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R&D Spillovers: Evidence from U.S. Food Processing, Farm Machinery and Agriculture

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ABSTRACT

This paper focuses on the private and social rates of return to R&D capital in the three vertically linked sectors, primary agriculture, food processing, and farm machinery and equipment. Evidence supporting a divergence between these rates is found for primary agriculture and food processing. Using a cost function approach, the private rates of return to R&D capital ranged from an average of 10.2% per annum for food processing to 22.3% for farm machinery and equipment. In the case of agriculture, the direct return to public R&D averaged 37.3% per annum. The social rates of return to R&D capital in agriculture and food processing are significantly larger than the private rates due to the existence of spillovers. While the divergence between rates is small in the farm machinery and equipment sector, its high direct rate may suggest relatively large intra-sector spillovers. We find that spillovers from public agricultural R&D to food processing exceeds the spillovers from food processing to the other two sectors. Thus, to a degree, public R&D in agriculture mitigates the market's failure in food processing to fully appropriate the returns to their R&D capital.

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I. Introduction

Growth in factor productivity is closely linked to the level of investment in research and development (R&D), which in turn, depends upon the degree to which firms can appropriate the returns to their R&D capital. Both private and federally supported R&D investments in primary agriculture, food processing and farm machinery and equipment have fallen in recent years. In the case of food processing, growth in private R&D investments have fallen from average rate of 2.7% in the 1970s to 1.5% in the 1980s, while in farm machinery they have fallen from an average of 6.2% to 2%.[1] Primary agriculture and food processing have also experienced declines in the growth of their total factor productivity since about 1985.

Previous studies of rates of return to R&D at the industrial level (Scherer 1982, Bernstein and Nadiri 1988) and at the firm level (Mansfield et al., 1977) find large differences between what is referred to as private and social benefits of R&D capital. Estimates of the private rates of return are based on the extent to which R&D capital lowers own costs of production, while the social rates include the extent to which R&D capital spills over to lower the production costs of others. Bernstein and Nadiri (1988) find private rates of return to R&D capital in five manufacturing industries ranging between 12% to 24%, and corresponding social rates of return in these industries of 16 % to over 45 %. Since the products of R&D capital tend to have public good properties of non-rivalness and often only partial excludability, a market failure problem arises when arrangements to appropriate the total returns to R&D capital are not possible.

The R&D models of endogenous growth by Romer (1990) and Grossman and Helpman

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[1]The decline in federal support for R&D is not unique to these sectors. The share of federally funded research and development (R&D) in total industrial R&D in the U.S. economy has declined from 40% in 1953 to under 18% in 1995 (National Science Foundation, 1995). Since 1989, federal funds for R&D has increased only marginally in nominal terms, with growth in real R&D funds averaging a negative 3% per year.

(1991) depict this type of market failure in a general equilibrium context. The calibration of a R&D model of this nature to country data by Diao et al. (1996) yielded a growth rate of approximately twice the Walrasian growth rate when the R&D externality was internalized, thus suggesting large potential social gains. The extent of R&D spillovers in these general equilibrium models depends upon the growth in "knowledge" as proxied by the production of patents, while the level of R&D capital is influenced by the degree of product differentiability which permits firms to appropriate returns from these investments. This later feature is also consistent with the contributions of Mansfield (1983), and Helpman and Krugman (1985). However, aside from the above mentioned literature and other macro economic studies (Backus et al. 1992), there tends to be a paultry of econometric evidence on technological spill-overs, and particularly so for the case of U.S. farm, farm input and food processing sectors.[2]

The case of agriculture is particularly interesting because of its vertical linkages to other sectors, and the contrast in structure among these sectors. Primary agriculture is highly competitive, and a large part of its R&D activity is conducted by the public sector. Technological spillovers from agriculture to food processing may come about over time because its R&D has tended to result in products of more uniform quality and less perishability, as in the case of milk, fruits and vegetables. The benefits of these spillovers are obviously important to determining the social profitability of public investments in primary agricultural R&D. The upstream input supplying sectors (agricultural chemicals, farm machinery and equipment) and downstream processing sectors (food processing, wholesaling and retailing, and food services) are producers of relatively differentiated products. This structure tends to allow firms investing in the development of, for example, a new cake mix or breakfast cereal, to earn rents depending on whether the process innovation can be patented or concealed as a trade secret. Nevertheless, the returns to these investments may only be partially excludable, which can lead to investment levels lower than is socially optimal. Non-excludability can result when knowledge spillovers to

