Private R&D Investments in Agriculture: The Role of Incentives and Institutions

by

Oscar Alfranca and Wallace E. Huffman*

December 1999

Staff Paper #332

*478C Heady Hall
Iowa State University
Ames, IA 50011-1070
whuffman@iastate.edu
515-294-6359

Abstract

Private R&D Investment in Agriculture:
The Role of Incentives and Institutions

by Oscar Alfranca and Wallace E. Huffman

This paper presents econometric evidence of the effects of economic incentives and institutions on national aggregate private agricultural R&D investments. A model is proposed and fitted to annual data for seven European Union countries, 1984-1995. We find strong impacts of both incentives and institutions on private agricultural R&D investment, and including institutional factors strengthens the story and in some case changes greatly the results. In particular, we reject the hypothesis that quality of property rights does not matter. We find that stronger contract enforcement, more efficient public bureaucracies, and stronger patent rights lead to larger aggregate private agricultural R&D investment, other things equal. Furthermore, we show that the impact of a country's patent rights on private agricultural R&D investment is amplified by it also having a more efficient public bureaucracy and a larger stock of agricultural higher education capital. We also find evidence of public R&D crowding-out private agricultural R&D, which does support recent privatization policies. Inter-country private R&D spillins increase national agricultural R&D investment.

Key words: private R&D, incentives, institutions, property rights, European Union, agriculture, spillovers.

12-29-99

4 tables (filename: Oscar.tbl) go with this paper

Private R&D Investments in Agriculture: The Role of Incentives and Institutions

by Oscar Alfranca and Wallace E. Huffman *

Research and development (R&D) produce knowledge and innovations that have become a major source of productivity change and economic growth of agriculture in developed countries. In these countries, agricultural R&D is largely a shared activity between the public and private sectors, but since the mid-1970s, private agricultural R&D has been growing much faster generally than public R&D (Alston, Pardey, and Smith 1998; Huffman and Just 1999).[1] Private agricultural R&D is undertaken to increase the expected long-term profitability of such firms. However, public policies, quality of property rights, and economic incentives can be expected to affect these investment decisions, and absence of secure property rights and contractual rights seems likely to discourage private investment (Knack and Keefer 1995).

The objective of this paper is to present econometric evidence of the effects of economic incentives and institutions on national aggregate private agricultural R&D investments. Although the European Union is undergoing major economic integration, member countries continue to exhibit substantial variation in the quality of property rights and in the size and relative importance of agriculture. We suggest that this provides a fertile area for testing the hypothesis that the

---

* The authors are professors at the University Politicnica de Catalunya, Barcelona, Spain, and Iowa State University, Ames, IA, respectively. An earlier draft was completed while Alfranca was a visiting scholar at Iowa State University in 1999. We are grateful to Philip Keefer and Stephen Knack for generously providing us with their data on quality of property rights. Financial support provided by the CICYT project SEC96-2300, CIRIT project SGR97-333, and the Iowa Agriculture and Home Economics Experiment Station.

quality of property rights, e.g., the strength of patent rights, extent of contract enforcement, public bureaucratic delays, and nationalization risk, does not affect aggregate private agricultural R&D investments. A model is proposed and fitted to annual data for seven European Union countries, 1984-1995. We find strong impacts of both incentives and institutions on private agricultural R&D investment, and including institutional factors strengthens the story and in some cases changes greatly the results.

Private R&D

In Agriculture

In the European Union and in OECD countries, a large share of private agricultural R&D is invested in agricultural inputs--agricultural chemicals, plant breeding, farm machinery, and animal health--and food and kindred products but relatively little (less than 10 percent) in farm level technologies (Klotz, Fuglie, and Pray 1995; Alston, Pardey, and Smith 1997). In the EU, private agricultural R&D has been focused on agro-chemistry (folliculars, fertilizers, micro-nutrients, fungicides, insecticides, and soil disinfectants), plant breeding and varietal development, plant nutrition, plant growth regulators, plant parasitology, marine aquiculture, raw material production from cultured media (e.g., corn syrups, sugars), enzymatic conversion of starch to sugars, biotechnology in plants, combine and harvesting machine development, safety and ergonomics in farm machinery, and veterinary pharmaceuticals.

The private R&D system differs across western European countries, and the focus of private agricultural R&D differs (Arnon 1989). In the U.K., agricultural chemicals, machinery, and feeding stuffs have been important (Thirtle et al. 1997, Whittemore 1998). Also, the Cambridge Plant Breeding Institute was transferred from the public sector to the private sector

(Unilever) in 1998. In the Netherlands, private research on horticultural crops is large. In France, private R&D, e.g., in Vilmoria, the Cooperative Society for Research and Experimentation of the Eastern Pyrenees, the Technical Institute of the Sugar Beet Industry are mainly focused on plant breeding, pesticides, and fertilizers. In Germany, private R&D is focused on pesticides and fertilizers, e.g., BASF, Baker, Kali + Salz, Hochst, agricultural machinery, e.g., Deutz, Mercedes, and animal feed and pharmaceuticals. In Sweden and Denmark, private research is on fertilizers, forestry, and communication systems.

Cross-country comparisons of private and public agricultural R&D expenditures are made difficult by the fact that each country has its own definition of what is included in private and public research and the restructuring of public agricultural research in some of these countries over the past two decades has changed what is now included in public and private research (Huffman and Just 1999). For example, in the United Kingdom, some public agricultural research institutions have been sold to the private sector (Thirtle, Palladino, and Piesse 1997) and in the Netherlands, research institutions of the Ministry of Agriculture, Nature Management, and Fisheries have been turned into quasi-public or private institutions. German data have special problems due to the fact that two separate countries existed before 1990 and pre-1990 data cover only West Germany.

