# Public R&D, Private R&D, and U.S. Agricultural Productivity Growth: Dynamic and Long-Run Relationships

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If accelerated productivity growth is to be an effective policy response for reducing greenhouse gas emissions from agriculture, the appropriate means for raising productivity needs to be addressed. Previous research has shown a close correlation between investments in public agricultural research and total factor productivity (TFP) growth in agriculture (Huffman and Evenson 2006; Alston et al. 2010; Wang et al. 2012, among the most recent, comprehensive studies). Largely neglected from this framework, however, has been the role of the private sector. Private sector spending on agricultural research and development (R&D) has grown more rapidly than public agricultural R&D and is now greater than that of the public sector (Fuglie et al. 2011). While it is widely perceived that both public and private R&D make significant contributions to agricultural productivity growth, private R&D (because of data limitations) has rarely been included in empirical models of agricultural TFP growth.

Moreover, there are competing views on the dynamic relationship between public R&D and private R&D. One line of argument is that both compete (provide substitute technologies) with each other, in which case public R&D can crowd out private R&D, especially if the public sector offers its technologies at marginal cost. Alfranca and Huffman (2001) found evidence of crowding out in European Union countries, where increases in public agricultural R&D spending appeared to be followed by reductions in private R&D spending. Another view is that public and private R&D are complementary. This can come about if the public sector focuses on "precommercial" R&D that gives rise to new technological opportunities that the private sector can then further develop into new commercial products. Complementarity can also occur if each sector focuses on different dimensions of the productivity constraints facing agriculture. For example, private R&D may emphasize new technologies that can be embodied in manufactured capital or material inputs, while public R&D may focus on disembodied technologies (e.g., management practices) or environmental dimensions of production, where private incentives may be weak. Both Tokgoz (2006) and Wang, Xia, and Buccola (2009) found that private investments in agricultural and life sciences R&D were significantly correlated with past trends in public spending on life sciences research. However, the complementary hypothesis also implies that the public sector would respond to changes in private R&D behavior. All the empirical tests cited above treat public R&D as an exogenous shock and then examine private sector response; none have examined how the public sector might respond to an exogenous shock

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in private R&D. Understanding these dynamics has important implications for how long-run agricultural productivity growth might respond to public R&D policy.

This study takes advantage of new, long-term time series on public and private agricultural R&D spending in the United States to examine their relationship with one another and to agricultural productivity growth. We estimate a vector autoregression (VAR) model, which includes disaggregated public and private R&D spending (e.g., for crops, livestock, and noncommodity specific general science research where applicable) as well as agricultural TFP growth. This model allows us to assess the two-way dynamic effects of public and private R&D on each other. We also estimate a model of TFP as a function of knowledge stocks generated by public and private R&D, assuming a variety of lag structures for creating R&D stocks from annual expenditures.

## Methodology

In this study we first estimate a VAR model to analyze the dynamic relationships among different research investments and the growth of TFP. We then estimate a regression model to identify the long-run relationships among TFP, public R&D stock, and private R&D stock. For the VAR model our data series cover 1960 to 2009. Because of the need to use a long time series on R&D expenditures to generate R&D stocks, our TFP regression model uses data from 1970 to 2009.

For the dynamic analysis we consider the following *VAR* model of order *p*, or in terms of *VAR(P)*:

$$(1) \qquad y_t = A_0 + \Sigma_{i=1}^{p} A_i y_{t-i} + \varepsilon_i,$$

where $y_t$ is a $(n \times 1)$ vector of endogenous variables, $A_0$ is a $(n \times 1)$ intercept vector of the VAR, $A_i$ is the $i^{th}$ $(n \times n)$ matrix of autoregressive coefficients for $I = 1 \ldots p$, $\varepsilon_i$ is a vector representing a $(n \times 1)$ white noise process. Six variables are used in the VAR model, including public research expenditure in crop-related science (PUC), public research expenditure in livestock-related science (PUL), public research expenditure in general productivity-oriented science (PUG), private research expenditure in crop-related science (PRC), private research expenditure in livestock-related science (PRL), and TFP. The "general science" category (PUG) may consist of more fundamental noncommodity-specific sciences and the crop and livestock categories may be composed of more applied sciences. All research expenditure series were converted to constant 2005 dollars using the research deflator updated from Huffman and Evenson (2006). In the VAR model, the six variables are all in logarithmic term and expressed in first differences.