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[2]Numerous studies (Ball et al. 1996, Jorgenson and Gallop 1992) report estimates of agriculture's total factor productivity, and some (Gopinath, Roe and Shane, 1995) have estimated total factor productivity in food processing. However, there is no empirical work on the extent to which factor productivity is affected by spillovers from other agriculturally related sectors.

other firms through the information revealed by a patent, or that can be inferred through reverse engineering. It can also result in spillovers to other sectors. For instance, innovations in poultry processing appear to have motivated the development of higher yielding birds of more uniform quality, although some of these spillovers may have been internalized through vertical market contracts. These spillovers to other sectors can be measured as efficiency gains which lower unit costs.

The purpose of this paper is to determine whether empirical evidence can be found in support of technological spillovers by fitting sectoral cost functions to time series data. This approach follows that of Bernstein and Nadiri (1988); it permits us to investigate inter-sectoral R&D spillovers among food processing, primary agriculture, and the farm machinery and equipment sectors, where each sector is treated as a separate spillover source.[3] This specification permits the computation of the private and social private rates of return to R&D capital, presuming that sectors' cannot internalize the returns from spillovers. [4]

Results suggest that unit variable costs for all three sectors are reduced by R&D capital (knowledge) spillovers. We also find strong evidence for factor biases associated with the spillovers in all three sectors. The private rates of return to R&D capital range from 10.2% for food processing to 22.3% for farm machinery and equipment. In the case of agriculture, we estimate the direct effect of public R&D on its variable costs and find a direct rate of return averaging 37.3%. The social rates of return for agriculture and food processing were significantly larger than the private rates of return. The spillovers from public agricultural R&D

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[3]The choice of sectors was limited by the availability of R&D data.

[4] A caveat needs to be placed on the use of the private and social rate of return terminology prevalent in this literature. The presence of contracts between poultry, pork, and fruit and vegetable processors and farmers suggests that some of the inter-sectoral spillovers from R&D capital by food processors may be internalized. Moreover, use of sectoral data implies that intra-sectoral spillovers are not identified, but appear in the private rate of return. Thus, the private rate of return may instead be more precisely defined as the direct rate of return, and the social rate of return as the total rate of return. This caveat should be kept in mind even though, to stay within the tradition of this literature, we use the established terminology.

capital to food processing and farm machinery are relatively large.[5] The R&D capital of food processing contributes significantly to cost reduction in agriculture and modestly to farm machinery. While the farm machinery and equipment sector appears to have received substantial spillovers from agriculture, its contribution to the food processing sector was relatively low.

II. Model

A unit variable cost function is specified for each of the three sectors, primary agriculture, food processing , and farm machinery and equipment. To test for R&D spillovers, the cost function and the accompanying factor demands of a sector are expressed as functions of not only of own R&D capital, but also of the stock of R&D capital accumulated by other sectors. Specifically, the unit variable cost function for the i-th sector is represented by a Generalized Leontieff function as:

$$VC^{i} = \alpha_0 + \sum_{n=L,C,M} \sum_{k=L,C,M} \alpha_{nk} w_j^{\frac{1}{2}} w_k^{\frac{1}{2}} + \alpha_r K_r^{i} + \sum_{n=L,C,M} \alpha_{nr} w_n K_r^{i}$$
$$+ (K_r^{i} + \alpha_{Ls} w_L + \alpha_{Cs} w_C + \alpha_{Ms} w_M) \sum_{j=1,\ i \neq j}^{I} \alpha_{ij} K_r^{j} \quad \text{for all } i=1,..I \tag{1}$$

where VC^i is unit variable cost, (w_L, w_C,w_M) are the factor prices for labor, capital, and materials, K_r^i is the sector's own R&D capital and K_r^j is another sector's R&D capital and I is the number of sectors (3).[6]

Controlling for factor prices w, and hence the quality and embodied technological efficiencies of purchased inputs, each sector's R&D capital generates a distinct influence on the unit variable cost and unit factor demands of every other sector. In this specification there are I-1

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[5]Indirect and less conclusive evidence of this relatively large spill over was found in a growth accounting exercise by Gopinath, Roe and Shane (1996).