Even with these deficiencies, we believe that it is useful to present some comparisons across EU countries. Table 1 presents information showing large differences in the share of private agricultural research expenditures in total public and private agricultural research expenditures of 13 European Union countries for 1985, 1990, and 1995. The Netherlands and Sweden stand out for their large private sector shares, and Germany, Ireland, and Spain have unusually small shares. Furthermore, these data do not suggest a strong increase in the private R&D share over 1985-1995.

Prior Evidence

Private firms invest in R&D to increase their expected long term profitability.[2] Research and development leads to discoveries which are frequently embodied in new products or processes that can be used in an on-going commercial production and marketing operation, patents that can be used or licensed for a fee to others, and other intellectual property (Geroski 1995).[3]

Previous empirical studies have found effects of private R&D on cost of production, factor intensities, and productivity and on patenting rates. At the industry level, Bernstein and Nadiri (1988) found strong production cost reducing and factor intensity effects of own R&D and inter-industry R&D spillins. Knowledge spillovers/spillins are a type of positive externality of scientific discoveries on the productivity of firms or laboratories which neither make the discovery themselves nor licensed its use from the holder of intellectual property rights. Adams (1990) found that within and between industry R&D spillins operate with a long lag as key determinants of industry productivity. At the firm level, Bernstein and Nadiri (1989) found that a firm's own R&D and inter-firm spillins reduce production cost and that R&D spillins are a substitute for a firm's own investment in R&D. Mairesse and Hall (1995) explore the timing of the relationship between R&D and productivity in a panel of French and American manufacturing firms. International studies of spillovers include Lichtenberg (1992), Grossman and Helpman (1991), and Coe and Helpman (1995), and Park (1995).

Adams (1998) used data for firms in the U.S. chemical, machinery, electrical equipment, and transportation equipment industries to examine effects of academic, largely public, research and other firm's industrial R&D research on the productivity of industrial laboratories. Own laboratory R&D, R&D spillins from the rest of the company's R&D activities, and R&D spillins from the rest of the industry are shown to have positive effects on the number of patents granted for a laboratory. Academic research is shown to have spillin effects on private laboratories largely through a positive impact on the share of the staff holding Ph.D. degrees and not directly on the number of patents granted. In contrast, Zucker, Darby and Armstrong (1998) found that research universities have a positive impact on nearby biotechnology firms through identifiable market exchange between particular university star scientist and not to generalized knowledge spillovers.

A related strand of the literature has examined the potential complementary relationship between capital, technology and skilled labor. This literature finds that capital and technology are complementary with skilled labor, but factor saving in unskilled labor or skill biased, e.g., see Griliches (1969), Bound and Johnson (1992), and Berman, Bound, and Griliches (1994). Adams (1999) finds that a firm's own R&D, industry wide R&D, and plant level capital are factor using in labor, and factor saving in materials.

It is widely accepted that absences of secure property rights and contractual rights discourage private investment, e.g., North 1990, p. 54, Olsen 1982, Knack and Keefer 1995, Mauro 1995, by reducing the expected rate of return and increasing the riskiness of investments. Weak property rights might arise as non-existent or ineffective patent laws but more generally from inefficient and weak institutions, e.g., weak contract enforcement, bureaucratic delays in provision of civil services, and possible nationalization of private property without fair compensation. For example, Knack and Keefer (1995) show that the rate of average gross private investment over 1974-1989 for a set of about 100 countries was increased significantly by lower business environment risk, i.e., more secure and efficient property rights.

For private investments in R&D, the presence and strength of intellectual property rights are very important. Without formal intellectual property rights, private innovators and firms are left to rely on trade secrets which vary greatly across discoveries in the amount of protection they provide. In hybrid plant varieties, the hybridization process gives relatively strong intellectual property protection. For production processes, trade secrets give a major competitive edge to the discoverer (Geroski 1995). However, for chemical, mechanical, and electrical innovations, trade secrets are largely ineffective because skilled innovators or scientists can “reverse engineer” the product.

Other intellectual property rights include patents, breeders’ rights, copyrights, and trademarks. The patent, which provides protection for embodied inventions, is a key intellectual property right for private firms investing in agricultural R&D in western developed countries. The creator must reveal his/her discovery and in turn receives a limited monopoly position on use or control for about 20 years. When innovators charge high prices for the use of their discoveries or a relative high price for products embodying their innovation, this creates a strong economic incentive for a new innovator to use the revealed information as a basis for innovating around the existing patent or to infringe on the patent. In agriculture, where there are a large number of farmers and economic, land, and climatic conditions are heterogenous, innovators’ profits are heavily conditioned by achieving large scale, perhaps international adoption. This can only be achieved if the private companies share a significant part of the economic surplus with farmers (and land owners). Private companies selling new agricultural technologies can capture some of the economic rents (e.g., only about one-third to one-half), but it is economically impossible for them to perfectly discriminate or collect all the rents. See Falck-Zepada, Traxler, and Nelson (1999) for evidence on Bt cotton.

During the 1980s, patent protection was extended to the creative products of human ingenuity in living organisms, plants, and nonhuman mammals. These discoveries have been dramatic enough that patent courts have ruled that they are not the "products of nature" and, hence, can be patented. Transgenetic plants and animals have been the source of ethical and consumer concerns (e.g., see Gaskill, Bauer, Durant, and Allum 1999).

