultural research stock can be expressed as (for simplicity the time subscript t is dropped):

$$(8) \quad \frac{\Delta TVC}{\Delta RD} = \frac{\Delta \ln TVC}{\Delta \ln RD} \frac{TVC}{RD} = \varepsilon_{RD} \cdot \frac{TVC}{RD}$$

To obtain the own-state internal rate of return, we substitute equations (3), (7), and (8) into (6), and solve for r_l :

$$(9) \quad 1 = - \left[\sum_{i=1}^4 \theta_{iRD} \ln w_i + \sum_{l=1}^3 \phi_{lRD} \ln y_l + \sum_{h=1}^4 \xi_{E_hRD} \ln E_h \right] \cdot \frac{TVC}{RD} \cdot \sum_{\tau=1}^s \frac{\omega_\tau}{(1+r_1)^\tau}$$

Given that R&D investments in agriculture have the characteristics of an impure public good³, the relevant concept in evaluation should include not only the own-state effects but also the benefits to other states from R&D spillovers (i.e., the social rate of return). Taking into account these effects, the social internal rate of return, r_2 , is derived by solving for r_2 in the following equation:

$$(10) \quad 1 = \sum_{\tau=0}^s \frac{-\Delta TVC_{it+\tau}}{\Delta R_{it}} \cdot \frac{1}{(1+r_2)^\tau} + \sum_{j=1}^{n-1} \sum_{\tau=0}^s \frac{-\Delta TVC_{jt+\tau}}{\Delta R_{it}} \cdot \frac{1}{(1+r_2)^\tau}$$

where n is the number of states in a particular region. Therefore, the number of states benefiting from state i 's research is $n-1$. The first term of this equation is the same as in equation (8), and it represents the own-state benefits. The second term of the equation captures the social benefits generated by state i 's research and can be alternatively expressed as follows:

$$(11) \quad \sum_{j=1}^{n-1} \sum_{\tau=0}^s \frac{\Delta TVC_{jt+\tau}}{\Delta R_{it}} \cdot \frac{1}{(1+r_2)^\tau} = \sum_{j=1}^{n-1} \sum_{\tau=0}^s \frac{\Delta TVC_{jt+\tau}}{\Delta SR_{jt+\tau}} \cdot \frac{\Delta SR_{jt+\tau}}{\Delta R_{it}} \cdot \frac{1}{(1+r_2)^\tau}$$

The weights used in constructing the R&D spill-ins at time period $t+\tau$ in state j from a one-dollar investment in R&D in state i at time period t is:

$$(12) \quad \frac{\Delta SR_{jt+\tau}}{\Delta R_{it}} = \omega_\tau$$

³ Pure public goods are non-excludable and non-rival. Public research in other states, though “public”, is not fully non-excludable, and therefore an “impure public good” (Cornes and Sandler, 1996).

The impact on state j 's cost of research spill-ins from other states can be expressed as follows:

$$(13) \quad \frac{\Delta TVC}{\Delta SR} = \frac{\Delta \ln TVC}{\Delta \ln SR} \frac{TVC}{SR} = \varepsilon_{SR} * \frac{TVC}{SR}$$

We obtain the social internal rate of return by substituting equations (4), (9), (11)-(13) into (10), and solving for r_2 :

$$(14) \quad 1 = - \left[\sum_{i=1}^4 \theta_{iRD} \ln w_i + \sum_{l=1}^3 \phi_{lRD} \ln y_l + \sum_{h=1}^4 \xi_{E_hRD} \ln E_h \right] \cdot \frac{TVC}{RD} \cdot \sum_{\tau=1}^s \frac{\omega_{\tau}}{(1+r_2)^{\tau}} -$$

$$\sum_{j=1}^{n-1} \sum_{\tau=0}^s (\xi_{SRRD} \ln RD_j + \sum_{i=1}^4 \rho_{iSR} \ln w_{ij}) \cdot \frac{TVC_j}{SR_j} \cdot \frac{\omega_{\tau}}{(1+r_2)^{\tau}}$$

Data

Output quantities and input prices

Our data consist of a panel of state-level observations spanning the years 1980 to 2004. This section provides a brief overview of data sources and aggregation procedures. A more detailed description of the data can be found in Ball et al. (1999).

We construct state-specific aggregates of output and labor, capital and intermediate inputs as Törnqvist indexes over detailed output and input accounts. Törnqvist output indexes are formed by aggregating over agricultural goods and services using revenue-share weights based on shadow prices. The changing demographic character of the agricultural labor force is used to build a quality adjusted index of labor input. Construction of a measure of capital input begins with estimating the capital stock and rental price for each component of capital input. For depreciable assets, the capital stocks are the accumulation of all past investments adjusted for discards of worn-out

assets and loss of efficiency of assets over their service life. For land and inventories, capital stocks are measured as implicit quantities derived from balance sheet data. Implicit rental prices for each asset are based on the correspondence between the purchase price of the asset and the discounted value of future service flows derived from that asset. Indexes of capital input are formed by aggregating over the various capital assets using cost share-weights based on assets-specific rental prices. Intermediate input consists of goods and services used in production during the calendar year, whether purchased or withdrawn from opening stocks. Price and quantity data corresponding to purchases of feed and seed are available and directly enter the calculation of intermediate goods. Törnqvist indexes of energy consumption are calculated for each state by weighting the growth rates of petroleum fuels, natural gas, and electricity consumption by their share in the overall value of energy input. Fertilizers and pesticides are important intermediate inputs. Price indexes for fertilizers and pesticides are constructed using hedonic methods. The corresponding quantity indexes of fertilizers and pesticides are formed implicitly by taking the ratio of the value of each aggregate to its hedonic price index. We also calculate price and implicit quantity indexes of purchased services such as contract labor, custom machine services, and custom livestock feeding. A Törnqvist index of intermediate input is constructed for each state by weighting the growth rates of each category of intermediate inputs by their value share in the overall value of intermediate inputs. Finally, considerable effort was expended to develop output and input measures that have spatial as well as temporal integrity. The result is data for a panel of states that can be used for both cross section and time series analysis.

Local R&D

There are many different methods used to construct knowledge stocks. In studies of the impact of private research in manufacturing, research stocks are frequently constructed from data on research expenditures using the perpetual inventory method. However, as noted by Griliches (1998), the usual declining balance or geometric depreciation does not fit very well the likely gestation, blossoming, and eventual obsolescence of knowledge. He also notes that there is no agreement as to the best model to use in constructing R&D stocks. Except for some studies that have based the construction on best statistical fit, most approaches are ad-hoc based on intuition.

We construct knowledge stocks assuming a trapezoidal lag structure as proposed by Huffman and Evenson (2006). More specifically, we assume a 2 year gestation period during which the impacts of research are negligible, followed by 7 years of increasing impacts, 6 years of maturity with constant weights, and 20 years of decay with declining weights. A description of the procedures can be found in Huffman (2009). Annual research expenditures were provided by Huffman (2009). Nominal research expenditures were deflated by an agricultural research price index. This index assumes that roughly seventy percent of research expenditures are labor costs, an assumption that is broadly consistent with available data on the composition of research expenditures.