[6]Bernstein and Nadiri (1988) specify a truncated translog form for the cost function. Our specification is more flexible as it includes cross-product terms and also simplifies the computation of returns to R&D capital and spillovers.

(2) spillovers for each sector and the sum of these spillovers. is given by $\sum_{j\neq i} \alpha_{ij} \ln K_r^j$. The key parameters of interest are (α_{Ls}, α_{Cs}, α_{Ms}). They indicate the level of spillover effects on variable cost, and the incremental effects on the demand for labor, capital and materials.

The envelope properties of the cost function imply the unit factor demand functions:

$$\frac{L_i}{Y_i} = \alpha_L + \sum_{n=C,M} \alpha_{nL}\left(\frac{w_n}{w_L}\right)^{\left(\frac{1}{2}\right)} + \alpha_{LR}K_r^i + \alpha_{Ls}\sum_{j=1,\ i\neq j}^{I} \alpha_{ij}K_r^j + \mu_{Le}$$

$$\frac{C_i}{Y_i} = \alpha_C + \sum_{n=L,M} \alpha_{nC}\left(\frac{w_n}{w_C}\right)^{\left(\frac{1}{2}\right)} + \alpha_{CR}K_r^i + \alpha_{Cs}\sum_{j=1,\ i\neq j}^{I} \alpha_{ij}K_r^j + \mu_{Ce} \tag{2}$$

$$\frac{M_i}{Y_i} = \alpha_M + \sum_{n=L,C} \alpha_{nM}\left(\frac{w_n}{w_M}\right)^{\left(\frac{1}{2}\right)} + \alpha_{MR}K_r^i + \alpha_{Ms}\sum_{j=1,\ i\neq j}^{I} \alpha_{ij}K_r^j + \mu_{Me}$$

where L_i is labor demand, C_i is the physical capital demand, and M_i is the demand for material inputs (See the section III for description of data). The error terms (μ_{Le}, μ_{Ce}, μ_{Me}) are added to the demand equations. The model is non-linear as a result of the parameters (α_{Ls}, α_{Cs}, α_{Ms}). The envelope properties imply the restriction that these three parameters sum to zero. This restriction allows us to identify the factor biases associated with the R&D spillovers depending on the other spillover parameters $\{\alpha_{ij}\}$. The conditions described by equation 1 can be viewed as short-run in nature where the choice of R&D capital levels is quasi-fixed and not contemporaneous with the dependent variables. That is, we assume these levels are determined prior to the realization of the dependent variable.[7] This assumption seems reasonable since investments in R&D capital typically involve some lag before the final completion of an R&D project.

The effect of spillover from j-th sector into i-th sector can be derived as:

$$\frac{\partial VC_i}{\partial K_r^j} = \alpha_{ij}\ (K_r^i + \alpha_{Ls}w_L + \alpha_{Cs}w_C + \alpha_{Ms}w_M) \tag{3}$$

[7]See Bernstein and Nadiri (1989) for the application of a dynamic duality model to estimate "intra-sectoral" spillovers. Firm level data are not available at this time for the sectors considered here.

Note that the spillover from j-th sector into i-th sector is a function of i-th sector's own R&D capital. This simply accounts for the notion that the underlying R&D production function may depend on other resources that are required to imitate, reverse engineer, or accommodate the product or process innovations of another sector. The parameter α_{ij} defines the distinct effect that the R&D capital from sector j exerts on the i-th receiving sector.

The factor-bias effects of spillovers can be inferred from the parameters (α_{Ls}, α_{Cs}, α_{Ms}). These parameters translate spillovers into specific effects on factors (labor, capital and materials):

$$\frac{\partial X_i}{\partial K_r^j} = \alpha_{Xs} * \alpha_{ij} \qquad \text{for} \quad X_i = L_i,\ C_i,\ M_i \qquad i \neq j,\ j = 1,..3 \tag{4}$$

where, $\alpha_{Ms} = -(\alpha_{Ls} + \alpha_{Cs})$. The sign of these coefficients indicate the factor-bias associated with the spillover. For instance, $\alpha_{Ls} > 0$ (< 0 or $= 0$) implies that inter-sectoral spillover is labor-using (labor-saving or labor-neutral). Given the normalization with respect to α_{Ms}, the sum of the productivity effects and factor-bias effects (equations 3 and 4) yield the total effect on factor demand. This general specification permits the variable factors to be complementary, substitutable or independent of each of the inter-sectoral spillovers.