Two technological innovations have the potential to greatly strength IPRs associated with biological innovations. DNA finger-printing technology adds new precision to identification and ownership claims and makes "moonlight" plant breeding easily punishable. The recent discovery and patent by the USDA and Delta and Pine Land Company of the technology protection system (TPS) has the potential to greatly strengthen innovators rights to improvements in open pollinate crops. TPS is a transgenic system comprised of a complex array of genes and gene promoters which in the normal state are inactive. Seeds carrying TPS can have a treatment applied before sale to farms which will trigger an irreversible series of events at the time of germination and renders the seed produced by farmers sterile. Hence, the net result for "saved seed" is essentially the same as for hybrid crop varieties which have been around for almost a century. Seeds from hybrid varieties do not reproduce themselves either.

Private companies have historically found it unprofitable to invest in R&D for open pollinated crops because of farmers' ability to save and replant their own seed. With TPS, farmers can be prevented from using saved-seed for replanting. This outcome poses no ethical issue in developed countries, but some have raised ethical issues of farmers in developing countries being excluded from access to new plant varieties that carry TPS. Since TPS treated seeds are sterile, the technology cannot accidentally be transferred to wild plant species or non-TPS carrying crop varieties.

Patent laws for the European Union countries have been strengthened over the past four decades, and are in general much stronger than in developing countries, but somewhat less than in the United States. Ginarte and Park (1997) have produced a national patent rights index for over 100 countries by combining scores on five separate components of patent law: (i) extent of coverage, (ii) membership in international patent agreements, (iii) provision for loss of protection, (iv) enforcement mechanisms, and (v) duration of protection. Each separate component is assigned a value between 0 and 1, and a county's patent rights index is then the summation over the five component scores. Among EU countries, Finland, Portugal and Ireland have had relatively low values over 1960-90, and Sweden, Germany, and Denmark have significantly strengthened their patent rights (see Table 2).

Even with strong intellectual property rights, the private sector will significantly under invest in discoveries that are of a pure public good type, e.g., discoveries from the basic and pretechnology sciences, or applied discoveries that do not lead to profitable products, e.g., resource and environmental quality, food safety, policy, minor crops Huffman and Evenson 1993; Huffman and Just 1999). Hence, financing these discoveries is left largely to the public sector, and they provide the potential for public and private R&D to be complementary rather than substitute activities in generating new agricultural technologies. On the other hand, if public

R&D competes directly with private R&D, public and private R&D will be substitutes, or one will tend to crowd out the other.

The Econometric Model, Data, and Results

An econometric model of national aggregate annual private R&D investment is specified and fitted to panel data consisting of seven EU countries (Austria, Germany, Italy, Netherlands, Portugal, Spain, and Sweden) over 1984-1995. The primary reason why all EU countries are not included in the data set is missing data on some of the relevant variables.

The Econometric Model

The econometric model of aggregate gross real private R&D investment is one that incorporates variables representing the effect of incentives, public policies, and institutions. The institutional variables represent both the extent and security of property rights and contractual arrangements. Definitions of variables are summarized in Table 3.[4]

The econometric private agricultural R&D investment equation is:

$$
\begin{aligned}
(1)\quad \ell n(\mathrm{PRRINV}_{it}) = {} & \sum_{i=1}^{7} \mathrm{CONSTANT}(i) + \beta_2 \mathrm{IRATE}_{it} + \beta_3 \ell n(\mathrm{PRRCAP}_{it_1}) + \beta_4 \ell n(\mathrm{PSPILL}_{it-2}) \\
& + \beta_5 \ell n(\mathrm{FPA}_{it}) + \beta_6 \mathrm{CROP}_{it} + \beta_7 \ell n\,\mathrm{PURCAP}_{it_1} + \beta_8 \ell n(\mathrm{HEDC}_{it-1}) + \beta_9 \mathrm{CE}_{it} \\
& + \beta_{10} \mathrm{BD}_{it} + \beta_{11} \mathrm{NP}_{it} + \beta_{12} \mathrm{PAT}_{it} + \beta_{13} \mathrm{IQ}_{it} + \beta_{14} \left[\ell n\,\mathrm{PRRCAP}_{it-1}\right] * \left[\ell n\,\mathrm{PURCAP}_{it-1}\right] \\
& + \beta_{15} \left[\ell n\,\mathrm{PRRCAP}_{it-1}\right] * \left[\ell n\,\mathrm{HEDC}_{it-1}\right] * \mathrm{PAT}_{it} * \mathrm{BD}_{it} \\
& + \mu_{it},\ E\,\mu_{it} = 0,\ E\,\mu_{it}^2 = \sigma_{ii}^2,\ E\,\mu_{it}\,\mu_{qt} = \sigma_{iq}^2,\ \forall\, i, q, t
\end{aligned}
$$

where μ_{it} is a random disturbance term representing the effects of omitted variables that are peculiar to both a country (i) and time period (E). It has a zero mean, constant variance over time for any given country but to differ across countries, and to have non-zero contemporaneous correlation across countries.