R&D Spill-ins

In this study, we construct two public research stock variables, an own-state variable and a research spill-in variable. Most studies that include potential spill-ins assume that discoveries from public research in a given state are an impure public good. While

alternative spillover measurements have been applied to and compared with in the manufacturing studies (Kaiser, 2002) many agricultural studies impose the simplifying assumption that research benefits are regionally confined and apply simple aggregation over USDA production regions (see Huffman et al., 2002; Yee et al., 2002). Studies by Alston et al. (2010) and Plastina and Fulginiti (2011) are the exception. Alston et al. (2010) constructed the spillover variable based on ‘similarity’ of the production mix, while Plastina and Fulginiti (2011) used a stochastic ‘concentric rings’ approach.

Because this is a key variable in the calculation of social returns, and because other studies estimated rates of return using just one of these approaches, we construct four alternative R&D spill-in variable. Our objective is to provide information on the sensitivity of the estimated rates of return to the alternative measures of potential R&D spill-ins. The first two approaches we use are based on geographic proximity, while the last two reflect the ‘production profile’ in each state.

The R&D spill-in variable is constructed as a weighted sum of own R&D stocks from other states:

$$(15) \quad SR_i = \sum \Omega_{ij} RD_j \quad i \neq j$$

where SR_i is the potential R&D spill-in for state i , Ω_{ij} are the weights used to capture the j th state’s contribution, and RD_j is the j th state’s own R&D stock. The weights used in (15) are based on the models described below.

Model 1: $\Omega_{ij}=1$ for state j in the same USDA production region (table 1). The R&D spill-in stock for state i is the sum of research stocks in all other states in that region.

Model 2: $\Omega_{ij}=1/dist_{ij}$ for an R&D spill-in variable generated based on the geographic distance among states. This approach, inspired by gravity-type trade models (Tinbergen, 1962), is offered to allow for a geographic ‘correction’ to Model 1. The R&D stock generated by a state is scaled using the inverse distance between the sending state and the receiving state. The distance between Montana and New Mexico is chosen as the cutoff distance. Any state j within the cutoff distance was assumed to have an impact on state i ’s production and was given a weight equal to the inverse of the distance between two states, while states beyond that distance were assigned a zero weight.

Model 3: $\Omega_{ij}=1$ for R&D spill-ins based on production profiles. We use cash receipts from twelve categories of outputs to generate a production profile for each state. The twelve outputs categories are: Meat animals, Dairy products, Poultry/eggs, Miscellaneous, Food grains, Feed crops, Cotton, Tobacco, Oil crops, Vegetables, Fruits/nuts, and All other crops. We use cluster analysis to group the states with similar production profiles. While there are several clustering techniques, we use the complete linkage clustering method following Sorensen (1948)⁴. In complete linkage clustering, the distance between two clusters is the maximum distance between an observation in one cluster and an observation in the other cluster, considering multiple elements. It can avoid the drawback of the single linkage

⁴ While we prefer using the complete linkage method we compared results with those based on alternative cluster methods, such as the centroid method and the average linkage method (Hansen and Jaumard (1997) among others). The results were similar so we only report the results based on the complete linkage method.

method that may force states to be grouped together due to closeness in one single element while many other elements could be very different. The procedure is implemented using the SAS econometric package and results are presented in Table 2. Under this methodology, distant states such as Florida and California may be in the same group due to similar production profiles.

Model 4: $\Omega_{ij}=1/Tecdist_{ij}$ for an R&D spill-in variable generated based on the technical distance among states within the same cluster from model 3. $Tecdist_{ij}$ is the technological distance measured by the inverse of the Spearman correlation coefficient on the production mix among states. The higher is the correlation relationship, the smaller is the technical distance among states within the same cluster.

Descriptive statistics for the four R&D spill-in variables, along with other efficiency variables described below, are presented in table 3.

Extension

The extension full-time equivalent (FTE) staff has been declining for most of the states over the 1980-2004 period. Ahearn et al. (2003) reported the series of state FTEs for the period 1977-92 by 4 major program areas and by total FTE's for the period 1977-97. The disaggregated data are no longer available. We use total FTEs at the state level to construct the extension capacity indexes for each state. The extension capacity index uses total FTEs as the numerator and the number of farms as the denominator to

capture multilateral scale differences⁵. Data on FTEs by state were drawn from the Salary Analysis of the Cooperative Extension Service, Human Resource Division, USDA.

Roads

We construct a road density index to examine the impact of road infrastructure on dissemination of technical information. The state road density index was constructed using total annual road miles, excluding local (i.e. city street) miles for each state, obtained from the Department of Transportation's Highway Statistics Publications, divided by total land area. We expect that with higher road density the cost of disseminating technical information is lower and the impact of public R&D on productivity is enhanced. Although this variable is rather stable for each state, it varies considerably among states.

Weather

Weather is treated as a control variable in this model. While several alternative weather indexes such as the Palmer index and the Stallings index have been used in empirical work, we use total precipitation in inches from March to November (Schlenker and Roberts, 2006, 2008).

Empirical Results

⁵ Normalizing by number of farms has potential implications as number of farms as well as extension FTE's have been declining. It is also important to notice that along with the changes in farm size distribution and information technology, the nature of service has changed from one-on-one to group-level engagement. This change in delivery mode reflects the increasing public-good characteristic of the service provided.

We estimate the variable cost function (1) and the cost share equations (2) using the four alternative measures of R&D spill-ins defined above. Prior to estimation, we investigate the time series properties of the data. We conduct panel unit root tests proposed by Levin, Lin, and Chu (2002). All of the test statistics presented in table 4 are less than the critical value at the 5% level. Therefore, we reject the presence of a unit root and proceed by estimating equations (1) and (2) assuming stationarity.

We then estimate a total of 100 parameters based on 1200 observation for each model subject to symmetry and linear homogeneity in input prices. The curvature and monotonicity properties of the cost function were inspected after estimation. Monotonicity was satisfied globally. Concavity in prices implies a negative semi-definite Hessian. We find that this condition holds locally.

In table 5, we present the parameter estimates for the four models, excluding constant and interactive terms between regional dummies and input prices from each model. We note that 184 of the 236 parameter estimates (across the four models) are significant at the 5% confidence level. Moreover, the parameter estimates (other than those for the R&D spill-in variables) are stable across the different model specifications, giving an indication of the robustness of the estimates. Finally, as can be seen in table 5, the coefficients on the interactive terms between own R&D and the efficiency variables (extension activities, roads, and R&D spill-ins) are all significant except for the coefficient on the R&D spill-in variable in Model 2.

The impacts of public R&D, extension activities, roads, and R&D spill-ins on agricultural productivity growth can be examined through the alternative cost elasticities

and the marginal effects of the efficiency variables on R&D's cost saving effect. The cost elasticities of own R&D, extension activities, road density, and R&D spill-ins are all negative (see table 6). From table 6, we see that a 1-percent increase in own R&D reduces total variable cost by 0.13-0.15 percent, depending on the model specification. Extension activities led to the greatest reduction in costs (0.23%-0.25%), followed by the effect of R&D spill-ins (0.01%-0.16%) and road density (0.04%-0.06%).

Table 7 presents the marginal effect of each efficiency variable on cost diminution through their interaction with own R&D (see equation 5). The estimates are all significant at 1% level except when we proxy spill-ins using geographic distance (Model 2). We find that an increase in extension activities, road density, and R&D spill-ins significantly enhance the cost-reducing effect of own R&D investments. Among the efficiency variables, extension activities have the greatest impact, while road density has the smallest impact. This effect, paired with the decreasing trend in extension activities through time, is important in understanding the evolution of the own-state internal rate of return, as will be seen later.