Given the ambiguity in the literature regarding the dynamics between public and private research, we use an unrestricted VAR model to let the data direct us to the possible links among variables of interest. We use the moving average representation of the *VAR(p)* estimates to obtain impulse-response functions and forecast error variance decompositions (Enders 1995). Note that the R&D variables in the VAR model are expenditures and not stocks and thus represent short-run impacts (if any) of R&D on productivity.

To test for the long-run impacts of public and private R&D on TFP, we construct R&D knowledge stocks (using three alternative specifications of the lag structure) and estimate an Ordinary Least Squares regression model with TFP as the dependent variable and public and private R&D stocks as the independent variables:

$$(2) \qquad LnTFP_t = a_0 + \beta_1 LnX_{1t} + \beta_2 LnX_{2t} + e_t,$$

where *Ln* is the natural log form, *t* is the time subscript, $X_1$ is public R&D stock, $X_2$ is private R&D stock, *e* is the error term, α and βs are coefficients to be estimated. $\beta_i$ also represents the research elasticity, or the percent change in TFP given a 1% change in R&D stock.

## Data and Variable Construction

In this study, we use the TFP index developed by the U.S. Department of Agriculture for U.S. agriculture. TFP is the ratio of an index of farm outputs to inputs, and TFP growth measures farm output growth that is unexplained by growth of inputs under the control of farmers. A complete description of how TFP is constructed can be found in Ball, Wang, and Nehring (2012).

Our series for public expenditures for farm productivity–oriented research builds on data constructed by Huffman and Evenson (Huffman and Evenson 2006; Huffman 2010). The research expenditure data are originally drawn from the Current Research Information System (CRIS), maintained by the

National Institute for Food and Agriculture. The CRIS Commodity/Subject of Investigation classification was used to divide productivity-oriented research from 1970–2009 into 19 research categories that could be further aggregated into crops and livestock research totals. The residual—productivity-oriented research minus crops and livestock research—is designated "general science" research. For earlier years, state-level commodity research expenditures are available from State Agricultural Experiment Station reports for 1948–1965; however, information for expenditures by federal agencies at the state level is not available. Methodology developed by Friedman (1962) for interpolating time series using other series, as well as regularities in the pattern of relationships between national totals for SAES and federal agencies, were used to develop estimates of productivity-oriented research for earlier years (Huffman 2010). In our study, crop and livestock research can be classified as applied, commodity-specific research, while "general science" can be related to fundamental research.

Private sector research expenditures in the United States for 1960–2009 were obtained from Fuglie et al. (2011), which extended earlier estimates reported in Klotz, Fuglie, and Pray (1995). These sources give annual R&D spending for seven agricultural input industries between 1960 and 2010. We group these into crop sectors (crop seed/biotechnology, crop protection chemicals, fertilizer, and farm machinery) and livestock sectors (animal health, animal genetics, and animal nutrition). For years prior to 1960 (necessary for constructing research stocks) we used estimates of total private sector agricultural research reported in Huffman and Evenson (2006).

Figure 1 shows public and private agricultural research spending between 1970 and 2009 in constant dollars. Public expenditures grew rapidly until 1983 and then leveled off, except for general science research, which exhibited more steady growth over the whole period. Total public research expenditures grew more slowly than total private research expenditures. Private crops research expenditures grew more rapidly (and were larger) than other research expenditure series, while private livestock research, after growing from 1970 to 1976, remained essentially unchanged in subsequent years.

To account for the lag time between when research is done and when productivity is likely to be affected, we consider three alternative lag structural specifications to create the R&D stock variables. Moreover, because private research may be more applied than public sector research (an assumption empirically supported for agricultural research by Chavas and Cox [1992]), we use a shorter lag structure compared with public research. The first is a trapezoidal lag specification developed by Huffman and Evenson (2006) with total lag