We turn to a formal statement of hypotheses about the aggregate private agricultural R&D investment relationship. We expect $\beta_2 < 0$, or a larger real interest cost reduces private R&D investment. Lagged private R&D stock represents both a stock of past discoveries that may be useful in future discoveries but also provides an indicator of the "using up" of some of the innovative potential of earlier scientific discoveries (Huffman and Evenson 1993). The impact of the lagged stock of private R&D may be affected by the lagged stock of public agricultural R&D (PURCAP) and stock of higher educational capital as modified by patent laws and bureaucratic delays. The overall impact is summarized in equation (2):

$$(2) \qquad \frac{\partial \ell n(\mathrm{PRRINV}_{\ell t})}{\partial \ell n(\mathrm{PRRCAP}_{\ell t-1})} = \beta_3 + \beta_{14}\,\ell n\,\mathrm{PURCAP}_{\ell t-1} + \beta_{15}\left[\ell n\,\mathrm{HEDC}_{\ell t-1}\right] * \mathrm{PAT}_{\ell t} * \mathrm{BD}_{\ell t}.$$

β_{14} will be positive if public research complements private R&D and to be negative if they are substitutes or cause crowding out. Human capital investments in agricultural scientists, managers, and agricultural input sales representatives are expected to raise the profitability of private R&D with given patent laws (PAT) and quality of civil services (BD). Hence, β_{15} is expected to be positive. Thus, the expected net effect of lagged private R&D stock on current private R&D investment could be positive, negative, or zero.

Private agricultural R&D investments in one country may impact investment decisions in other countries through R&D spillovers. See Evenson (1991) and Johnson and Evenson (1999, Table 10) for a discussion of evidence for spillins of patented innovations in Europe.[5] These spillovers are expected to be larger and more direct when the R&D is undertaken by large multinational companies, but even for R&D undertaken by national companies, some inter-country externalities may occur. The spillins are expected to reduce the cost of local innovation, to increase the expected return to local private R&D and to increase private R&D investment, i.e., $\beta_4 > 0$. The two-year lag for PSPILL incorporates the likely slower transmission of information and technology when it must cross national boundaries, e.g., due to different languages, cultures, etc.[6]

The potential size of the market for private agricultural innovations is proxied by the volume of agricultural production (FPA) and the crop shares of final agricultural production (CROP). The potential for using commercial intermediate inputs in the EU is higher in crop than in livestock production because of the stigma against long-term use of medicated livestock feeds and growth hormones. The expected signs for β_5 and β_6 are positive.

The marginal effects of the public stock of local agricultural R&D on current investment in private R&D is

(3) $$\frac{\partial \ln(PRRINV_{Rt})}{\partial \ln(PURCAP_{Rt-1})} = \beta_7 + \beta_{14} \ln PRRCAP_{Rt-1} .$$

If public R&D is generally crowding out private R&D, then the sign for equation (3) will be negative. This is more likely to occur if public and private R&D stocks are substitutes (i.e., $\beta_{14} < 0$) than if they are complementary (i.e., $\beta_{14} > 0$).

Larger public agricultural human capital is expected to increase private R&D investment (Huffman and Evenson, 1993; Huffman 1999), i.e., the overall sign for equation (4) is positive:

(4) $$\frac{\partial \ln(PRRINV_{Rt})}{\partial (\ln HEDC_{Rt-1})} = \beta_8 + \beta_{15}\left[\ln PRRCAP_{Rt-1}\right] * PAT_{Rt} * BD_{Rt}$$

A large stock of public agricultural R&D, stronger local patent laws, or more efficient civil services are expected to complement private agricultural R&D and to increase the size of the investment (i.e., $\beta_{15} > 0$).

The effects of property rights and quality of institutions are represented in indexes for contract enforcement (CE), bureaucratic delays (BD), nationalization potential (NP), and patent rights (PAT). Greater contract enforcement and fewer bureaucratic delays are expected to increase private R&D investment. Thus, the expected sign of β_9 is positive. The effects of bureaucratic delays, however, may be moderated/amplified by other variables. The hypothesis advanced here is that a larger stock of private R&D, stock of agricultural higher education capital or stronger patent laws are complementary with efficiency in public bureaucracy,

$$(5) \qquad \frac{\partial \ln(PRRINV_{Rt})}{\partial(BD_t)} = \beta_{10} + \beta_{15}\left[\ln PRRCAP_{Rt-1}\right] * \left[\ln HEDC_{Rt-1}\right] * PAT_{Rt} \ ,$$

and β_{15} is positive. Preferential treatment of local companies is expected to increase their private investment in agricultural R&D but to reduce foreign direct investment. Hence, the net effect of NP and the sign of β_{11} are ambiguous. Stronger patent rights are expected to increase private R&D investments because private firms can expect to obtain a larger share of the social benefits from innovations resulting from their research and development. However, in our model we allow for and test to see if the effects of patent laws are modified by the stock of lagged private agricultural R&D capital, the stock of lagged agricultural higher education capital, or absence of bureaucratic delays.

$$(6) \qquad \frac{\partial \ln(PRRINV_{Rt})}{\partial(PAT_t)} = \beta_{12} + \beta_{15}\left[\ln PRRCAP_{Rt-1}\right] * \left[\ln HEDC_{Rt-1}\right] * BD_{Rt}$$

We expect the signs of β_{12} and β_{15} to be positive.

Public policies are important for determining the quality of infrastructure in a country, e.g., quality of communication and transportation. Better quality infrastructure is generally seen as reducing communication and transport costs and thereby facilitating technical change and increasing the profitability of private R&D. The expected sign of β_{13} is positive.

The CONSTANT terms in equation (1) are country-specific intercept terms or fixed effects. They represent time invariant but unspecified country-specific factors that affect private agricultural R&D investment, including definitions of private R&D, agro-climatic conditions, major soil types. Because the econometric model is to be fitted to data over a relatively short time period, a random-effect model is not used because under these conditions estimates tend to be quite imprecise (Hsiao 1986).

The Results

Equation (1) is fitted by the Zellner SUR estimation method to the 77 observations obtained by pooling the 11 observations for seven EU countries. The estimated coefficients and t-value are reported in Table 4, regression equation (1).

