Research Spillovers and Returns to Wheat Research Investment

by

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Abstract:

This study evaluates the rates of return to US wheat research investment, focusing on research spillovers. Results show that research spillovers exist among various classes of wheat. Due to the spillover effects, social rates of return to research investment are substantially higher than the corresponding private rates of return.

Research Spillovers and Returns to Wheat Research Investment

The growth economic literature in the 1990's reemphasized an important point that unless there are significant externalities, spillovers, or other sources of social increasing returns, it is unlikely that economic growth can proceed at an undiminished rate for a long period of time. The importance of externalities and research spillovers for the explanation of productivity increase is the driving force behind a great amount of research activities (Griliches, 1992).

The issue of research spillovers in the agricultural sector is particularly interesting and important. The size and skill requirement for efficient research activity makes it impractical for farm firms to do fundamental research, such as those of a biological and chemical nature. Moreover, the homogeneity of agricultural products and the nature of the inventions or technological changes make it difficult for a small farm to capture the benefits from research or inventive efforts it undertakes. As a result, much of the research and development activities are conducted by the federal and state government. It is important to measure the rate of returns to research investment so that public funds can be used optimally. The rates of return to research investment can be measured accurately only when spillovers are accounted for. If technology spillovers can be anticipated, then allocation efficiency of research investment can be improved by targeting resources to spillover generating research programs.

This study measures the rate of returns to US investment in wheat research, with special efforts made to identify spillover sources and receivers among five major classes of wheat, including hard red winter, hard red spring, soft red winter, durum, and white. Identification of spillover sources and receivers can help to measure rate of returns to research investment more accurately and hence contributes to enhance the allocation efficiency of public funds. Although several studies (e.g. Araji, Sim, and Gardner; Araji, White, and Guenthner) evaluated the returns to investment in wheat research in the United States, they shed no light on spillover effects among various wheat classes.

The Model

A popular approach to measure rate of returns to investment is the cost function approach. The cost function approach considers not only the impacts of research on the total cost of production, but also the impacts on the specific input costs. It facilitates the estimation of the effects of research on the demands for production factors. This approach also facilitates the discrimination between the potential spillover sources and receivers.

A translog model is usually specified for empirical estimation when rate of returns is measured using the cost function approach. A translog model has the advantage of being flexible and linear in parameter estimates. In this study, a modified translog model is specified for each class of wheat. For hard red winter wheat, the model is

$$\begin{aligned}
\ln\left(\frac{c}{m}\right) = {} & b_o + b_l \ln\left(\frac{l}{m}\right) + b_h \ln\left(\frac{h}{m}\right) + b_k \ln(K) + b_q \ln(Q) + b_w \ln(W) \\
& + b_{lh} \ln\left(\frac{l}{m}\right) \ln\left(\frac{h}{m}\right) + b_{lk} \ln\left(\frac{l}{m}\right) \ln(K) + b_{lq} \ln\left(\frac{l}{m}\right) \ln(Q) \\
& + b_{hk} \ln\left(\frac{h}{m}\right) \ln(K) + b_{hq} \ln\left(\frac{h}{m}\right) \ln(Q) + b_{kq} \ln(K) \ln(Q) \\
& + b_{ll} \tfrac{1}{2} \ln(l)^2 + b_{hh} \tfrac{1}{2} \ln(h)^2 + b_j \ln(k_j) + e
\end{aligned} \qquad \textbf{(1)}$$

where C is the total variable cost, m is the price index of materials, l is the wage of labor, h is the price index of mechanical inputs, K is the annual research investment of hard red winter wheat, Q denotes the annual yield, W is the weather variable, k_j is the sum of the research expenditure of all the other classes of wheat. For other classes of wheat, the model is

$$\begin{aligned}\ln\left(\frac{c}{m}\right) &= b_o + b_l \ln\left(\frac{l}{m}\right) + b_h \ln\left(\frac{h}{m}\right) + b_k \ln(K) + b_q \ln(Q) + b_w \ln(W) \\ &+ b_{lh} \ln\left(\frac{l}{m}\right) \ln\left(\frac{h}{m}\right) + b_{lk} \ln\left(\frac{l}{m}\right) \ln(K) + b_{lq} \ln\left(\frac{l}{m}\right) \ln(Q) \\ &+ b_{hk} \ln\left(\frac{h}{m}\right) \ln(K) + b_{hq} \ln\left(\frac{h}{m}\right) \ln(Q) + b_{kq} \ln(K) \ln(Q) \\ &+ b_{ll} \tfrac{1}{2} \ln(l)^2 + b_{hh} \tfrac{1}{2} \ln(h)^2 + b_j \ln(k_j) + b_{hw} \ln(k_{hw}) + e\end{aligned} \qquad \textbf{(2)}$$

where K is the annual research investment of the class under consideration, k_{hw} is the research expenditure of hard red winter wheat, and k_j denotes the sum of the research expenditures of the other three classes of wheat. All the other terms are defined as in equation (1).