The results presented in tables 6 and 7 provide evidence that own R&D, as well as R&D spill-ins, extension activities, and road density, have a positive and significant effect on the productivity of U.S agriculture (except R&D spill-ins from Model 2). It also shows that the estimated impacts of R&D spill-ins on productivity vary across models with Model 1, based on the USDA production regions, having the largest impact and Model 2, based on geographical distances, having the smallest.

Next, we use the estimated coefficients and equations (10) and (14) to calculate own and social rates of return to agricultural research by state and by year. The mean rates of return for all states and all years are shown in table 8. Note that own-state rates of return (r_1) are robust across the different model specifications. Note also the sensitivity of the estimated social rates of return to alternative proxies for research spill-ins. Estimates from Models 3 and 4 that use the production profile approach to the construction of the R&D spill-in stocks are very close, while those from Models 1 and 2, based on geographical proximity, are very different. The rates in Model 1, estimated using the most common approach found in the literature (i.e., grouping states according to the USDA production regions) are the largest, while those from Model 2 are the smallest.

Figures 1 and 2 show the evolution of the internal rates of return. We see that both the own-state internal rate of return r_1 and the social rate of return r_2 in all four models declined beginning in the mid-1980s. While the own-state internal rates of return (r_1) continued to decline over the sample period, the social internal rates of return (r_2) stabilized or exhibited a slight increase. The declining own-state internal rates of return estimated here are associated with declining extension staffing during these years. However, in the estimation of the social rates of return, this effect seems to be outweighed by research spill-in effects.

Table 9 reports the rates of return by production region. The estimates of local rates of return are robust to the model specification. Estimates of the social rates of return across the regions are much lower for Model 2 than for the other three models. The rates of return for the Lake States, Corn Belt, Appalachia, Delta, Southern Plains, and Pacific

regions are more similar than the rates for the Northeast region, as indicated by the standard deviation. The states in the Lake States, Corn Belt, Northern Plains, and Southern Plains regions have, on average, both higher local and social rates of return.

Based on the estimated marginal effects (see equation (5)) of extension activities, road density, and R&D spill-ins, we calculate the impacts of these variables on the internal rates of return (equations (9) - (14)). These results are presented in table 10. A 10-percent increase in extension activities increases the local internal rate of return, on average, by approximately 1.4 percentage points. For example, in model 1, the local internal rate of return on investments in R&D is 10.75 percent. A 10-percent increase in extension service raises this rate to 12.15 percent. This boosts the social rates of return by an average of 0.36 percentage points using Model 1 and 1.18 percentage points using the specification in Model 2. We note, however, that the extension variable shows a decreasing trend during the period of analysis. Research spill-ins also have an important positive effect on social rates, ranking second in magnitude to investments in extension activities. Contrary to the evolution of the extension variable, the spill-in stock variables have all trended higher over the sample period.

Summary and Conclusions

This paper uses data for a panel of states to estimate the own and social internal rates of return to public R&D expenditure. The social rates of return incorporate the interactions with R&D spill-ins, extension activities, and road density. We construct four alternative measures of potential R&D spill-ins based on geographic proximity and similarities in production to determine the sensitivity of the estimated rates of return to

model specification. Our estimates indicate that extension activities, road density, and R&D spill-ins from other states play an important role in determining the efficacy of R&D expenditures. Among these variables, the impact of extension activities seems to be the strongest. These activities enhance productivity growth by facilitating the dissemination of technical information.

The estimates of the own internal rates of return are robust across the alternative models, while the social internal rates of return deviate from each other depending on the particular measure of potential R&D spill-ins. The social rates of return based on USDA production regions are much higher than those estimated by the other models. This is important given the prevalence in the literature of this approach for the calculation of knowledge spill-in stocks. We find that the decline in own rates of return is associated with declines in extension investments during this period.

This study provides evidence that the returns to agricultural research during the 1980-2004 period have been quite high. It confirms that they were higher still as a result of extension activities, research spillovers across states, and a higher road density. These findings have important implications for policy and should not be disregarded when allocating public resources to alternative research activities.

References

- Alston, J. M., Chan-Kang, C., M. Marra, P. Pardey, T. Wyatt. 2000. *A Meta-analysis of rates of return to agricultural R&D: Ex Pede Herculem?* Research Report No. 113, IFPRI.
- Alston, J. M., M. A. Anderson, J. S. James, and P. G. Pardey. 2010. *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending*. Springer.
- Antle, J. (1983) Infrastructure and aggregate agricultural productivity: International evidence . *Economic development and Cultural Change* 31, 3, 609-619.
- Ahearn, M., J. Yee, and J. Bottum. 2003. *Regional Trends in Extension System Resources*. AIB No. 781, Economic Research Service, USDA.
- Ball, V. E., F. Gollop, A. Kelly-Hawke, and G. Swinand. 1999. "Patterns of Productivity Growth in the U.S. Farm Sector: Linking State and Aggregate Models." *American Journal of Agricultural Economics*, 81:164-79.
- Birkhauser, D., Evenson R. and Feder, G. 1989. "The economic impact of agricultural extension: a review." *Econ. Dev. Cult. Changes*, 39: 607-650.
- Caves, D. W., L. R. Christensen, and W. E. Diewert. 1982. "Multilateral Comparisons of Output, Input, and Productivity Using Superlative Index Numbers." *The Economic Journal*, Vol. 92, No. 365, pp. 73-86.
- Coe, D., and E. Helpman. 1995. "International R&D Spillovers." *European Economic Review* 39 (5), 859–887, May.

- Cornes, R. and T. Sandler. 1996. *The Theory of Externalities, Public Goods and Club Goods*. New York, NY: Cambridge University Press.
- Evenson, R. E., 1967. "The contribution of agricultural research to production." *Journal of Farm Economics* 49, 1415-1425.
- Evenson, R.E.. 1989. "Spillover Benefits of Agricultural Research: Evidence from U.S. Experience". *American Journal of Agricultural Economics*. Vol. 71, no. 2.
- Evenson, R. E. 2001. "Economic Impacts of Agricultural Research and Extension." chapter for *Handbook of Agricultural Economics*. Bruce L., Gardner and Gordon C. Rausser. Eds. published by Elsevier Science.
- Esposti, R. 2002. "Public agricultural R&D design and technological spill-ins: A dynamic model". *Research Policy* Vol. 31, Issue 5: 693-717.
- Esposti, R. and P. Pierani, 2003. "Public R&D Investment and Cost Structure in Italian Agriculture, 1960-1995." *European Review of Agricultural Economics* Vol. 30, Issue 4. Pp. 509-537.
- Funk, M. F. 2001. "Trade and International R&D spillovers Among OECD Countries." *Southern Economic Journal*, 67(3), pp. 725-737.
- Fugile, O. K. and P. W. Heisey. 2007. *Economic Returns to Public Agricultural Research*. EB No. 10, Economic Research Service, USDA.
- Fulginiti, L. E. 2010. "Estimating Griliches' K-shift." *American Journal of Agricultural Economics*. Vol. 82 (1): 86-101.
- Griliches, Z., 1958. "Research Costs and Social Returns: Hybrid corn and Related Innovations." *Journal of Political Economy* 66: 419-431.