Overall, the fitted model performs well. Most coefficients are different from zero at the 5 percent significance level, and the hypothesis that the R&D investment equation has no explanatory power (i.e., all coefficients except for country fixed effects are zero) is rejected at the 1 percent significance level. Turning to particular effects, higher real interest cost, a larger volume of agricultural production, or a larger share of crop output in total agricultural production increases private agricultural R&D investments as expected. The effect of a larger (lagged) private agricultural R&D stock is to reduce current private agricultural R&D investments. The elasticity at the sample mean is -0.49, and the negative elasticity implies that past private R&D is limiting current R&D through net exhaustion of the innovative potential. This seems to be occurring because public and private agricultural R&D are substitutes (i.e., $\hat{\beta}_{14} < 0$) rather than being complements. The effect of (lagged) intercountry spillin of private agricultural R&D capital is as expected to increase private agricultural R&D investment.

The effect of larger domestic public agricultural R&D capital is to decrease private agricultural R&D investment, and the elasticity at the sample mean of ℓn(PRRCAP) is -0.640. This is the crowding out effect at work. The effect of larger agricultural higher education capital is to increase private agricultural R&D investment as expected. When equation (4) is evaluated at the sample mean of the regressors using our estimated coefficients, the elasticity is 0.31. Furthermore, the positive impact arises from the positive interaction effect of education capital with private agricultural R&D capital, strength of patent laws, and more efficient bureaucracies, i.e., a generally favorable private R&D investment environment.

More generally our results show that the quality of a country's property rights has a significant and important effect on private agricultural R&D investment. When a country has better contract enforcement (larger CE), agricultural R&D investment increases. A more efficient public bureaucracy also increases the investment in private agricultural R&D. At the sample mean when equation (5) is evaluated using our estimated coefficients, the marginal effect is 0.05. The results also show that the positive impact is operating largely through interaction effects with private agricultural R&D capital, agricultural higher education capital, and a country's patent rights.

Consistent with expectation, and not too surprising, when a country has stronger patent rights, as reflected in the level of PAT, private agricultural R&D investment increases significantly. The size of the marginal effect of PAT obtained form evaluating equation (6) at the sample mean of regressors using our estimated coefficients is 1.9. Furthermore, larger private agricultural R&D capital, larger agricultural higher education capital, and a more efficient public bureaucracy are complementary with stronger patent rights in affecting private R&D investment.

Increasing a country's nationalization potential (NP) has a negative and significant effect on private agricultural R&D investment. In countries where the expropriation of private property is unlikely, the interpretation is that stronger preferences of national companies over foreign ones increases private agricultural R&D investment. This result suggests that giving preferences to domestic companies may be important to the development of new technologies to meet country-specific needs and that country-specific conditions are relatively important to agricultural R&D investment.

The estimated coefficient of a country's infrastructure quality is negative and significant, which contradicts our expectations. It may be that undeveloped agricultural input markets have much more potential than developed ones, but the undeveloped markets are located where infrastructure is poor. If this is the case, then IQ could be measuring another dimension of the expected profitability of national markets for agricultural innovations. Alternatively, with high infrastructure quality, it may be easier for agricultural technologies to be imported, and this could reduce domestic investment in private agricultural R&D.[7]

The estimates of the country-specific fixed effects are largest for the Netherlands, Austria, and Sweden (ordered from largest). They are smallest for Portugal, Italy and Spain (ordered from smallest). This leaves the fixed-effect for Germany in the mid-range. Furthermore, the differences in size of these fixed effects do imply large differences in private agricultural R&D investments associated with time-invariant country-specific effects, e.g., by a factor of 16 from smallest (Portugal) to largest (Netherlands).

Although our empirical results for the institutional variables are quite strong, we also perform a joint test of the null hypothesis that $\beta_9 = \beta_{10} = \beta_{11} = \beta_{12} = \beta_{15} = 0$ in equation (1), i.e., “no institutional effects.” The sample value of the F statistic for this test is 11 which is large relative to the critical value with 5 and 49 degrees of freedom of 4.4 at the 5 percent significance level. Hence, we soundly reject the null hypothesis that institutional variables, as reflected in the quality of property rights, do not effect domestic private agricultural R&D investments.

The estimated coefficients of regression equation (1) with the restriction of no institutional effects are reported in Table 4, regression equation (2). It is noteworthy that signs for the marginal impacts of PSPILL, CROP, and HEDC on private agricultural R&D investment are reversed, compared to regression (1), and that many of the other coefficients differ by more than 50 percent. Hence, excluding the institutional variables biases greatly the implied impact of the included variables on private agricultural R&D investment. This is consistent with the institutional variables being correlated with the other variables and being important factors determining domestic private agricultural R&D investments.

Conclusions

Research and development have been shown to be major forces behind growth in agricultural output, especially agricultural productivity increases. Some prior research has focused on modeling and explaining the public sector's willingness to invest in agricultural research in an environment where R&D produces impure public goods and positive inter-jurisdictional spillins are regional rather than global (e.g., Khanna, Huffman, and Sandler 1994). The current study, however, is the first to examine aggregate private agricultural R&D investment using a panel of developed countries and to identify separate effects of economic incentives and economic institutions.

Using annual data for seven European Union countries, we rejected the hypothesis that quality of property rights does not matter. We have shown that stronger contract enforcement, more efficient public bureaucracies, and stronger patent rights lead to larger private agricultural R&D investment, other things equal. Furthermore, we have shown that the impact of a country's patent rights on private agricultural R&D investment is amplified by it also having a more efficient public bureaucracy and a larger stock of agricultural higher education capital.