The private rate of return to R&D capital for the ith sector is defined as the ratio of the cost diminution effect of own R&D capital over the price of R&D capital. To see this, consider the direct effect of I-th sector's R&D capital on its own variable costs:

$$\frac{\partial VC^i}{\partial K_r^i} = \alpha_r^i + \sum_{n=L,C,M} \alpha_{nr} w_n < 0 \tag{5}$$

Then, the private rate of return to R&D (ρ^i) is given by:

$$\rho^i = \frac{-(\partial VC^i / \partial K_r^i)}{P_r^i} \tag{6}$$

Note that this private rate of return to R&D capital is similar to a benefit-cost ratio. Given equation 4, the social rate of return to the ith sector's R&D is:

$$\gamma^i = \frac{-(\partial VC^i/\partial K_r^i)}{P_r^i} - \frac{\sum_{j \neq i} -(\partial VC^j/\partial K_r^i)}{P_r^i} \tag{7}$$

Equation 7 adds to ρ^i the effect of ith sector's R&D capital stock on jth sector's unit variable costs. Summing over the spillover receiving sectors ($j \neq I$) we obtain γ^i the social rate of return to the i-th sector's R&D capital. In other words, the benefits of i-th sector's R&D to j-th sector ($j \neq I$) are added to the private benefits in equation 6 to arrive at the social benefits.

Since we are rely on sectoral data, our model cannot identify intra-sectoral spillovers that arise from the deciphering of another firm's trade secrets, or the hiring of another firm's scientists. It is for this reason that our private (direct) rates of return measure the returns to sectoral R&D and exceed "true" private rates of return to the extent that intra-sectoral spillovers are present.

III. Data and Estimation

Three sectors are defined; primary agriculture, food processing (SIC 20 & 21) and farm machinery and equipment (under SIC 35). Except for the R&D data, the time series for primary agriculture are from Ball et al. (1996), while the remaining data are from Bartelsman and Gray's (1994) NBER manufacturing productivity database for the period 1960-1991. The data consist of gross output in 1982 dollars; labor are measured as number of persons; wages are derived from compensation to employees; physical capital stock is derived using the perpetual inventory method; value added is in nominal dollars; value of material inputs is in nominal and constant dollars. Public R&D expenditures (real and nominal) for primary agriculture are taken from Huffman and Evenson (1993). The data on R&D expenditures (real and nominal) in the other two sectors are from Fuglie at al. (1996). The stocks of R&D capital are derived following the procedure outlined by Hall (1993). The price of R&D capital for food processing and farm machinery and equipment is obtained using the familiar user-cost formula with 15% depreciation and 10% tax rates.

The unit variable cost function in equation (1) is estimated along with the set of factor demand equations in (2) for the three mentioned sectors. The estimation procedure is the following. Since there are three sectors, all spillover combinations are estimated. In other words, the cost and factor demand functions are estimated pairwise, since the set of equations with all three cost functions and all input demand equations (total of 12) is otherwise too large for non-linear estimation. So, the combinations of agriculture and food processing, agriculture and farm machinery and equipment, and food processing and farm machinery and equipment are estimated. The sample period, as mentioned earlier, is 1960-1991. The non-linear SUR procedures in SAS are used for estimation and the convergence criteria is 0.001. The %AR procedure in SAS is used to correct for serial correlation. Each sector's own R&D capital and each of the spillovers are lagged one period in the estimation since all R&D capital stocks are treated as exogenous in the model.

The parameter estimates of the non-linear system are presented in table 4. The non-linear specification (equations 1 and 2) was tested against a linear specification with no spillover terms (setting parameters α_{Ls}, α_{Cs}, α_{Ms}, and α_{ij} equal to zero) for each set of sectors. Based on the chi-square statistic (with 4 degrees of freedom) for Gallant test, we failed to accept the null hypothesis of zero spillover parameters. Therefore, we estimated the non-linear model using a wide range of starting values for the parameters. The model appears to fit the data reasonably well, with relatively small estimates of standard errors and system R^2 of 90%.

IV. Results

The empirical results are reported in Tables 1 to 3. Equation 5 is used to estimate the private (direct) rate of return to R&D capital (table 1), while equation 7 computes the social (total) rate of return (table 3). The factor biases are computed using equation 4 (table 2).