- Griliches, Z., 1964. "Research expenditures, education and the aggregate agricultural production function." *American Economic Review* 54, 6, 961-974.
- Griliches, Z., 1998. *R&D and Productivity: The Econometric Evidence*. Chicago Ill. The University of Chicago Press.
- Hansen P. and B. Jaumard. 1997. "Cluster analysis and mathematical programming". *Mathematical Programming* 79: 191-215.
- Huffman, W. E., and R. E. Evenson. 1992. "Contributions of Public and Private Science and Technology to U.S. Agricultural Productivity." *American Journal of Agricultural Economics*. Vol. 74, No. 3, pp. 751-756.
- Huffman, W. E., and R.E. Evenson. 2006. "Science for Agriculture—A long-Term Perspective." second edition, Blackwell Publishing.
- Huffman, W. E., V. E. Ball, M. Gopinath, and A. Somwaru. 2002. "Public R&D and Infrastructure Policies: Effects on Cost of Midwestern Agriculture." *Agricultural Productivity: Measurement and Sources of Growth*. edited by V. E. Ball, and G. W. Norton, Kluwer Academic Publishers, Boston/Dordrecht/London.
- Huffman, W. E. 2009. "Measuring Public Agricultural Research Capital and Its Contribution to State Agricultural Productivity." Iowa State University, Department of Economics Working Paper #09007.
- Jaffe, A. B. 1986. "Technological opportunity and spillovers of R&D: evidence from firm's Patents, profits, and market value." *American Economic Review*. 76 (5): 984-1001.

- Johnson, D. K. N. and R.E. Evenson. 1999. "R&D Spillovers to Agriculture: Measurement and Application." *Contemporary Economic Policy*. Vol. 17, Issue 4: 432-456.
- Kaiser, U. 2002. "Measuring knowledge spillovers in manufacturing and services: an empirical assessment of alternative approaches". *Research Policy* 31: 125-144. .
- Levina, Andrew Chien-Fu Lin, Chia-Shang James Chu. 2002, "Unit root tests in panel data: asymptotic and finite-sample properties." *Journal of Econometrics* 108 (2002) 1–24.
- McKinsey and R.E. Evenson. 2003. "Crop Genetic Improvement Impacts on Indian Agriculture." *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agriculture Research*, edited by R.E. Evenson and D. Gollin, CABI publishing.
- McCunn, A. and W. E. Huffman 2000. "Convergence in U.S. Productivity Growth for Agriculture: Implications of Interstate Research Spillovers for funding Agricultural Research." *American Journal of Agricultural Economics*, vol. 82, No. 2: 370-388.
- Mullen, J., 2007. "Productivity growth and the returns from public investment in R&D in Australian broadacre agriculture." *The Australian Journal of Agricultural and Resource Economics*, 51: 359-384.

- Nin Pratt, A., B. Yu, and S. Fan, (2008) "The total factor productivity in China and India: new measures and approaches", *China Agricultural Economic Review*, Vol. 1 Iss: 1, pp.9 – 22.
- Onofri, A. and L. E. Fulginiti. 2008. "Public Inputs and Dynamic Producer Behavior: Endogenous Growth in U.S. Agriculture." *Journal of Productivity Analysis*, Vol 30 (1): 13-28.
- Pardey, P. G., J. M. Alston, C. C. Kang, E. C. Magalhaes, and S. A. Vosti. 2006. "International and Institutional R&D Spillovers: Attribution of Benefits Among sources fro Brazil's New Crop Varieties." *American Journal of Agricultural Economics* Vol. 88, No. 1: 104-123.
- Paul, C. J. M., V. E. Ball, R.G. Felthoven, R. Nehring. 2001. "Public Infrastructure Impacts on U.S. Agricultural Production: Panel Analysis of Costs and Netput Composition." *Public finance and Management*: 183-213.
- Plastina, A. and L. E. Fulginiti. 2011. "Internal Rates of Return to R&D in Agriculture in 48 U.S. States." *Journal of Productivity Analysis*.
- Schlenker, W. and M. J. Roberts. 2006. "Nonlinear Effects of Weather on Corn Yields." *Review of agricultural Economics* (Proceedings of the American Agricultural Economics Association, 2006 Allied Social Science Associations Meeting, Boston, MA), 28(3): 391-398.
- Schlenker, W. and M. J. Roberts. 2008. "Estimating the Impact of Climate Change on Crop Yields: The Importance of Nonlinear Temperature Effects." NBER Working Paper No. 13799.

- Schimmelpenninck, D., and C. J. O'Donnell, and G. W. Norton. 2006. "Efficiency Effects of Agricultural Economics research in the United States." *Agricultural Economics* 34 (2006), pp. 273-280.
- Schimmelpenninck D. and C. Thirtle, 1999. "The Internationalization of Agricultural Technology: Patents, R&D Spillovers, and Their Effects on Productivity in the European Union And United States," *Contemporary Economic Policy*, vol. 17(4): 457-468.
- Sørensen, T. 1948. "A Method of Establishing Groups of Equal Amplitude in Plant Sociology Based on Similarity of Species and Its Application to Analyses of the Vegetation on Danish Commons." *Biologiske Skrifter/Kongelige Danske Videnskabernes Selskab*, 5 (4): 1-34.
- Thirtle, C., J. Piesse, and D. Schimmelpenninck. 2008, "Modeling the length and shape of the R&D lag: an application to UK agricultural productivity." *Agricultural Economics*. vol. 39, issue 1, pp.73-85. July 2008.
- Tinbergen, Jan. 1962. *Shaping the World Economy: Suggestions for an International Economic Policy*. New York: The Twentieth Century Fund, 1962.
- U.S. Department of Agriculture, Economic Research Service. *Agricultural Productivity in the United States*. <http://ers.usda.gov/Data/AgProductivity/>
- U.S. Department of Agriculture, National Agricultural Statistics Service. *Data and Statistics*. http://www.nass.usda.gov/Data_and_Statistics/index.asp
- U.S. Department of Agriculture, National Institute of Food and Agriculture. *Salary Analyses of State Extension Service Positions*.

http://www.csrees.usda.gov/about/human_res/report.html

U.S. Department of Transportation, Federal Highway Administration. *Highway Statistical Series*. <http://www.fhwa.dot.gov/policyinformation/statistics.cfm>

Yee, J., W. E. Huffman, M. Ahearn, and D. Newton. 2002. "Sources of Agricultural Productivity Growth at the State Level, 1960-1993." *Agricultural Productivity: Measurement and Sources of Growth*. edited by V. E. Ball, and G. W. Norton, Kluwer Academic Publishers, Boston/Dordrecht/London.

Table 1. USDA's Production Regions

Region	States
Northeast	NH, PA, ME, MD, RO, MA, DE, CT, VT, NY, NJ
Lake States	MN, MI, WI
Corn Belt	OH, IA, MO, IN, IL
Appalachian	WV, TN, NC, VA, KY
Southeast	SC, AL, GA, FL
Delta	LA, AR, MS
Northern Plains	ND, SD, KS, NE
Southern Plains	TX, OK
Mountain	CO, UT, AZ, NM, WY, NV, ID, MT
Pacific	OR, CA, WA

Data source: USDA

Table 2. Clusters for 48 States Based on Production Profile

Cluster	States
1	IA, IL, IN, MN, MO, NE, OH, SD
2	CO, ID, KS, MI, NM, NV, OK, OR, TX, UT, WY
3	AL, AR, DE, GA, MD, NC, SC, TN, VA, WV
4	NY, VT, WI
5	CT, NH, PA, RI
6	CA, FL, MA, ME, NJ, WA
7	AZ, LA, MS
8	MT, ND
9	KY

Data source: Developed by authors.