An unexpected result was the finding that a stronger preference of nationals over foreigners increases private R&D investment. This seems most likely due to cross-country heterogeneity of agriculture, and nationals being better positioned to develop technologies to meet domestic conditions. For these EU countries, we found evidence of public R&D crowding out private agricultural R&D, rather than being complementary. This suggests an imbalance in the public sector's investments in discoveries, i.e., the public sector may be investing too heavily in applied discoveries that compete directly with private R&D and too little in discoveries from basic/general and pretechnology sciences. Over time, the quality of intellectual property rights in our sample of EU countries has generally increased, and given our results, this is one force for larger private sector agricultural R&D investment, but the public sector--largely national governments--may have overlooked these changes. However, some of the recent efforts to privatize agricultural research in Europe are consistent with an attempt to re-establish the optimal public and private mixture of agricultural R&D.

References

Adams, J.D. (1999). "The Structure of Firm R&D, the Factor Intensity of Production, and Skill Bias," *The Review of Economics and Statistics*, 82:499-510.

Adams, J.D. (1998). "Endogenous R&D Spillovers and Industrial Research Productivity," University of Florida and NBER (December).

Adams, J.D. (1990). "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, 98:673-702.

Alston, J., P. Pardey, and V. Smith (1998). "Financing Agricultural R&D in Rich Countries: What's Happening and Why?" *Australian Journal of Agricultural and Resource Economics*, 42(Mar.):51-82.

Arnon, I. (1989). *Agricultural Research and Technology Transfer*. London, England: Elsevier Applied Science.

Berman, E., J. Bound and Z. Griliches (1994). "Changes in the Demand for Skilled Labor Within Manufacturing," *Quarterly Journal of Economics* 109:367-397.

Bernstein, J.I. and M.I. Nadiri (1989). "Research and Development and Intra-Industry Spillovers: An Empirical Application of Duality," *Review of Economics and Statistics*, 56:249-269.

Bernstein, J. and M.I. Nadiri (1988). "Interindustry R&D Spillovers. Rates of Return and Production in High-Tech Industries," *American Economic Review*, 78:429-434.

Bound, J. and G. Johnson (1992). "Changes in the Structure of Wages in the 1980's: An Evaluation of Alternative Explanation," *American Economic Review* 82:371-392.

Coe, D. and E. Helpman (1995). "International R&D Spillovers," *European Economic Review*, 39:859-887.

Evenson, R.E. (1991). "Inventions Intended for Use in Agriculture and Related Industries: International Comparisons," *American Journal of Agricultural Economics*, 73:887-891.

Falck-Zepada, J.B., G. Traxler and R.G. Nelson (1999). "Surplus Distribution from the Introduction of a Biotechnology Innovation," *American Journal of Agricultural Economics*, forthcoming.

Gaskill, G., M.W. Bauer, J. Durant, and N. Allum (1999). "Worlds Apart? The Reception of Genetically Modified Foods in Europe and the U.S." *Science* 285:384-387.

Geroski, P.A. (1995). "Markets for Technology: Knowledge, Innovation and Appropriability," in Paul Stoneman, Ed., *Handbook of the Economics of Innovation and Technological Change*, Oxford, U.K.: Blackwell Publishers, Inc. pp. 90-131.

Ginarte, J.C. and W.G. Park (1977). "Determinants of Patent Rights: A Cross-National Study," *Research Policy*, 26:283-301.

Griliches, Z. (1998). *R&D and Productivity: The Econometric Evidence*. Chicago, IL: The University of Chicago Press.

Griliches, Z. (1984). "Market Value, R&D and Patents," in Griliches, Z. (ed.) *R&D, Patents and Productivity*, University of Chicago Press, Chicago.

Griliches, Z. (1979). "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics*, 10, 1:92-116.

Griliches, Z. (1969). "Capital-Skill Complementarity," *Review of Economics and Statistics*, 51:465-468.

Grossman, G. and E. Helpman (1991). *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, MA.

Hsiao, C. (1986). *Analysis of Panel Data*, Cambridge University Press, Cambridge, MA.

Huffman, W.E. (1999). Human Capital: Education and Agriculture," in B.L. Gardner and G. Rausser, eds., *Handbook of Agricultural Economics,* Vol. I, Amsterdam, Netherlands: North-Holland.

Huffman, W.E. and R.E. Just (1999). "The Organization of Agricultural Research in Western Developed Countries," *Agricultural Economics*, 21(August):1-18.

Huffman, W.E. and R.E. Evenson (1993). *Science for Agriculture: A Long-Term Perspective,* Ames, Iowa State University Press.

Johnson, Daniel K.N. and R.E. Evenson (1999). "R&D Spillovers to Agriculture: Measurement and Application," *Contemporary Economic Policy*, forthcoming.

Khanna, J., W.E. Huffman, and T. Sandler (1994). "Agricultural Research Expenditures in the United States: A Public Goods Perspective," *Review of Economics and Statistics* 76(May):267-277.

Klotz, C., K. Fuglie and C. Pray (1995). Private-Sector Agricultural Research Expenditures in the United States, 1960-92, U.S. Dept. Agr., ERS Staff Paper No. 9525 (October).

Knack, S. and P. Keefer (1995). "Institutions and Economic Performance: Cross-Country Tests Using Alternative Institutional Measures," *Economics and Politics*, 7:207-227.

Lichtenberg, F. (1992). "R&D Investment and International Productivity Differences," NBER Working Paper, no.4161, September.

Mairesse, J. and B.H. Hall (1995). "Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms," *Journal of Econometrics*, 65:263-293.