During the years covered by this study, the trends of annual research expenditures of hard red spring, soft red spring, white and durum wheat show similar patterns. To mitigate the multi-collinear problem, they are grouped into one variable k_j. In the estimation process, if k_j has a significant effect, further efforts are made to trace the specific spillover source or sources.

According to Shephard's Lemma, input cost shares can be obtained by differentiating the cost function with the corresponding input prices. For each of the five classes, the labor factor cost share is

$$S_l = b_l + b_{lh} \ln\left(\frac{h}{m}\right) + b_{lk} \ln(K) + b_{lq} \ln(Q) + e . \qquad \textbf{(3)}$$

The machinery cost share is

$$S_h = b_h + b_{hl} \ln\left(\frac{l}{m}\right) + b_{hk} \ln(K) + b_{hq} \ln(Q) + e. \quad \textbf{(4)}$$

For translog cost model to behave well, the coefficients on the factor prices must sum to 1, the coefficients on the cross terms of the factor prices sum to 0, the coefficients on the terms involving k and the terms involving Q in the share equations must sum to 0 respectively. Because the cost shares sum to 1 and disturbance terms sum to 0, to avoid singularity problem in the estimation, the cost equation is normalized with the materials price and the materials cost share equation is excluded. Notice k is not included in the total cost, thus, k is not normalized by m. Green and Berndt give detailed discussion and good examples on how to apply translog cost model in empirical estimation. We follow Berndt's procedure to compute the coefficients on terms involving material prices. From the regularity conditions, we know that

$$\begin{aligned} &b_l + b_m + b_h = 1, \\ &b_{lm} + b_{lh} + b_{ll} = 0, \\ &b_{ml} + b_{mh} + b_{mm} = 0, \\ &b_{hl} + b_{hm} + b_{hh} = 0, \\ &b_{ql} + b_{qm} + b_{qh} = 0, \\ &b_{kl} + b_{km} + b_{kh} = 0. \end{aligned} \quad \textbf{(5)}$$

Symmetry is imposed in the estimation, that is, $\hat{a}_{ij} = \hat{a}_{ji}$. With the estimates from the above model, the estimates for the variables involving the m term are derived as

$$
\begin{aligned}
b_m &= 1 - b_l - b_h, \\
b_{ml} &= -(b_{lh} + b_{ll}), \\
b_{mh} &= -(b_{lh} + b_{hh}), \\
b_{mq} &= -(b_{lq} + b_{hq}), \\
b_{mk} &= -(b_{lk} + b_{hk}), \\
b_{mm} &= -(b_{ml} + b_{mh}) = 2b_{lh} + b_{ll} + b_{hh}.
\end{aligned} \qquad \textbf{(6)}
$$

For each class of wheat, the cost equation and share equation can be estimated simultaneously using seemingly unrelated regression (SUR) method to gain estimation efficiency because it is very likely that they are related through the variance and covariance matrix.

Data and Variable Specification

Total variable production cost per acre, the dependent variable in the model, is formed of the sum of the costs of wheat seed, fertilizers-lime-gypsum, chemicals, custom operations, fuel-lube-electricity, repairs, hired labor, unpaid labor and capital replacement. The data for production costs are obtained from *Costs of Production of Major Field Crops*. Table 1 presents the statistical summaries of cost items. The item material is the sum of the costs of fuel, seed, fertilizer and chemicals while the item machinery is the sum of the costs of custom operation, repair, and capital replacement.

Four types of production factors are considered in the study, including research investment, labor, machinery, and material. Research investment is the annual national-level research expenditures for hard red winter wheat, hard red spring wheat, soft red winter wheat, white wheat and durum wheat. The research expenditures consist of USDA approved federal research expenditures, other federal research expenditures and non-federal public research expenditures. The research expenditures are deflated by price deflator for research and measured in million dollars.