Table 3 Descriptive statistics for efficiency variables

statistics (unit)	extension (FTE per farm)	road density (mile per square mile)	R&D spilii-in (Model 1) (constant dollars)	R&D spilii-in (Model2) (constant dollars)	R&D spilii-in (Model3) (constant dollars)	R&D spilii-in (Model4) (constant dollars)
N	1200	1200	1200	1200	1200	1200
MIN	0.0000	0.0583	11696201	100129407	5406608	1270725
MAX	0.0476	2.5634	219463954	1155346530	217905010	175632026
MEAN	0.0100	0.6193	86160408	575183765	119101019	85945211
STD	0.0069	0.4828	39880052	239590346	60382324	48655117

Note: FTE indicates full time equivalent staff numbers

Table 4. Panel Unit Root Tests of Variables Used in the Study

Variables	LLC' Statistic ¹	p-value
LnTVC	-5.10	0.0000
S _K	-8.65	0.0000
S _L	-2.37	0.0090
S _M	-1.78	0.0377
LnV	-2.86	0.0021
LnC	-3.88	0.0001
LnO	-9.75	0.0000
LnRD	-36.83	0.0000
LnET	-2.48	0.0066
LnRO	-4.71	0.0000
LnSR1	-30.60	0.0000
LnSR2	-34.84	0.0000
LnSR3	-34.21	0.0000
LnSR4	-34.65	0.0000
LnA	-3.61	0.0002
LnM	-2.37	0.0088
LnK	-11.73	0.0000
LnL	-1.68	0.0462
LnW	-10.14	0.0000

Note 1: The LLC panel unit root test is based on the method proposed by Levin, Lin, and Chu (2002). Our tests include a constant term for every variable except LnK. In the case of LnTVC, LnET, a time trend was included.

Note 2: SR1, SR2, SR3 SR4 are alternative R&D spillins based on the estimates from Model 1 through Model 4.

Note 3: V stands for livestock, C for crops, O for other farm related goods and services, A for land, L for labor, M for materials, K for capital, RD for own agricultural R&D stock, ET for extension, RO for road density, SR for R&D spillins

Table 5. Coefficient Estimates of cost and share equations, 48 states, U.S. Agriculture, 1980-2004, alternative R&D spill-in stocks.

	Model 1			Model 2			Model 3			Model 4		
	t			t ratio			t ratio			t ratio		
Parameters	coefficients	ratio		coefficients	t ratio		coefficients	t ratio		coefficients	t ratio	
β_V	1.4720	5.46	***	1.7428	6.11	***	1.8615	6.39	***	1.7991	6.33	***
β_C	-0.6314	-2.59	***	-0.6989	-2.66	***	-0.9780	-3.61	***	-1.0304	-3.88	***
β_O	-0.5048	-1.81	*	-0.6410	-2.16	**	-0.3581	-1.20		-0.4313	-1.47	**
$\beta_{V\ V}$	0.0401	1.80		0.0579	2.45	**	0.0302	1.25		0.0463	1.96	**
$\beta_{V\ C}$	-0.0139	-0.77		-0.0059	-0.31		-0.0041	-0.21		-0.0147	-0.77	
$\beta_{V\ O}$	-0.0595	-3.54	***	-0.0869	-4.90	***	-0.0646	-3.48	***	-0.0692	-3.82	***
$\beta_{C\ C}$	0.1213	6.19	***	0.1221	5.88	***	0.1352	6.39	***	0.1441	6.89	***
$\beta_{C\ O}$	-0.1174	-7.16	***	-0.1306	-7.50	***	-0.1445	-8.21	***	-0.1390	-8.01	***
$\beta_{O\ O}$	0.1830	7.28	***	0.2376	9.00	***	0.2313	8.58	***	0.2284	8.54	***
γ_{RD}	-0.4867	-1.16		-0.5864	-1.29		-0.5960	-1.36		-0.7470	-1.71	
$\gamma_{RD\ RD}$	-0.0103	-0.50		-0.0085	-0.38		-0.0019	-0.09		-0.0017	-0.08	
$\alpha_{A\ A}$	0.0487	17.96	***	0.0517	19.02	***	0.0496	18.20	***	0.0497	18.21	***
$\alpha_{A\ M}$	-0.0350	-10.57	***	-0.0322	-9.85	***	-0.0343	-10.51	***	-0.0340	-10.42	***
$\alpha_{A\ K}$	-0.0029	-1.61		-0.0044	-2.45	**	-0.0029	-1.62		-0.0030	-1.65	*
$\alpha_{A\ L}$	-0.0108	-4.87	***	-0.0151	-6.91	***	-0.0125	-6.01	***	-0.0128	-6.16	***
$\alpha_{M\ M}$	0.1607	21.39	***	0.1675	22.98	***	0.1627	23.40	***	0.1679	23.90	***
$\alpha_{M\ K}$	-0.0760	-14.89	***	-0.0793	-15.76	***	-0.0744	-15.55	***	-0.0780	-15.98	***
$\alpha_{M\ L}$	-0.0498	-11.77	***	-0.0561	-13.79	***	-0.0541	-14.26	***	-0.0559	-14.72	***
$\alpha_{K\ K}$	0.1353	24.60	***	0.1364	24.96	***	0.1325	25.04	***	0.1350	25.08	***
$\alpha_{K\ L}$	-0.0563	-28.77	***	-0.0527	-27.92	***	-0.0552	-31.90	***	-0.0541	-30.62	***
$\alpha_{L\ L}$	0.1169	31.58	***	0.1238	34.62	***	0.1217	37.01	***	0.1228	37.38	***
$\delta_{A\ V}$	-0.0294	-15.17	***	-0.0297	-14.64	***	-0.0286	-14.37	***	-0.0278	-13.81	***
$\delta_{A\ C}$	0.0119	5.29	***	0.0151	6.80	***	0.0141	6.25	***	0.0124	5.41	***
$\delta_{A\ O}$	0.0032	1.35		0.0018	0.78		0.0027	1.16		0.0033	1.41	
$\delta_{M\ V}$	0.0713	19.37	***	0.0681	17.51	***	0.0667	18.54	***	0.0643	17.30	***
$\delta_{M\ C}$	-0.0675	-16.92	***	-0.0664	-16.66	***	-0.0585	-15.25	***	-0.0594	-15.05	***
$\delta_{M\ O}$	0.0395	9.25	***	0.0386	8.99	***	0.0316	7.61	***	0.0354	8.44	***
$\delta_{K\ V}$	-0.0093	-6.90	***	-0.0079	-5.60	***	-0.0076	-5.94	***	-0.0071	-5.20	***
$\delta_{K\ C}$	0.0214	13.49	***	0.0203	13.15	***	0.0164	10.84	***	0.0180	11.36	***
$\delta_{K\ O}$	-0.0273	-15.99	***	-0.0271	-16.00	***	-0.0238	-14.67	***	-0.0261	-15.61	***
$\delta_{L\ V}$	-0.0326	-12.31	***	-0.0305	-11.09	***	-0.0304	-11.67	***	-0.0294	-11.00	***
$\delta_{L\ C}$	0.0343	11.77	***	0.0309	10.85	***	0.0281	9.98	***	0.0290	10.07	***
$\delta_{L\ O}$	-0.0154	-4.87	***	-0.0133	-4.25	***	-0.0105	-3.38	***	-0.0126	-4.03	***

Note 1: The spillin RD stocks are based on production region, geographical distance, un-weighted production profile, and correlation weighted production cluster for Model 1 to Model 4, respectively.