Mansfield, E. (1964). "Industrial Research and Development Expenditures: Determinants, Prospects and Relation of Size of Firm and Innovative Output," *Journal of Political Economy*, 72:319-340.

Mauro, P. (1995). "Corruption and Growth," *Quarterly Journal of Economics*, 110:681-712.

Moschini, G. and H. Lapan (1997). "Intellectual Property Rights and the Welfare Effects of Agricultural R&D," *American Journal of Agricultural Economics*, 79:1229-1242.

North, Douglas C. (1990). *Institutions, Institutional Change and Economic Performance*. Cambridge, England: Cambridge University Press.

Olsen, M. (1982). *The Rise and Decline of Nations*. New Haven, CT: Yale University Press.

Park, W.G. (1995) "International R&D Spillovers and OECD Economic Growth," *Economic Inquiry* 33:571-91.

Schmookler, J. (1962). "Changes in Industry and in the State of Knowledge as Determinants of Industrial Innovation," in *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press for the National Bureau of Economic Research, pp. 195-232.

Schmookler, J. (1966). *Invention and Economic Growth*, Harvard University Press, Cambridge, MA.

Schumpeter, J.A. (1950). *Capitalism, Socialism and Democracy*. Harper, New York.

Voon, J.P. and G.W. Edwards (1999). Impacts of Foreign Policies on the Gains from Research and Promotion," *Agricultural Economics* 20:11-21.

Thirtle, C., P. Palladino and J. Piesse (1997). "On the Organisation of Agricultural Research in the United Kingdom, 1945-1994: A Quantitative Description and Appraisal of Recent Reforms," *Research Policy*, 26:557-576.

Whittemore, C.T. (1998). "Structures and Processes Required for Research, Higher Education and Technology Transfer in the Agricultural Sciences: A Policy Appraisal," *Agricultural Economics*, 19:269-282.

Zucker, L.G., M.R. Darby, and J. Armstrong (1998). "Geographically Localized Knowledge: Spillovers or Markets?" *Economic Inquiry* 36:65-86.

Endnotes

1. In European countries subject to the Common Agricultural Policy (CAP), which had high intervention prices and external protection, large surpluses of some agricultural commodities, e.g., milk and cereals, accumulated. This created a skepticism of the need for public agricultural research to increase agricultural productivity.

2. Schumpeter (1950) was a pioneer in the determinants of innovation in firms, and Schmookler (1962, 1966) and Mansfield (1964) provided early empirical evidence of the effects of industrial R&D on firm profitability and patenting rates.

3. See Moschini and Lapan (1997) on issues in optimal pricing of private innovations and the distribution of benefits of new technologies.

4. Our empirical measure of the stock of R&D capital draws heavily on the methodological approach suggested by Griliches (1979, 1984, 1998) when one has limited data.

5. See Voon and Edwards (1999) for a discussion of some of the general equilibrium effects of regional R&D policies in a trade model.

6. Evenson (1991) provides some evidence on international patenting of agricultural inventions and their country of origin.

7. We, however, found no statistically significant effect of a country's openness to trade on private agricultural R&D investment.

Table 1. Private Agricultural R&D Expenditures as a Share of Total Public and Private Agricultural R&D Expenditures, EU-13, selected years (percent)

Country	1985	1990	1995
Austria	41.2	30.9	37.6
Denmark	44.5	31.2	27.7
Finland	41.3	29.2	36.2
France	24.9	19.1	26.0
Germany	13.7	11.9	9.0
Greece	29.2	22.1	15.0
Ireland	16.6	25.6	12.8
Italy	30.1	24.6	28.4
Netherlands	60.8	62.2	58.5
Norway	34.2	46.6	38.4
Portugal	14.4	36.7	21.3
Spain	14.3	8.7	8.2
Sweden	52.4	43.3	45.0

Table 2. National Indexes of Patent Rights, Western Europe 1960-1990

Country/Region	1960	1965	1970	1975	1980	1985	1990
Western Europe							
Austria	3.38	3.38	3.48	3.48	3.81	3.81	4.24
Belgium	3.05	3.38	3.38	3.38	3.38	4.05	3.90
Denmark	2.33	2.66	2.80	2.80	3.62	3.76	3.90
Finland	1.99	1.99	2.14	2.14	2.95	2.95	2.95
France	2.76	3.10	3.24	3.24	3.90	3.90	3.90
Germany	2.33	2.66	3.09	3.09	3.86	3.71	3.71
Greece	2.46	2.46	2.46	2.46	2.46	2.46	2.32
Ireland	2.23	2.56	2.99	2.99	2.99	2.99	2.99
Italy	2.99	3.32	3.32	3.46	3.71	4.05	4.05
Netherlands	2.95	3.29	3.61	3.47	4.24	4.24	4.24
Norway	2.66	2.66	2.80	2.80	3.29	3.29	3.29
Portugal	1.98	1.98	1.98	1.98	1.98	1.98	1.98
Spain	2.95	3.29	3.29	3.29	3.29	3.29	3.62
Sweden	2.33	2.66	2.80	2.80	3.47	3.47	3.90
Switzerland	2.38	2.71	3.14	3.14	3.80	3.80	3.80
United Kingdom	2.70	3.04	3.04	3.04	3.57	3.57	3.57
subgroup mean	2.60	2.82	2.97	2.97	3.39	3.46	3.52
United States	3.86	3.86	3.86	3.86	4.19	4.52	4.52
Mean: 111 countries	2.13	2.22	2.27	2.28	2.40	2.44	2.46

Source: Adapted from Ginarte and Park 1997.