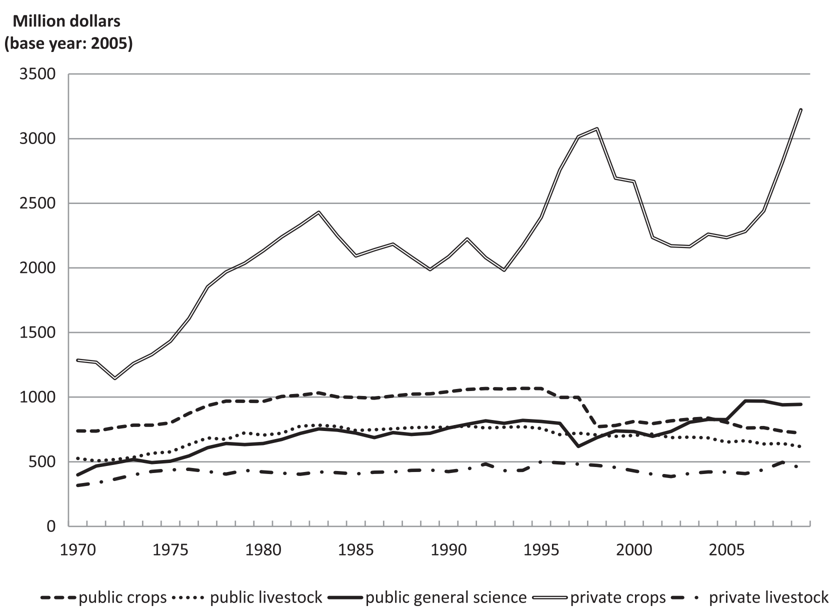


**Figure 1. Trends of public research investment and private research investment**

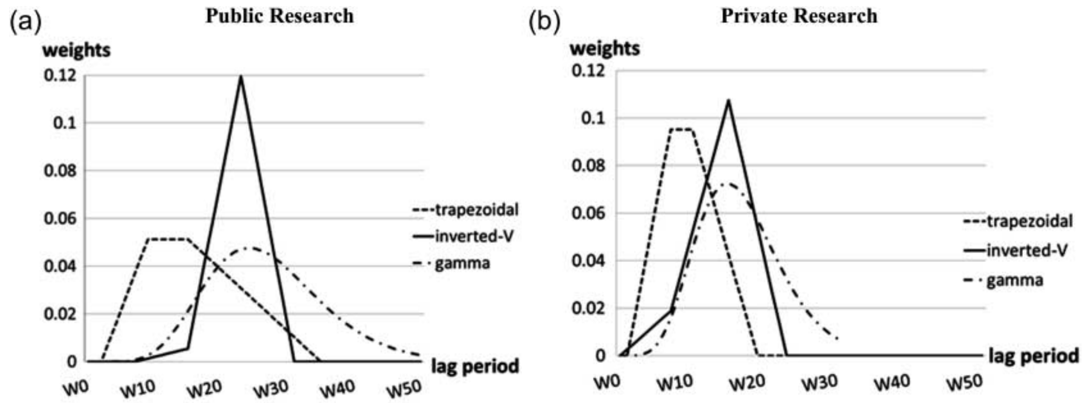


**Figure 2. Weights used in constructing research stocks**

lengths of 35 years and 19 years for public and private research, respectively. The second is based on a gamma distribution from Alston et al. (2010). Distribution parameters for public research stocks were assumed to be 0.9 and 0.7 extending for 50 years; for private sector research we assumed parameters of 0.89 and 0.6 extending for 30 years. The third specification is an inverted-V lag structure from Chavas and Cox (1992). The total lag length for public and private R&D is 31 and 23 years, respectively. Figure 2 compares these lag structures. In all cases the private research lag structures have mean, median, and peak values less than those for public research lags.

To examine stationarity properties of the variables, we conducted augmented Dickey–Fuller (ADF) and Phillip–Perron (PP) unit root tests for all level and first-differenced values of the variables (Enders 1995). The first-differenced values of the research expenditures and TFP (log form) were found to be stationary. The TFP series and most of the alternative research stock series were also found to be stationary based on either or both the ADF and PP tests. Only the private R&D stock with the inverted-V lag structure fails to reject the unit root hypothesis. Since our purpose in using alternative lag structures for constructing R&D stocks is to test for the robustness of our estimation to lag specification assumptions, we use level variables for all variables in our regression model of long-run TFP growth.

## Empirical Results and Discussion

### *Dynamic Relationships*

Based on the moving average representation of the VAR estimates, we formed impulse response functions that trace the effect of an exogenous, one-time shock (change in value) in each variable on its future values as well as on the current and future values of the other variables in the model (Figure 3). These results imply that there are significant and asymmetric interactions among and between public and private agricultural research. A shock (exogenous spending increase) to public crop research (PUC) causes private crop research (PRC) to rise, implying public sector crop research may be creating new technological opportunities, and therefore greater incentives for the private sector to further develop into improved inputs for crop production. On the other hand, within the public sector, there appears to be competition between "public general research" (PUG) and public crop research (PUC). An exogenous increase in one budget category causes the other budget category to fall, which may reflect a strong budget constraint to public agricultural research.

