Impact of Technology Policy on Research in the Agricultural Input Industries

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July 1989

Prepared for the American Agricultural Economics Meetings, August, 1989, Baton Rouge, Louisiana.

The research for this report was supported by the CSRS Interregional Project 6 and the New Jersey Agricultural Experiment Station.

#6486

Abstract

This paper tests the influence of technology policies on research expenditure of private agricultural input firms. Government research has a positive influence on private R&D; tougher pesticide regulation has a negative impact; but R&D tax credits, changes in patent laws and breakthroughs in biotechnology have no measurable impact.

Impact of Technology Policy on Private Research in the Agricultural Input Industry

US competitiveness in international markets has been of increasing concern over the past decade. The focus of this concern has centered on US industries poor performance in new technology development. In an effort to curb this trend, US policy in the 1980's has been directed at creating a climate conducive to encouraging private sector R&D investment (OMB,1989). To this end policy in the 1980s' has been directed towards improving incentives for innovation by strengthening intellectual property rights, tax code revisions to reduce the cost of R&D, relaxing antitrust laws to encourage joint industrial R&D efforts, and introducing legislation to facilitate joint public/private R&D and licencing agreements to transfer technology from the public to the private sector.

In the agricultural sector, which is particularly dependent on export markets, a major source of productivity gain has been the continual development of new technology. Investment in new food and agricultural production technology has come from both the public and private sectors (R&D has been 60 percent private and 40 percent public). Public sector support for R&D in agriculture differs from most industrial sectors of the economy in that the public sector conducts most of the publicly funded agricultural R&D. In the industrial sector, a high proportion of publicly funded R&D is conducted in the private sector. Also if National Defence R&D is excluded, agriculture has traditionally received a larger share of public support than other industries[1].

Given the importance of new technology development in maintaining competitive advantage and the real possibility that public support of agricultural R&D will decline, it is important to monitor the effectiveness of various policy instruments in creating incentives for the development of new technology. The objective of this paper is to examine the impact of

[1] Federal budgetary constraints have resulted in continuous pressure to reduce the public funding for R&D in agriculture. In 1989 support for Agricultural research will experience a 3% reduction from the 1,018 $M in 1988 (OMB,1989). For many years cutbacks in federal funding have been matched by increases in state funds thus preventing a decrease in R&D funding.

technology policy on the agricultural input industries to identify policy instruments that are effective in changing the level of private sector R&D investment.

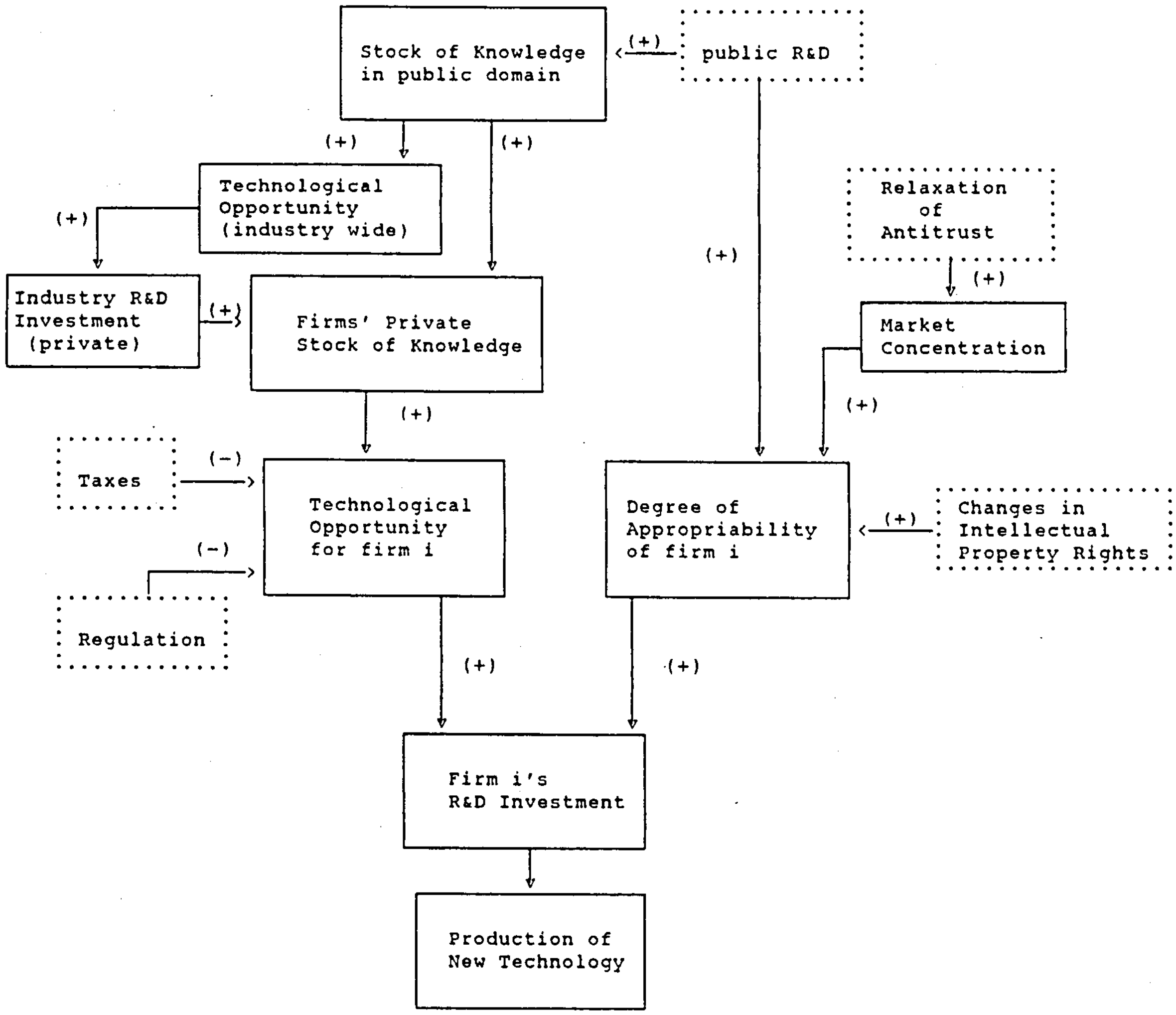
Impact of Policy on Private Sector R&D Investments