IV.I Private Rates of Return

Private rates of return to R&D capital for food processing, and farm machinery and equipment, and the direct rate of return to public R&D capital in primary agriculture are reported in Table 1. Of the three sectors, the results suggest that the food processing sector has the lowest private rate of return to R&D capital. The direct rate of return to public agricultural R&D capital averaged 37.3% over the period 1960-91. Note that our estimates show a relatively stable trend. Rates of return averaged about 37% throughout the sample, with a brief peak in 1981 at 40 %. The estimates of direct rates of return reported here seem reasonable as they fall in the lower range of 30 % to 60 % reported by several studies.[8] This is, in part, due to the attempts of these studies to account for some downstream benefits, but not necessarily due to spillovers. As we show in Table 3, the social rate of return to agricultural's R&D approaches the upper bound of their estimates.

The rates of return to R&D capital in the food processing sector averaged 10.2% over the period with some evidence of decline (from 10.1 % to 8.9 %). These relatively low private rates of return suggest the conjecture that firms' ability to appropriate returns to own R&D capital is relatively high, thus deriving the marginal returns to R&D to relatively low levels.[9] Appropriability may be relatively high, in part, because of little substitutability among R&D products in producing, for example, a new cake mix to R&D products used to produce a new breakfast cereal. It may also be the case that the nature of R&D products in this sector are protected by trade secrets because they are costly to decipher and thus not patented.

The rates of return to R&D capital in the farm machinery and equipment sector are relatively high, averaging about 22.3%, and appear to have also declined slightly in recent years. This rate of return is comparable to the rates obtained for non-electrical machinery by Bernstein and Nadiri (1988). In contrast to food processing, these results suggest that intra-sectoral spillovers may be relatively high as other firms in the sector can, at relatively low cost, appropriate the ideas and knowledge embodied in R&D products of other firms in the sector.

In general, there is a modest decline in the private rate of return to R&D in food

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[8]See Alston and Pardey (1996), Chapter 6 or Fuglie et al. (1996) for a summary and review.

[9]This conjecture is also supported by the annual average rates of growth in the sector's real R&D expenditures which averaged 3.4% during the 1960s, 2.7% during the 1970s and fell to under 1.5% in 1980s.

processing and farm machinery and equipment, while the direct rate of return to public agricultural R&D has been relatively stable.

IV.II Inter-Sectoral Spillovers: Source and Receiving Sectors

The effects of spillovers on unit variable costs and factor demand are presented in Table 2. The spillover effects on unit variable costs are based on equation (3), and the effects on input demand are based on (4).

Overall, the general results suggest the presence of spillovers among sectors. Agricultural R&D spillover appears to have significantly reduced the unit variable cost of both food processing and the farm machinery sectors. The R&D capital of the food processing sector is also a significant source for cost reductions in agriculture and a modest source for farm machinery and equipment. However, farm machinery and equipment was not a source for agriculture and its effect on the variable costs of food processing is relatively small.

More specifically, a unit increase in R&D capital in food processing decreases the variable cost of agriculture by an average of -4.0 percent.[10] For food processing, the agricultural sector accounts, on average, for more than four-fifths of the total spillover. A unit increase in agricultural and farm machinery R&D decreases the unit cost of food processing by 6.86% and 0.80 %, respectively, adding to a total of -7.66 %. Spillovers from agricultural R&D accounts for about 75% of the total spillovers to farm machinery (-2.16 %). While farm machinery and equipment benefitted from both food processing and agricultural R&D capital, its R&D capital in turn benefits food processing only marginally. The only source of spillovers to agriculture was from the food processing sector. This result suggests that even though investment in R&D by the farm machinery and equipment sector may yield machines which embody technological efficiencies, the effects of this R&D on agriculture is accounted for in their factor prices which appear in agriculture's unit cost function. The effects on factor biases suggest that spillovers to agriculture have been material input using, and labor and capital input saving, whereas for the other two sectors, spillovers are labor using, and capital and materials saving.

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[10]The effects of spillovers on variable costs is given by the numerator of the second term in the RHS of equation 7. They are divided by the price of R&D capital to obtain rates of returns.