The results also suggest the public sector responds to exogenous shocks in private sector R&D. In particular, a shock to PRC causes PUC to fall. With the passage of the Plant Variety Protection Act in 1970 and extension of utility patents to biotechnology inventions in 1980, there was significant expansion of private crop breeding research, including crops such as soybeans, which had until that time had been mainly performed by the public sector. In response, public breeding programs moved away from supplying finished varieties to more upstream areas like germplasm enhancement (Huffman and Evenson 2006; Fuglie and Walker 2001). This VAR result supports the hypothesis that public applied crop research avoids competing with private crop research when incentives for private research change.

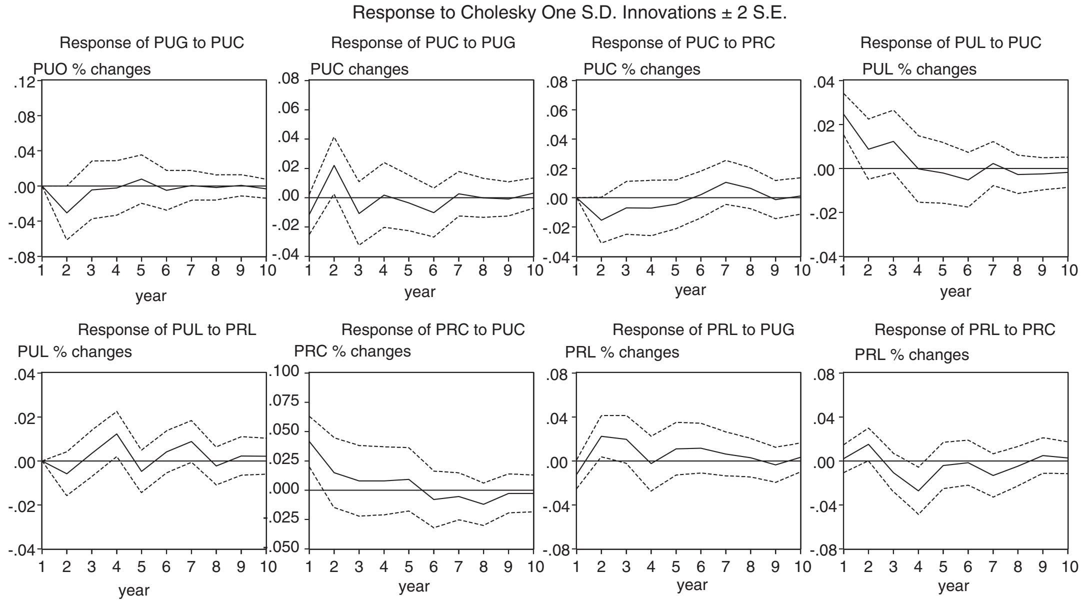


**Figure 3. Impulse responses to one-standard-deviation structural shocks**

Regarding livestock research, the VAR results imply no significant interactions between public and private livestock research. The great majority of private livestock research is in developing new veterinary pharmaceuticals to treat animal diseases and stimulate growth; these are often spin-offs from the companies' research on human pharmaceuticals (Fuglie et al. 2011). Interactions between public and private research may be stronger in animal genetics and nutrition, although private R&D in these areas has remained relatively small. However, there is some evidence that public and private livestock research responds positively to exogenous shocks to either PUG or PRC.

Using generalized forecast error variance decomposition based on our VAR estimates, we decompose the variation of each variable into six sources—a PUG shock, a PUC shock, a PUL shock, a PRC shock, a PRL shock, and a TFP shock (table 1). In general, public research investment variations were mainly explained by shocks from other public research areas. For example, in both the short-run (2 years) and long-run (6 years), PUC shocks explain 11% of the variation in PUG. Shocks to PUC also explain 27% of the short-run and 37% of the long-run variations in PUL. Shocks to PUG explain nearly 20% of PUC variation in both the short run and long run.

Contrarily, private research variations are explained primarily by public research shocks rather than R&D shocks within the private sector. Shocks to PUC explain 27% of the short-run variation and 24% of the long-run variation in PRC. A significant share of the variation in PRL (22% in both the short run and the long run) is explained by PUG.