Following the practices of previous studies, the machinery and the material inputs are constructed using the factor costs. Machinery is formed of costs on custom operation, repair, and capital replacement. Capital replacement represents a charge sufficient to maintain a machinery investment and production capacity through time. It is the major contributor in the machinery variable. The sum of the price indexes of custom operation, repair, and capital replacement, weighted by the corresponding costs, is used as an explanatory variable in the model.

Material consists of wheat seed, fertilizer-lime-gypsum (fertilizer), chemicals, fuel-lube-electricity (fuel). Data on seed quantities used per acre and seed prices of both hybrid varieties and home produced seed were used to form per acre seed cost. Because chemical fertilizers play a very important role in crop production, the quantity of chemical fertilizers used by major producing states and the corresponding prices were used to form the regional per planted acre fertilizer cost. Fuel costs for tractor are computed on basis of power takeoff, horsepower size and fuel consumption. For other kinds of machines, fuel consumption is gauged at the hourly rate. The total amount of fuel used for production is the sum of all the fuel used for each machine based on the required hours of machine use. The fuel cost is the product of the total amount used per acre and the corresponding fuel prices at state level. The sum of the price indexes of seed, fertilizer, chemicals, and fuel, weighted by the corresponding costs, is used as an explanatory variable in the model.

The labor variable includes hired labor and self-employed labor. Agriculture in the United States is mechanized and labor in crop production is mostly involved in machine handling.

Machinery labor requirement is directly related to machine time requirement. Labor requirement for other activities, such as for hand operation, are also included in the total per acre labor cost.

Annual yield, measured in million bushels, is included in the model to measure economy of scale. During the years covered in the study, hard red winter production showed a general decreasing trend while hard red spring wheat production showed an increasing trend. Soft red winter wheat production fluctuated sharply between 190 and 680 million bushes in late 70's and 80's, but become more stable in the 90's around 400 million bushels. White wheat production fluctuated sharply over the years and has no obvious trend. Durum wheat production fluctuated a lot in the late 70's and the 80's, then become rather stable around 100 million bushels.

Weather is known to affect crop production and is included in the model. The weather variable is formed of monthly precipitation of wheat producing states weighted by the production of the states. According to reports in wheat situation and outlook over the years, precipitation often affects wheat production significantly while extreme temperature was occasionally reported to affect wheat production to some extent. Thus, precipitation is used to represent weather. The weather variable for winter wheat is formed of the weighted sum of precipitation in August, September, October, November, December of previous years and January, February and March of the current year. For spring wheat, the weather variable is formed of the weighted sum of precipitation in March, April, May, June and July.

Estimation and Results

For each of the classes of wheat, the cost equation and share equations are estimated simultaneously using SUR method to gain estimation efficiency. Newton-Raphson maximum-likelihood (ML) method is used in the empirical estimation. Two criteria for convergence, invariability of the value of the ML function and the invariability of the parameter estimates, are taken into consideration in the estimation.

Mixed estimation method is used to ensure the estimates of $\hat{a}_l$, $\hat{a}_h$, and $\hat{a}_m$ to remain in an appropriate range. We follow the procedure proposed by Kmenta to impose the mixed estimation. First, an ordinary least square regression is applied on the old data to get the residuals and the estimate of the standard deviation, denoted by "s". Then, the mean value and the variance of the cost share are calculated. With these values, we set

$$(5.19)\quad (b-a) = 4\sqrt{var(u)}\ ;$$

$$\frac{a+b}{2} = \bar{x}\ .$$

Where $\bar{x}$ is the mean value of the cost share and var(u) is the variance of cost share. A new observation is formed on the basis of the above concept. Suppose we want to confine the estimate of the coefficient on the i[th] independent variable within an appropriate range according to pre-information, then we can form a new observation as

$$(5.20)\quad \frac{(a+b)s\sqrt{4}}{b-a} = 0,\ldots,\hat{a}_i\frac{s\sqrt{16}}{b-a},\ldots,0\ .$$

This new observation is then added to the old data.

The curvature condition is checked point for point by examining the Hessian matrix of the relevant parameter estimates. In the translog model, a necessary and sufficient condition for the factor prices to be quasi concave in cost is that the principal minor of the Hessian matrix alternate in sign between non-positive and non-negative, starting with $h_{11} \leq 0$, $(h_{11}h_{22}-h_{12}^2) \geq 0$. Antle and Capalbo give a detailed discussion on how to check curvature condition for translog model and we follow their procedure. We set a criterium that if the absolute value of the determinant of the Hessian matrix is smaller than or equal to 0.00000000001, then the curvature condition is satisfied.