Note 2: V stands for livestock, C for crops, O for other farm-related goods and services, A for land, L for labor,

M for materials, K for capital, RD for own agricultural R&D stock, ET for extension, RO for road density, SR for R&D spillins.

Note 3: '****' indicates significant at 1% level. '***' indicates significant at 5% level. '**' indicates significant at 10% level.

Table 5. (continue)

Parameters	Model 1			Model 2			Model 3			Model 4		
	coefficients	t ratio		coefficients	t ratio		coefficients	t ratio		coefficients	t ratio	
$\theta_{A\ RD}$	-0.0165	-6.06	***	-0.0205	-7.98	***	-0.0193	-7.61	***	-0.0199	-7.84	***
$\theta_{M\ RD}$	-0.0044	-0.94		-0.0010	-0.22		-0.0045	-1.04		0.0000	0.01	
$\theta_{K\ RD}$	-0.0129	-6.88	***	-0.0131	-7.41	***	-0.0122	-7.25	***	-0.0140	-8.04	***
$\theta_{L\ RD}$	0.0338	9.58	***	0.0346	10.32	***	0.0360	10.90	***	0.0339	10.18	***
$\varphi_{V\ RD}$	-0.0416	-2.73	***	-0.0574	-3.56	***	-0.0586	-3.58	***	-0.0557	-3.46	***
$\varphi_{C\ RD}$	0.0498	3.70	***	0.0560	3.80	***	0.0683	4.62	***	0.0690	4.79	***
$\varphi_{O\ RD}$	0.0453	2.95	***	0.0484	2.98	***	0.0311	1.89	*	0.0360	2.21	**
$\xi_{ET\ RD}$	-0.0154	-18.82	***	-0.0144	-16.48	***	-0.0149	-17.65	***	-0.0150	-17.49	***
$\xi_{RO\ RD}$	-0.0021	-4.38	***	-0.0031	-5.83	***	-0.0035	-7.27	***	-0.0033	-6.85	***
$\xi_{SR\ RD}$	-0.0091	-12.45	***	-0.0010	-1.12		-0.0037	-9.46	***	-0.0026	-8.42	***
$\rho_{ET\ A}$	-0.0106	-4.11	***	-0.0101	-3.82	***	-0.0104	-3.95	***	-0.0094	-3.62	***
$\rho_{RO\ A}$	-0.0063	-3.71	***	-0.0092	-5.21	***	-0.0083	-4.85	***	-0.0077	-4.55	***
$\rho_{SR\ A}$	-0.0159	-3.45	***	0.0110	3.08	***	-0.0013	-1.13		-0.0028	-3.02	***
$\rho_{ET\ M}$	0.0636	13.04	***	0.0582	11.87	***	0.0570	12.15	***	0.0593	12.45	***
$\rho_{RO\ M}$	0.0096	3.15	***	0.0119	3.76	***	0.0114	3.91	***	0.0118	4.01	***
$\rho_{SR\ M}$	0.0112	1.52		0.0029	0.48		0.0202	9.57	***	0.0133	7.83	***
$\rho_{ET\ K}$	-0.0210	-11.50	***	-0.0198	-10.91	***	-0.0180	-10.53	***	-0.0199	-11.24	***
$\rho_{RO\ K}$	-0.0056	-4.72	***	-0.0052	-4.35	***	-0.0049	-4.50	***	-0.0057	-5.04	***
$\rho_{SR\ K}$	-0.0006	-0.17		-0.0058	-2.33		-0.0086	-11.57	***	-0.0043	-7.03	***
$\rho_{ET\ L}$	-0.0320	-9.04	***	-0.0284	-8.14	***	-0.0287	-8.34	***	-0.0300	-8.66	***
$\rho_{RO\ L}$	0.0023	1.04		0.0025	1.09		0.0018	0.85		0.0016	0.75	
$\rho_{SR\ L}$	0.0051	0.87		-0.0081	-1.77	*	-0.0103	-6.79	***	-0.0062	-5.12	***
$\rho_{W\ A}$	-0.0002	-0.39		-0.0005	-0.99		-0.0002	-0.48		-0.0002	-0.46	
$\rho_{W\ M}$	0.0007	1.05		0.0004	0.67		0.0004	0.57		0.0003	0.51	
$\rho_{W\ K}$	-0.0014	-4.24	***	-0.0012	-3.73	***	-0.0013	-4.12	***	-0.0013	-3.93	***
$\rho_{W\ L}$	0.0009	1.55		0.0012	2.21	**	0.0011	2.03	*	0.0011	2.05	**
equations	R ²	adjusted R ²		R ²	adjusted R ²		R ²	adjusted R ²		R ²	adjusted R ²	
LnTVC	0.9811	0.98		0.9779	0.98		0.9795	0.98		0.9789	0.98	
S _M	0.4856	0.48		0.4719	0.47		0.5240	0.52		0.5026	0.50	
S _K	0.7396	0.74		0.7405	0.74		0.7737	0.77		0.7513	0.75	
S _L	0.6642	0.66		0.6711	0.67		0.6838	0.68		0.6740	0.67	

Note 1: The spillover RD stocks are based on production region, geographical distance, un-weighted production profile, and correlation weighted production cluster for Model 1 to Model 4, respectively.

Note 2: V stands for livestock, C for crops, O for other farm-related goods and services, A for land, L for labor, M for materials, K for capital, RD for own agricultural R&D stock, ET for extension, RO for road density, SR for R&D spillovers.

Note 3: '****' indicates significant at 1% level. '***' indicates significant at 5% level. '**' indicates significant at 10% level.

Table 6. Cost Elasticity of R&D, Extension Services (ET), Roads (RO), and Spill-in R&D Stocks (SR), 48 States, U.S. Agriculture, 1980-2004, alternative spill-in models.

Elasticity	Frequencies	Model 1		Model 2		Model 3		Model 4	
		mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation
ξ_{RD}	1200	-0.1287	0.0903	-0.1518	0.0860	-0.1347	0.0808	-0.1511	0.0889
ξ_{ET}	1200	-0.2482	0.0209	-0.2329	0.0191	-0.2419	0.0193	-0.2428	0.0197
ξ_{RO}	1200	-0.0361	0.0038	-0.0538	0.0054	-0.0608	0.0051	-0.0579	0.0049
ξ_{SRD}	1200	-0.1637	0.0103	-0.0142	0.0064	-0.0576	0.0061	-0.0402	0.0041

Note: The spillin RD stocks are based on production region, geographical distance, un-weighted production profile, and correlation weighted production cluster for Model 1 to Model 4, respectively.

Table 7. Marginal Effect of the Extension Service, Roads and R&D spill-ins on R&D's Cost Saving, 48 States, U.S. Agriculture, 1980-2004, alternative Spill-in models

Marginal effect	Model 1		Model 2		Model 3		Model4	
	value	t ratio	value	t ratio	value	t ratio	value	t ratio
ME_{RDET}	-0.015	-18.82	-0.014	-16.48	-0.015	-17.65	-0.015	-17.49
ME_{RDRO}	-0.002	-4.38	-0.003	-5.83	-0.004	-7.27	-0.003	-6.85
ME_{RDSR}	-0.009	-12.45	-0.001	-1.12	-0.004	-9.46	-0.003	-8.42

Note: The spillin RD stocks are based on production region, geographical distance, un-w eighted production profile, and correlation w eighted production cluster for Model 1 to Model 4, respectively.