### *Long-Run Relationships*

In the VAR model, agricultural TFP growth does not respond to shocks from any of the research spending variables. In other words, short-run impacts of R&D spending on productivity are not significant. This is consistent with the notion that it takes time to develop applicable technology from research and that research knowledge stocks, not current expenditures, are the appropriate variable for considering the effects of research on productivity.

Table 2 presents the results of the impacts of public and private R&D stocks on TFP growth under alternative assumptions about the R&D lag structure. Note that we also include a dummy variable for the post-1985 years. This is to capture the effect of a structural break in 1985 that was detected in the TFP series based on the Zivot–Andrews test. The results show that the public R&D stock contributes to TFP growth significantly and positively in all models. However, the signs for private R&D stock are ambiguous, with positive but insignificant impact on TFP in model 2 (gamma lag structure) and model 3 (inverted-V lag structure), but with a significant and negative impact in model 1 (trapezoidal lag structure).

**Table 1. Results of Variance Decompositions**

| | Variance Decomposition (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| Variance | PUG | PUC | PUL | PRC | PRL | TFP | Sum |
| **Short run (2 year)** | | | | | | | |
| Public R&D: general science (PUG) | 86.07 | 11.08 | 0.05 | 2.69 | 0.10 | 0.00 | 100.00 |
| Public R&D: crops (PUC) | 19.76 | 68.49 | 0.61 | 7.60 | 3.17 | 0.36 | 100.00 |
| Public R&D: livestock (PUL) | 1.41 | 44.65 | 51.49 | 0.14 | 2.25 | 0.07 | 100.00 |
| Private R&D: crops (PRC) | 0.09 | 27.25 | 0.17 | 70.89 | 0.40 | 1.19 | 100.00 |
| Private R&D: livestock (PRL) | 22.17 | 4.57 | 1.04 | 7.78 | 63.63 | 0.81 | 100.00 |
| TFP | 1.58 | 4.68 | 4.79 | 2.47 | 3.16 | 83.32 | 100.00 |
| **Long run (6 year)** | | | | | | | |
| Public R&D: general science (PUG) | 78.63 | 11.08 | 1.12 | 4.30 | 2.25 | 2.61 | 100.00 |
| Public R&D: crops (PUC) | 19.70 | 52.37 | 7.40 | 8.34 | 9.02 | 3.17 | 100.00 |
| Public R&D: livestock (PUL) | 6.08 | 37.35 | 42.12 | 2.74 | 10.21 | 1.50 | 100.00 |
| Private R&D: crops (PRC) | 4.79 | 24.31 | 0.90 | 60.96 | 2.52 | 6.53 | 100.00 |
| Private R&D: livestock (PRL) | 22.46 | 9.30 | 4.49 | 19.26 | 43.18 | 1.31 | 100.00 |
| TFP | 1.70 | 10.12 | 14.76 | 2.87 | 6.56 | 63.99 | 100.00 |

**Table 2. Estimation Results Using Alternative Lag Distributions**

| | Model 1 (Trapezoidal Lag) | | Model 2 (Gamma Lag) | | Model 3 (Inverted-V Lag) | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | *P* value | Coefficient | *P* value | Coefficient | *P* value |
| D1985 | 0.06 | 0.11 | 0.06 | 0.03 | 0.01 | 0.69 |
| Total public R&D | 1.19 | 0.00 | 0.55 | 0.00 | 0.43 | 0.00 |
| Total private R&D | −0.49 | 0.02 | 0.01 | 0.92 | 0.14 | 0.17 |
| Constant | −0.91 | 0.05 | 0.24 | 0.31 | 0.20 | 0.50 |
| Adjusted $R^2$ | 0.95 | | 0.97 | | 0.96 | |
| Variance inflation factor | 43.93 | | 32.80 | | 19.57 | |

*Note:* D1985 is a dummy variable for 1985 and subsequent years. All other variables are in natural logarithm form.

Note, however, that the sum of the public and private research elasticities is quite similar across the three R&D lag structures (ranging from 0.56 to 0.60).