Table 3 presents the estimation results of the five classes of wheat. To find the effect of own research on cost, first take the derivative of the cost function with respect to research variable to get the relevant cost elasticity. The mathematical form is $\partial \ln(c/m)/\partial \ln(k) = \hat{a}_k + \hat{a}_{kl}\ln(L) + \hat{a}kh \ln(h) + \hat{a}km \ln(m)$. Since it is a linear combination of several estimated coefficients and constants, it's variance can be derived from the corresponding variances. With the estimated variance, a T-test is applied to determine whether it is statistically significant. The marginal cost effects of research are found by multiplying the elasticity by $\bar{c}/\bar{k}$ where $\bar{c}$ is the mean of the log of cost and $\bar{k}$ is the mean of the log of research expenditures. Then, a private internal rate of return, which is the internal rate of return measured as the variable cost reduction due to own research capital expansion, is computed on the basis of the marginal cost effects and the lag length of the research variable.

For hard red winter wheat, the coefficient on research, $\hat{a}_k$, has a value of -1.477 and is statistically significant. Although the coefficients $\hat{a}_{kh}$ and $\hat{a}_{km}$ are not significant, the cost elasticity of research is significant at 1% level with a value of -1.478. Multiplying the elasticity by $\bar{c}/\bar{k}$ results in a marginal effect of -5.881. This means spending one more dollar on research will reduce the total production cost by five dollars and eighty-eight cents.

Efforts were made to find the optimal lag length and distribution of research effect. Lag length differs among different classes of wheat. This may be due to genetical difference, information efficiency difference, managerial efficiency difference and difference in willingness to take risk. For hard red winter wheat, the optimal lag length is found to be nine years distributed in quadratic form. The private internal rate of return calculated on the nine-year-lag basis is 49.3%. This rate of return is within the range of previous findings. For example, Griliches (Griliches, 1958) got an internal rate of return of 35%-40% for hybrid corn, and 20% for hybrid sorghum. Durai found an internal rate of return to wheat research as high as 91.34%.

Although Durai found a very high rate of return, it is not necessary in conflict with that of this research. His research covered 1966 to 1980, the period of the green revolution when the rate of return to research was high. His results imply that wheat research was substantially under invested. Starting from the late 70's, research expenditures of hard red winter wheat kept increasing all the way until 1995 with little fluctuations. It is likely that the relevant institutions discovered that hard-red-winter-wheat research was under invested. As a result, the research expenditure was increased. Increase in research expenditures leads to a lower rate of return. This reflects the process of adjustment to economic efficiency.

Research investment of hard red spring wheat was found to have a significant effect on the production cost, with a cost elasticity -0.523. The optimal lag length of research effect is found to be seven years, the shortest of all the five classes of wheat. Former studies found lag length for agricultural research is between six and twelve years. Thus, this lag length is within the range of previous findings. The private rate of return to research investment is 43.2%, a rate within the range of earlier findings.

Strong evidence is found that research investment of white wheat affects factor demand, increasing the use of machinery input while decreasing the use of material input. However, research investment does not have a significant effect on production cost. This does not mean that research has no impact on production. Research may be largely mission oriented to improve product quality. More and more attention is paid to improve quality recently, such as to increase the protein in wheat or to meet special needs. With limited information, it is difficult to quantify the quality improvement.

Research investment of durum has a significant impact on the production cost of this class of wheat. The cost elasticity of research has a value of -1.686 and the marginal effect is -7.537. The private rate of return, computed on the nine-year lag effect, is 59%.

Soft red winter wheat benefits substantially from the research achievements of hard red spring wheat, but its own research investment has little impact on its production cost. The private rate of returns to research is 3%, very low compared with earlier findings. Further, soft red winter is second only to hard red winter in production and research expenditures, yet it is the only one which is not a spillover source for any other class of wheat. One possible reason is that soft red winter wheat is produced in more than twenty states. Compared with other classes of wheat, each state spends much less money for research. Average expenditures per state are small, hence, economies of scale may not be achieved.

Spillovers and Social Rate of Return

A social rate of return is the sum of private rate of return plus the marginal cost reductions due to the inter-class research spillovers. The private rate of return and social rate of return to research investment of the five classes of wheat are reported in table 4.