Table 8. Internal Rate of Return of Public R&D in Agriculture by Year, 48 U.S. States, 1980-2004, alternative Spill-in models

Year	Model 1				Model 2				Model 3				Model 4			
	r_1		r_2		r_1		r_2		r_1		r_2		r_1		r_2	
	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation
1980	13.89	11.02	39.26	19.49	15.90	12.85	16.43	12.77	14.31	12.37	25.96	15.46	15.48	12.60	28.11	21.72
1981	16.01	11.65	43.36	21.02	18.11	13.51	18.58	13.43	16.12	12.82	29.11	16.80	17.42	13.12	31.63	23.94
1982	13.87	8.45	42.56	19.51	16.56	10.70	17.01	10.65	14.96	10.86	28.60	15.54	16.20	10.95	30.91	23.88
1983	15.05	9.11	42.23	18.90	17.35	11.18	17.74	11.13	16.22	11.48	28.69	15.49	17.30	11.57	31.36	23.66
1984	14.95	9.19	43.08	19.37	17.30	11.45	17.11	11.93	15.57	11.63	29.31	15.93	16.69	11.82	31.85	24.59
1985	13.02	7.67	41.29	18.47	15.74	9.98	16.19	9.99	14.34	10.31	28.20	15.19	15.51	10.35	30.42	23.98
1986	10.95	7.08	38.03	17.19	13.77	9.19	14.38	9.17	12.31	9.87	26.11	14.31	13.59	9.74	28.25	22.75
1987	10.53	7.07	36.87	16.53	13.01	9.35	13.65	9.33	11.67	10.01	25.36	14.07	12.93	9.84	27.41	22.59
1988	10.59	7.22	37.51	16.58	13.33	9.46	13.53	9.89	12.56	10.15	25.91	14.21	13.52	10.15	28.07	22.38
1989	10.19	7.50	37.76	16.94	12.71	9.43	13.51	9.39	11.62	10.34	25.95	14.44	12.82	10.11	27.73	22.78
1990	10.07	6.85	38.14	17.13	12.82	9.10	13.67	9.09	11.64	9.80	26.44	14.59	12.76	9.74	28.24	23.74
1991	9.75	6.69	37.23	16.73	12.42	8.85	13.22	8.86	11.48	9.62	25.73	14.36	12.49	9.59	27.63	23.51
1992	9.77	6.91	37.38	17.10	12.42	8.98	13.25	9.01	11.14	9.52	25.80	14.58	12.23	9.49	27.52	24.02
1993	10.07	7.01	37.56	16.67	12.73	9.03	13.60	9.01	11.60	9.73	26.31	14.62	12.69	9.65	28.75	24.98
1994	9.23	6.42	38.40	17.25	12.57	8.73	13.51	8.74	11.09	9.42	26.88	14.91	12.30	9.38	29.26	25.75
1995	9.66	6.84	38.23	16.81	12.72	9.17	13.64	9.13	11.71	10.09	26.96	14.95	12.80	10.01	28.92	25.61
1996	9.92	7.55	39.43	17.15	13.15	9.51	14.12	9.42	11.65	10.25	27.74	15.10	12.91	10.11	29.75	26.86
1997	9.30	6.77	39.70	17.20	12.77	8.68	13.77	8.64	11.38	9.63	27.86	14.81	12.61	9.41	30.54	26.65
1998	7.95	7.44	39.31	17.24	11.37	7.87	12.58	7.79	10.31	9.08	28.00	15.14	11.34	8.95	30.59	28.00
1999	8.27	6.37	39.15	17.04	11.37	7.79	12.43	7.77	10.41	9.11	28.04	14.93	11.64	8.78	30.51	27.37
2000	8.78	6.87	40.32	17.35	12.65	8.79	13.64	8.76	11.47	10.20	28.96	15.27	12.74	9.87	31.23	27.71
2001	8.35	7.50	40.39	17.34	12.42	8.29	13.46	8.26	11.62	9.44	29.01	15.01	12.40	9.56	31.72	28.07
2002	9.03	6.91	40.28	17.23	12.78	8.94	13.90	8.86	11.98	9.92	29.14	15.18	12.73	10.15	32.30	29.08
2003	9.55	6.71	40.69	17.51	12.21	8.95	13.46	8.74	11.17	10.07	29.18	15.49	12.65	9.50	32.16	29.30
2004	8.55	6.60	40.77	17.89	11.53	7.39	12.37	8.05	9.91	8.81	29.23	15.63	11.48	8.22	31.47	28.85

Note 1: The spillin RD stocks are based on production region, geographical distance, un-weighted production profile, and correlation weighted production cluster for Model 1 to Model 4, respectively.

Note 2: r_1 indicates local internal rate of return, and r_2 indicates social internal rate of return.

Table 9. Internal Rate of Return by Region, U.S. Agriculture, 1980-2004, alternative Spill-in models

Region	Model 1				Model 2				Model 3				Model 4			
	r1		r2		r1		r2		r1		r2		r1		r2	
	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation
1.Northeast	9.88	10.06	31.14	19.85	10.98	11.28	11.43	11.42	10.13	11.23	19.57	20.02	11.18	11.38	29.98	30.56
2.Lake States	11.35	5.30	51.09	8.54	15.02	4.15	15.86	3.90	12.59	4.74	35.34	4.31	13.72	4.40	25.25	5.43
3.Corn Belt	13.05	6.00	55.22	11.47	16.58	6.57	17.19	6.74	13.31	6.20	36.94	8.25	14.26	6.65	28.55	6.59
4.North Plains	16.16	13.86	52.95	16.11	24.70	16.70	25.92	16.04	23.62	19.44	38.84	15.22	25.82	18.84	38.03	15.42
5.Appalachian	11.62	5.55	26.09	9.73	14.10	6.55	14.38	6.58	13.03	6.38	26.90	10.33	14.09	6.44	43.02	45.81
6.Southeast	7.32	5.14	34.69	9.43	9.65	4.04	10.15	3.72	8.22	5.44	25.05	5.91	9.40	4.28	16.91	3.91
7.Delta States	7.62	3.34	34.87	5.86	9.19	4.18	9.53	4.17	8.42	4.20	24.18	7.82	9.22	4.07	23.38	4.31
8.Southern Plains	20.76	6.64	54.53	18.42	27.26	4.77	27.63	4.59	29.51	4.69	47.44	9.97	29.82	4.54	32.25	4.76
9.Mountain	9.31	5.17	40.14	14.30	10.72	5.92	12.58	5.79	9.78	6.09	20.53	8.74	10.99	6.00	31.98	26.52
10.Pacific	9.27	3.23	36.99	16.45	11.67	3.88	11.98	5.53	8.97	4.09	31.40	9.37	10.74	4.02	18.28	4.98

Note 1: The spillin RD stocks are based on production region, geographical distance, un-weighted production profile, and correlation weighted production cluster for Model 1 to Model 4, respectively.

Note 2: r_1 indicates local internal rate of return, and r_2 indicates social internal rate of return.