IV.III Social Rates of Return

As measured by equation 7, the social rates of return are presented in table 3. The spillovers in table 2 are converted into rates of return (by dividing by the price of R&D capital) and added to the private rates of return.

For agriculture, the social rate of return to its R&D capital averaged 46.2 %, an 8.8 % additional average rate of return. Eight-two percent of this spillover was to food processing (7.2 %) and the remainder to the farm machinery and equipment sector. Note that both the direct rates of return and spillover effects of agricultural R&D have been relatively stable with the exception that the spill overs to food processing have declined in recent years.

The social rate of return to R&D capital in food processing averaged 15.1%, or a spillover of 32%, (4.9 /15.1). The spillovers from food processing to agriculture accounted for over 85 % of the total. The effects of spillovers from food processing to farm machinery are very small (0.6/4.9 < 15%). These spillovers remained fairly constant over the period.

The farm machinery and equipment sector's R&D capital is a source of spillovers to food processing sector only, but the effect is small, averaging only 0.8%. The spillovers into food processing declined from 1.3% in 1961 to 0.2% in 1991. So, the average social rate of return (23.1%) diverged only slightly from its private rate of return (22.3%). The extent of spillovers as measured by our ratio (0.9/23.1) is less than 4%. The relatively stable rates of return to R&D capital masks the rapid structural change that took place in this sector in the 1970s and 1980s (Sisco and Hansen, 1990). The sector is a tight oligopoly with top four firms accounting for 80% of the sales in 1986. The booms of the 1970s saw rapid expansion by 1 or 2 dominant firms and the reversal in the 1980s further consolidated the position of these top firms, with a single firm accounting for about 30% of the sales in this sector (Sisco and Hansen, 1990).

In summary, the social rate of return to public R&D in agriculture ranks high among the three sectors investigated here. It also contributes significantly to the variable cost reduction in food processing and farm machinery and equipment sectors. In the case of farm machinery and equipment sector the extent of spillovers to other sectors is very small (under 4%) suggesting that appropriability of the return to this sectors R&D spillovers to agriculture and food processing is not an important source of market failure.[11] The extent of spillovers from food processing sector is 32% which suggests a relatively more significant problem of market failure. However, the spillover from public agricultural R&D to food processing exceeds the spillover from food processing to the other two sectors.

Summary and Conclusions

The motivation for this research stems from the concern that products of investments in R&D are much like quasi-public goods with market failure arising from non-rivalry and the difficulty of firms to fully appropriate the returns to these investments. We specify a variable cost function to analyze the extent of R&D spillovers in three closely related sectors, agriculture, food processing, and farm machinery and equipment. We treat a sector's own R&D capital as quasi-fixed and allow for R&D capital of other sectors to generate spillovers that can be factor biased.

Results show that unit variable costs are reduced by R&D capital spillovers with evidence of factor biases associated with the spillovers in all three sectors. The private rates of return to R&D capital range from an average of 10.2% for food processing to 22.3% for farm machinery and equipment. In the case of agriculture the direct rate of return to public R&D averaged 37.3%, a value that seems reasonable in light of other studies . Since our analysis cannot identify intra-sectoral spillovers, we conjecture that the relatively high private returns to R&D in the farm machinery and equipment sector may be indicative of high intra-sectoral spillovers relative to the food processing sector. The presence of trade secrets and the possibly low substitutability among R&D products between, for example, a new cake mix and breakfast cereal, may partially explain the relatively low private rate of return to R&D capital in food processing.

Strong empirical evidence is found supporting the presence of inter-sectoral spillovers. Spillovers appear to occur from primary agriculture to food processing and, to a lesser extent, to farm machinery and equipment, and from food processing to agriculture and to small extent, to

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[11]Of course, spillovers from farm machinery and equipment to other related sectors are not included in this study (non-electrical machinery, transportation sectors).

farm machinery and equipment. Little spillover occurs from farm machinery and equipment to the other two sectors. Adding the spillover effects to the private rates of return yields a social rate of return to investments in agricultural R&D averaging 46.2%, and an average rate of 15.1 % in food processing. These results confirm the likelihood of relatively high rates of return to public R&D in primary agriculture where market failure is well known but the extent of spillovers to food processing and farm machinery has received less attention.

We find that the spillover from public agricultural R&D to food processing exceeds the spillover from food processing to the other two sectors. Thus, public R&D mitigates the market's failure in food processing to fully appropriate returns to their R&D capital.