Research of hard red winter is identified to be the spillover sources for durum wheat and hard red spring wheat. Due to the spillover generating ability of its research activities, the social rate of return to research investment of hard red winter wheat is about 12% higher than its private rate of return.

There are several possible reasons for hard red winter being a spillover source for hard red spring. First, hard red winter has greater financial support for its research, which generally results in more discoveries. This makes hard red winter a good candidate for spillover source. Second, hard red winter and hard red spring are genetically the same type of wheat. Research achievements of hard red winter wheat can be readily used in the production of hard red sprig wheat. Third, hard red spring is mostly produced in North Dakota and South Dakota while Kansas is the most important producer of hard red winter wheat. Geographically, these two classes of wheat are grown in bordering regions. Previous researches show geographic closeness has significant impact on spillover.

Durum wheat is relatively small in production and has much less financial resource for research. It may draw heavily from the fundamental discoveries brought forth by hard red winter.

No other class of wheat is found to be a significant spillover source for hard red winter wheat. The result is not surprising because hard red winter is the dominant research performer among all the five classes of wheat. It could be that hard red winter wheat dominates other wheat in both fundamental research and mission oriented research. Therefore, it does not benefit substantially from other's research findings.

Hard red spring is found to be a spillover source for soft red winter wheat. With a substantial impact on the production cost of soft red winter wheat, research investment in hard red spring wheat has a social rate of return of 102.3%, the highest social rate of return among the five classes of wheat, and about 59% higher than its private rate of return.

Research of durum is identified as a spillover source for white wheat although research investment in durum is relatively small. The social rate of return to research investment in durum wheat is 91.5%, about 32.5% higher than the private rate of return. With the highest private rate of return and the second highest social rate of return, investment in durum research is highly profitable. The effect could be due to production concentration because durum wheat is almost exclusively produced in North Dakota.

As far as own production cost is concerned, investment in white wheat research is not found to have a significant impact on cost. However, research of white wheat is identified as a spillover source for durum wheat. White wheat and durum wheat are mutually beneficial.

Concluding Remarks

Research spillovers exist among the five major classes of wheat. Four out of the five classes of wheat are found to generate research spillovers to other classes of wheat. Likewise, four of the five classes of wheat are found to be spillover beneficiaries or receivers. The spillover generating ability may be linked to research scale and production concentration while such factors as genetic closeness may determine whether a specific class of wheat benefits from the research achievements of another class of wheat.

Due to the existence of research spillovers, social rate of return to research investment of a particular class of wheat can be more than double of the corresponding private rate of return. Further, even though research investment of a particular class of wheat does not substantially reduce the production cost of this class of wheat, it may generate cost reduction research spillovers to other classes of wheat. Likewise, the results show that, as far as production cost is concerned, a particular class of wheat can benefit substantially from research spillovers while its own research investment does not help to reduce its production cost. All these provide evidence to the importance of research spillovers.

Rates of return to research investment differ substantially among the five classes of wheat. The results show that research investment of hard red spring, hard red winter, and durum wheat is highly profitable. Compared with the findings of previous studies evaluating rates of return to research investment in crop production, the rates of return to research investment of soft red winter and white wheat are very low. However, information from this single study is not enough to draw a conclusion that research investment of these two classes of wheat are not profitable because research activities may focus on other purposes such as quality improvement instead of cost reduction.

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Table 1. Mean annual research expenditures in millions dollars (1978 to1995).

	Mean	Std. Dev.	Minimum	Maximum
Hard Red Winter	15.744	3.561	10.143	21.257
Hard Red Spring	5.565	0.971	4.234	7.269
Soft Red Winter	6.730	1.810	4.268	9.960
White Wheat	5.521	1.131	3.889	8.376
Durum Wheat	1.733	0.240	1.213	2.162

Table 2. Mean Production Costs per Planted Acre.

Variables	Hard red winter	Soft red winter	Hard red spring	White	Durum
Labor	11.526	13.801	10.297	16.681	10.63
Fuel	10.260	7.903	7.681	15.018	7.70
Seed	5.228	11.997	7.245	8.813	7.42
Fertilizer	12.580	35.093	11.263	25.800	9.37
chemicals	2.618	3.520	6.011	12.200	5.96
Custom operation	6.175	6.253	2.358	4.677	1.94
Repair	8.034	7.020	7.944	11.749	8.19
Capital replacement	17.170	17.686	19.497	26.451	19.69
Material	30.686	58.512	32.201	61.832	30.45
Machinery	31.378	30.959	29.780	42.878	29.82

Table 3. Parameter Estimates for the five classes of wheat.