Table 3. **Definitions of variables**

PRRINV	Aggregate private investment in agricultural R&D. National annual aggregate real private expenditures or gross investment on agricultural R&D divided by the price index for final agricultural production (OECD, *Economic Indicators*).
IRATE	Interest costs. The real interest cost of private investment is the short term interest rate on national government bonds less the annual rate of inflation on gross domestic product (Int. Monetary Fund).
$PRRCAP_{-1}$	Aggregate private agricultural R&D capital. The one-year lagged value of the real national stock of private agricultural R&D; nominal R&D expenditures were deflated by the price index for final agricultural production then the stock derived using the perpetual inventory method assuming a 12 percent depreciation rate.
$RSPILL_{-2}$	Index of the spillin potential of private agricultural research. The stock of public agricultural R&D in other sample countries lagged two years.[1/]
FPA	Aggregate agricultural production. Total value of final agricultural production (OECD, *Economic Indicators*) divided by the price index for final agricultural production.
CROP	Crop share. Value of crop production as a share of total value of final agricultural production (OECD, *Economic Indicators*).
$PURCAP_{-1}$	Aggregate public agricultural R&D capital. One year lagged nominal national public agricultural R&D expenditures (OECD, *Basic Science and Technology*, Technology Statistics) deflated by the price index for final agricultural production, then the stock derived using the perpetual inventory method assuming a 12 percent depreciation rate.
$HEDC_{-1}$	Aggregate agricultural higher education capital. One year lagged national nominal higher education expenditures were deflated by the price index for final agricultural production and the stock derived using the perpetual inventory method assuming a 12 percent depreciation rate.
CE	Contract enforcement. Measures the relative degree to which contractual agreements are honored and complications presented by language and mentality difference, scored 0-4 with higher scores for greater enforcement (Knack and Keefer 1995).

Table 3 (continued)

BD	Bureaucratic delays. Measures the speed and efficiency of the civil service, scored 0-4 with higher scores for greater efficiency (Knack and Keefer 1995).
NP	Nationalization potential. Measures the extent of preferential treatment of nationals over foreigners in legal matters (and risk of expropriation for no compensation), scored 0-4 which higher scores indicating relatively more favorable treatment or less risk to foreign interests (Knack and Keefer 1995).
PAT	Patent rights index. An index obtained by summing 0-to-1 scores for each of five categories of patent law: extent of coverage, membership in international patent agreements, provision for loss of protection, enforcement mechanism, and duration of protection (Ginarte and Park 1997). Overall the index takes values 0-5 with large index indicating stronger patent rights.
IQ	Infrastructure quality. An assessment of facilities for and ease of communication between company headquarters and operations, and within country, and quality of transportation, scored 0-4 with higher scores indicating better quality (Knack and Keefer 1995).
CONSTANT(j)	Dummy variable taking a value of 1 if observation is country j (j=Austria, Germany, Italy, Netherlands, Portugal, Spain, Sweden) and 0 otherwise.

1/ Each country's private agricultural R&D expenditures were converted to real 1990 purchasing power of parity dollars before creating the capital stock. The aggregation of private R&D stocks across countries applies the methodology employed by Khanna, Huffman, and Sandler (1994) for aggregating across U.S. states. Of course, other weighting schemes exist.

Table 4. SUR Estimates of Investment Equation for National Aggregate Private Agricultural R&D: Seven EU Countries 1984-1995 (t-values in parentheses)

		Regression			
	Sample Mean	Eq (1)		Eq (2)	
Regressors	of variable	coeff	t-value	coeff	t-value
IRATE	0.031	-1.530	(3.92)	-2.748	(3.40)
ℓn($PRRACAP_{t-1}$)	6.848	0.679	(3.08)	1.407	(8.37)
ℓn($PSPILL_{t-2}$)	-0.700	0.638	(3.35)	-0.170	(0.49)
ℓn(FPA_t)	8.438	1.194	(3.28)	1.362	(3.44)
$CROP_t$	0.326	1.584	(1.68)	-1.094	(1.05)
ℓn($PURCAP_{t-1}$)	5.095	1.318	(4.67)	1.604	(5.63)
ℓn($HEDC_{t-1}$)	4.815	-0.087	(0.42)	-1.192	(6.20)
CE_t	3.30	0.688	(2.53)		
BD_t	2.40	-0.791	(3.20)		
NR_t	3.08	-0.593	(3.86)		
PAT_t	4.03	1.424	(3.49)		
IQ_t	3.30	-0.933	(3.04)	-0.709	(3.87)
(ℓn$PRRCAP_{t-1}$) x (ℓn$PURCAP_{t-1}$)		-0.286	(6.00)	-0.175	(5.86)
(ℓn$PRRCAP_{t-1}$) x (ℓn$HEDC_{t-1}$) x PAT_t x BD_t		0.006	(3.08)		
CONSTANT (Austria)		-10.043	(3.40)	-9.423	(2.79)
CONSTANT (Germany)		-14.275	(3.87)	-11.495	(2.75)
CONSTANT (Italy)		-23.906	(5.87)	-15.375	(3.79)
CONSTANT (Netherlands)		-8.97	(2.60)	-10.101	(2.50)
CONSTANT (Portugal)		24.667	(6.74)	-16.128	(4.76)
CONSTANT (Spain)		-20.723	(5.77)	-17.296	(4.61)
CONSTANT (Sweden)		-11.823	(4.07)	-8.011	(2.42)
R^2 (adjusted)		0.967		0.966	
Durbin Watson		1.333		1.309	