Table 10. Impacts of the Extension Service, Roads, and Spill-in R&D on Internal Rate of Return in U.S. Agriculture, 1980-2004, alternative Spill-in models

	Model 1				Model 2				Model 3				Model 4			
	r1		r2		r1		r2		r1		r2		r1		r2	
	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation
internal rate of return	10.75	7.98	39.56	17.62	13.61	9.71	16.96	10.32	12.36	10.29	27.54	14.96	13.52	10.23	29.29	15.56
add 10% of ET	12.15	8.35	39.92	17.55	15.06	10.15	18.17	10.67	13.79	10.77	28.21	15.09	15.01	10.72	30.01	15.64
contribution of ET	1.40	0.38	0.36	0.43	1.44	0.44	1.18	0.59	1.43	0.48	0.67	0.57	1.49	0.49	0.72	0.61
add 10% of RO	10.95	8.03	39.61	17.61	13.94	9.81	17.22	10.41	12.71	10.41	27.70	14.99	13.86	10.35	29.46	15.58
contribution of RO	0.20	0.05	0.05	0.06	0.32	0.10	0.26	0.15	0.35	0.12	0.16	0.13	0.34	0.11	0.16	0.14
add 10% of SR	11.60	8.20	39.77	17.58	13.72	9.74	17.04	10.35	12.73	10.42	27.71	14.99	13.78	10.32	29.42	15.57
contribution of SR	0.84	0.23	0.22	0.26	0.10	0.03	0.08	0.05	0.37	0.12	0.17	0.14	0.27	0.09	0.13	0.11

Note 1: The spillin RD stocks are based on production region, geographical distance, un-weighted production profile, and correlation weighted production cluster for Model 1 to Model 4, respectively.

Note 2: r_1 indicates local internal rate of return, and r_2 indicates social internal rate of return.

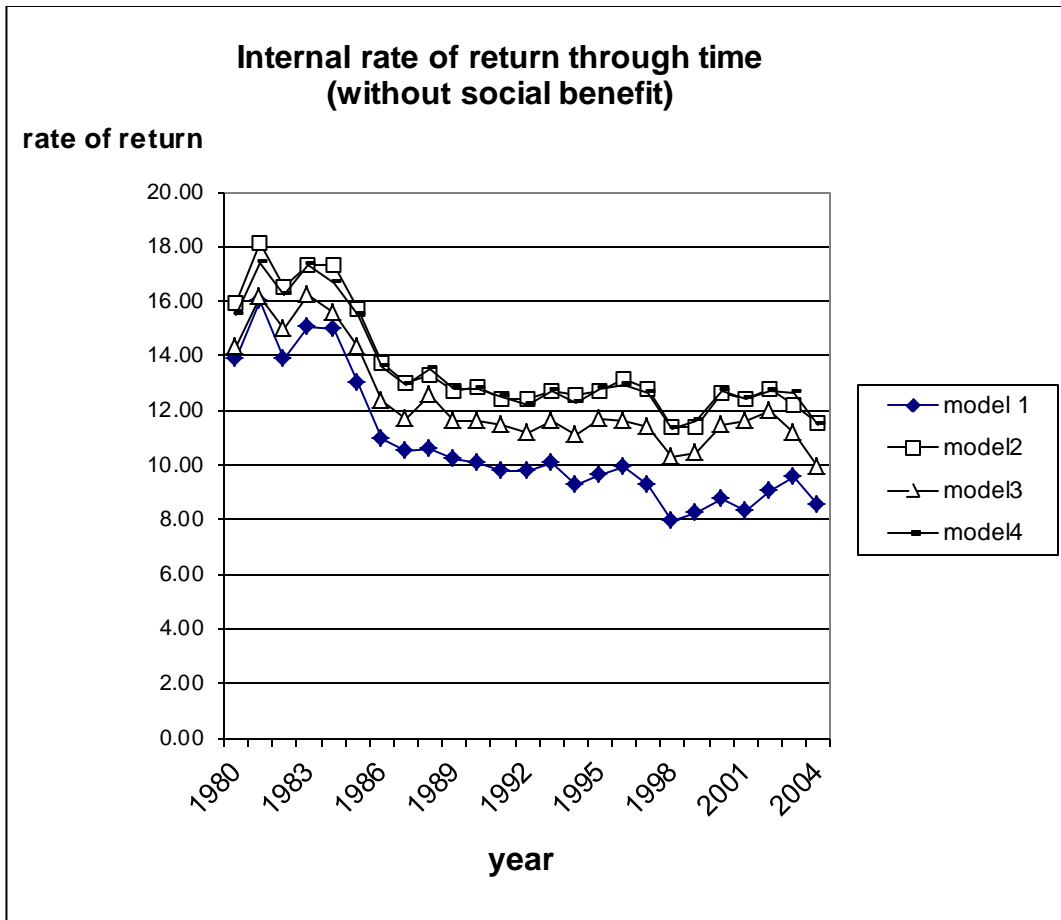


Figure 1. Own internal rate of return, U.S. agriculture, 1980-2004, alternative spill-in models (without social benefit).

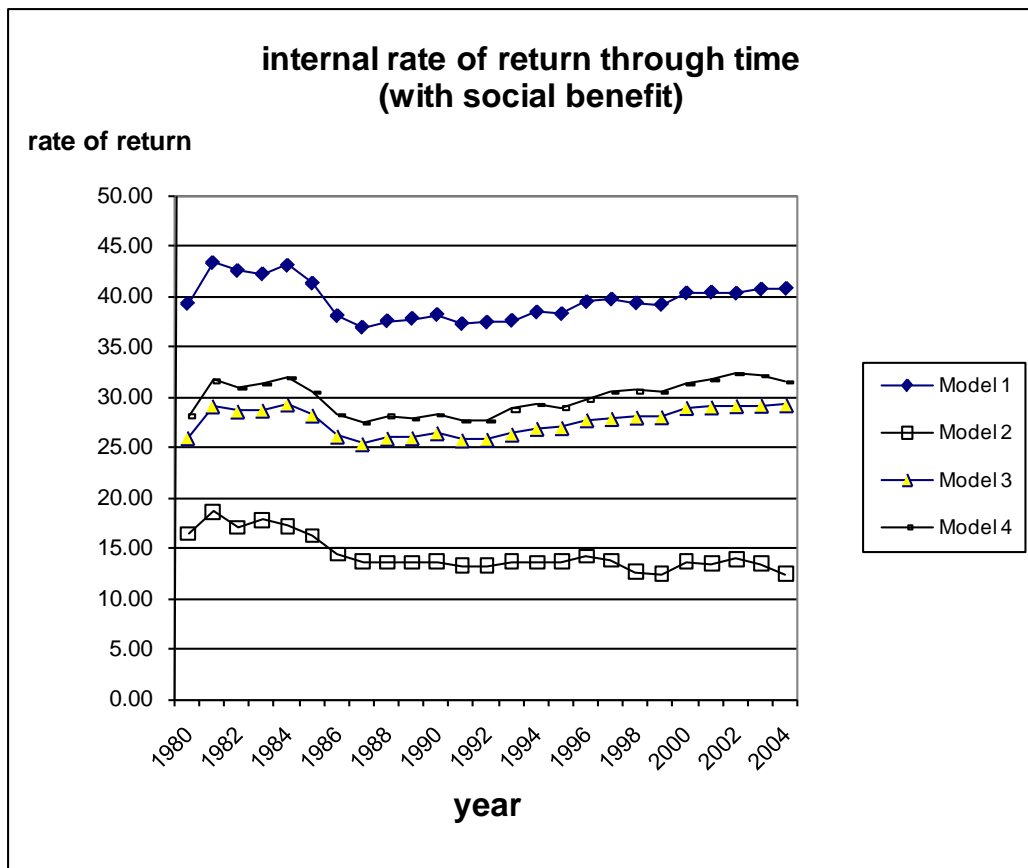


Figure 2. Social internal rate of return, U.S. agriculture, 1980-2004, alternative spill-in models. (with social benefit).