	Hard Red Winter	Hard Red Spring	Soft Red Winter	White	Durum
Constant	3.672 (3.48)	1.376 (4.479)	-1.068 (-1.403)	2.911 (1.689)	6.723 (5.618)
Machinery	0.381 (32.71)	0.476 (53.463)	0.188 (30.838)	0.441 (39.411)	0.277 (53.719)
Labor	0.089 (12.29)	0.119 (19.144)	0.048 (13.739)	0.117 (14.814)	0.064 (19.541)
Production	0.327 (2.41)	0.392 (7.037)	0.651 (5.606)	0.417 (2.625)	0.309 (2.523)
Weather	0.085 (0.82)	-0.078 (-1.071)	0.219 (1.061)	0.221 (2.346)	-0.132 (-1.121)
Machinery-labor	-0.651 (-5.42)	-0.411 (-0.209)	-0.684 (-9.721)	-0.864(-5.707)	-0.015 (-0.104)
Machinery-research	-0.112 (-1.21)	0.091 (0.534)	-0.008 (-0.177)	0.302 (1.941)	0.378 (1.907)
Machinery-production	-0.045 (-1.21)	-0.106 (-2.994)	-0.069 (-3.099)	-0.261 (-5.079)	-0.021 (-0.704)
Labor-research	0.103 (2.04)	-0.005 (-0.051)	0.181 (6.631)	-0.058 (-0.711)	-0.295 (-1.769)
Labor-production	0.044 (1.42)	0.076 (3.492)	-0.025 (-1.581)	0.196 (5.617)	0.053 (2.256)
HRW. research	-1.376 (- 4.60)	-0.609 (-5.227)	N/A	N/A	-1.241 (-4.184)
HRS. research	N/A	-0.531 (-1.694)	-1.489 (-2.065)	N/A	-0.882 (-2.301)
SRW research	N/A	N/A	-0.136 (-0.685)	N/A	N/A
White research	N/A	N/A	N/A	0.667 (1.447)	-0.882 (-2.301)
Durum research	N/A	N/A	N/A	-1.221 (-3.039)	-1.989 (-3.316)
Squre of machinery	0.782 (3.57)	0.365 (1.134)	0.649 (5.846)	0.465 (1.997)	0.025 (0.127)
Square of labor	0.503 (4.05)	0.413 (3.515)	0.348 (5.385)	1.034 (8.157)	-0.022 (-0.133)
Material	0.529 (1.77)	0.404 (1.291)	0.764 (3.839)	0.443 (0.961)	0.659 (1.098)
Labor-material	0.149 (1.63)	-0.002 (-0.028)	0.335 (7.847)	-0.171 (-2.881)	0.037 (0.486)
Machinery-material	-0.131 (-0.73)	0.046 (0.294)	0.035 (0.429)	0.399 (3.349)	-0.009 (-0.094)
Square of material	-0.019 (-0.11)	-0.044 (-0.511)	-0.371 (-4.803)	-0.229 (-2.968)	-0.028 (-0.428)
Material-production	0.001 (0.03)	0.029 (1.591)	0.095 (4.468)	0.065 (2.149)	-0.032 (-1.957)
Material-research	0.009 (0.10)	-0.086 (-0.977)	-0.173 (-3.907)	-0.244 (-2.451)	-0.083 (-0.732)
Cost elasticity of research	-1.478 (-4.90)	-0.523 (-1.681)	-0.369 (-1.889)	0.649 (1.417)	-1.686 (-2.842)
Marginal effects of research	0.285 (2.07)	0.312 (5.633)	0.721 (6.599)	0.256 (1.613)	0.259 (2.129)
Lag length	9	7	8	8	9
R-squared	0.993	0.999	0.997	0.997	0.983

Note: T-values are in parentheses.

Table 4. Spillover sources, spillover beneficiaries, and private rate of return and social rate of return to research investment of spillover sources.

Spillover sources	Private rate of return to research investment	Social rate of return to research investment	Spillover beneficiaries
Hard red winter	49.3%	61%	Hard red spring, Durum
Hard red spring	43.2%	102.3%	Soft red winter, Durum
Soft red winter	3%	3%	N/A
White	Not Computed	Private rate + 7%	Durum
Durum	59%	91.5%	White