While we view these findings as evidence in support of technological spillovers, micro economic analyses, such as firm level case studies, are required to identify the underlying structure causing spillovers and whether firms engage in arrangements, and if so of what type, to appropriate the rewards of spillovers to others from their investments in R&D. If spillovers are confirmed and their sources identified, then, in principle, institutional arrangements should be considered for internalizing these externalities.

Table 1: Private (Direct) Rates of Return to R&D Capital (percent)

Sector	1961	1971	1981	1991	Mean
Agriculture[12]	37.6	34.5	40.4	36.7	37.3
Food Processing	10.1	9.9	13.0	8.9	10.2
Farm Machinery	21.9	21.3	27.9	18.5	22.3

[12]As mentioned in section IV.I, the rates of return to R&D in agriculture are from public R&D.

Table 2: Spillover Effects on Variable Cost and Factor Demand

Receiving Sector	1961	1971	1981	1991	Mean
From Food processing					
To Agriculture					
Variable cost[13]	-0.0373	-0.0403	-0.0354	-0.0401	-0.0399
Labor[14]	-0.0084	-0.0164	-0.0370	-0.0484	-0.0286
Capital	-0.0004	-0.0011	-0.0040	-0.0039	-0.0020
Materials	0.0131	0.0187	0.0471	0.0537	0.0321
From Agr & Farm machy					
To Food processing					
Variable cost	-0.0861	-0.0805	-0.0812	-0.0616	-0.0765
Labor	0.0173	0.0273	0.0586	0.0833	0.0450
Capital	0.0078	0.0101	0.0191	0.0262	0.0173
Materials	-0.0252	-0.0319	-0.0729	-0.0852	-0.0529
From Agr & Food procg					
To Farm machinery					
Variable cost	-0.0207	-0.0196	-0.0242	-0.0235	-0.0216
Labor	0.0106	0.0167	0.0399	0.0464	0.0289
Capital	-0.0076	-0.0115	-0.0310	-0.0347	-0.0214
Materials	-0.0041	-0.0053	-0.0135	-0.0156	-0.0095

[13]Based on equation 3

[14]Based on equation 4

Table 3: Social (Total) Rates of Return to R&D Capital (percent)

Source & Receiving Sector	1961	1971	1981	1991	Mean
Agriculture					
Food Processing	7.7	7.0	9.9	4.5	7.2
Farm Machinery	1.5	1.4	2.4	1.4	1.6
Social Rate of Return	46.8	42.9	52.8	42.7	46.2
Food Processing					
Agriculture	3.8	3.9	5.1	3.3	4.3
Farm Machinery	0.6	0.6	0.8	0.5	0.6
Social Rate of Return	14.5	14.4	18.8	12.7	15.1
Farm Machinery					
Food Processing	1.3	1.1	0.7	0.2	0.9
Social Rate of Return	23.2	22.4	28.7	18.7	23.1

Table 4: Parameter Estimates of the Unit Variable Cost Function

Parameter	Food Processing	Farm Machinery	Agriculture
α_0	-321	-344	145
	(-5.94)	(-1.82)	(0.83)
α_{LL}	34.91	12.09	-60
	(4.23)	(0.76)	(-2.11)
α_{LC}	66.99	19.59	25.33
	(8.34)	(3.09)	(1.88)
α_{LM}	45.94	71.71	208.6
	(7.18)	(9.13)	(16.12)
α_{CC}	-49.53	8.85	85
	(6.75)	(0.63)	(2.8)
α_r	-0.098	-0.21	-0.37
	(-5.17)	(-1.26)	(0.99)
α_{Cr}	0.02	-0.011	-0.101
	(12.12)	(-0.93)	(-11.49)
α_{Mr}	-0.0018	0.01	-0.122
	(-1.35)	(0.79)	(-4.71)
α_{Ls}	-1147	-1472	910
	(-1.67)	(-1.01)	(-1.72)
α_{Cs}	287.15	777	596
	(0.22)	(0.87)	(1.93)
α_{ij}	-0.0002	-0.00002	-0.00005
	(-4.36)	(-1.05)	(-2.97)
$\alpha_{ij'}$	-0.000006	-0.000004	
	(-1.43)	(-0.87)	

t ratios in parenthesis.

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