The ambiguous result for private R&D may be due to high collinearity between public and private R&D stocks. The mean variance inflation factor (VIF) shows a high degree of multicollinearity (VIF > 10) among the independent variables irrespective of the assumptions on research lag structure. One common way to resolve this problem is to leave out one variable from the regression. Results (not shown) that include only one R&D stock (public R&D stock, private R&D stock, or total R&D stock) show a significant and positive impact of research on TFP, although the estimated research elasticities are sensitive to excluding variables as well as to assumptions about lag structure. Unless further sources of variation can be introduced into models of this type, it might not be feasible to disentangle the productivity impacts of public R&D from private R&D. Nonetheless, omitting private R&D may overattribute productivity impacts to the public sector, leading to overestimation of the marginal rate of return to public research.

## Summary and Conclusion

The increasing importance of private industry in agriculture research has important implications for public science policy and future productivity growth in U.S. agriculture. This study finds econometric evidence of complementarity between public and private agricultural research investments, with both sectors responsive to what the other sector is doing (or not doing). Increased spending on public fundamental or applied crop research appears to stimulate an increase in private research on crops, possibly because of new technological opportunities for commercialization opened up by public research. At the same time, public crop research appears to decline following an exogenous increase in private crop research, possibly because the public sector withdraws from areas it sees private companies pursuing. Within the public sector, there appear to be trade-offs between different types of research (an increase in one leads to a decline in another), which could be explained by binding budget constraints faced by public research institutions. These dynamic relationships are most evident in the crop sector; public and private livestock research seems to be largely exogenous of each other.

Other results from the study confirm that research affects agricultural productivity only over the long term. Changes in either public or private research expenditure have no significant impact on agricultural TFP growth, but research stocks (accumulation of several years of research expenditures) do. However, due to the high collinearity between public and private agricultural research stocks (even with 40 years of time series data), it remains difficult to estimate the respective impacts of public and private research on productivity. The estimates of research elasticities are sensitive to the model structure and assumptions about the lag structure used to construct research stocks of knowledge capital. Future studies will need to address this multicollinearity issue in order to untangle the separate productivity impacts of public and private R&D.

## References

Alfranca, O., and W.E. Huffman. 2001. Impact of Institutions and Public Research on Private Agricultural Research. *Agricultural Economics*. 25(2-3): 191–198.

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*. New York: Springer.

Ball, V.E., S.L. Wang, and R. Nehring. 2012. Agricultural Productivity in the U.S.: Documentation and Method. Economic Research Service, U.S. Department of Agriculture. Available at http://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/documentation-and-methods.aspx. Accessed May 2012.

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

Enders, W. 1995. *Applied Econometric Time Series*. New York: Wiley.

Friedman, M. 1962. The Interpolation of Time Series by Related Series. *Journal of the American Statistical Association* 57(300): 729–757.

Fuglie, K.O., P.W. Heisey, J.L. King, C.E. Pray, K. Day-Rubenstein, D. Schimmelpfennig, S.L. Wang, and R. Karmarkar-Deshmukh. 2011. *Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide*. Economic Research Report 130. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Fuglie, K.O., and T.S. Walker. 2001. Economic Incentives and Resource Allocation in U.S. Public and Private Plant Breeding. *Journal of Agricultural and Applied Economics* 33(3):459–473.

Huffman, W.E. 2010. Measuring Public Agricultural Research Capital and Its Contribution to State Agricultural Productivity. Iowa State University, Department of Economics Working Paper #09022, 2010.

Huffman, W.E., and R.E. Evenson. 2006. *Science for Agriculture: A Long-Term Perspective* (second edition). Ames, IA: Blackwell Publishing.

Klotz, C., K.O. Fuglie, and C. Pray. 1995. Private Sector Agricultural Research Expenditures in the United States, 1960–1992. Staff Paper AGES-9525, Economic Research Service, U.S. Department of Agriculture, Washington, DC, October.

Tokgoz, S. 2006. Private Agricultural R&D in the United States. *Journal of Agricultural and Resource Economics* 31(2): 212–238.

Wang, S.L., V.E. Ball, L.E. Fulginiti, and A. Plastina. 2012. Accounting for the Impacts of Public Research, R&D Spill-ins, Extension, and Roads in U.S. Agricultural Productivity Growth. In K. Fuglie, S.L. Wang, and V.E. Ball, eds., *Agricultural Productivity: An International Perspective*. Walingford, UK: CABI.

Wang, C., Y. Xia, and S.T. Buccola. 2009. Public Investment and Industry Incentives in Life Science Research. *American Journal of Agricultural Economics* 91(2): 374–388.