Figure 1 presents a schematic representation of the impact of policy on private sector R&D investment. Policy instruments can be used to change both the technological opportunity and degree of appropriability of an industry thus changing the incentives for private sector investment in technology development.

Technological opportunity refers to the potential for development of new technology in an area. It is useful to think of technological opportunity as having two components: the physical component, which accounts for the technical efficiency of the research production process; and the price or market component, which is influenced by factors affecting the cost of R&D through prices of R&D inputs. The degree of technological opportunity is dependent on the inherent nature, as well as the understanding of, the science base of an industry's technology. Policies which encourage increasing the scientific knowledge base like public sector research improve an industry's technological opportunity if the new knowledge results in increased potential for technological innovations. Technological opportunity may also increase if the price of R&D inputs decline. Policies such as reducing taxes or less stringent licencing regulations will decrease the cost of R&D thus increasing the technological opportunity of an industry.

The degree of appropriability refers to a firm's ability to capture the returns to innovations resulting from its own R&D efforts. The degree of appropriability characterizing an industry is a result of the interaction of the characteristics of the technology, market structure and institutional arrangements of an industry. New products/processes differ with respect to ease of duplication, for example crops which have been hybridized facilitate proprietary protection in the form of trade secrecy. Therefore we would expect interindustry differences simply due to the technology base of an industry. Market structure may influence firms ability to appropriate returns to investments in R&D. All things equal, the more concentrated the market, the higher the expected payoff to the individual firm. Market structure can be affected by both antitrust policy as well as public sector research (which

Figure 1. Effect of Policy Instruments on R&D Investments



lowers entry costs in industries requiring long R&D gestation periods). Policies affecting institutional arrangements such as intellectual property rights, contracts for collaborative R&D, institutional arrangements for marketing and transferring R&D products also affect the degree of appropriability of an industry.

Model

The model used in this study is based on Levin and Reiss (1984). This model allows R&D spillover within an industry. Thus knowledge generated by one firms' R&D efforts benefits other firms in the industry. A firm invests in R&D to reduce its unit costs:

$$c_i = c(x_i \ , Z) \qquad (1)$$

where x_i is the R&D expenditure of the i^{th} firm, Z is the common pool of industry R&D where $Z = \Sigma_i^n \theta_i x_i$, θ_i is the i^{th} firms conjectural variation on R&D and c_x, $c_z < 0$, c_{xx}, $c_{zz} > 0$. Solving the firms profit maximization problem[2] and assuming a symmetric equilibrium over n firms we obtain the industry R&D intensity equation:

[2] The model developed by Levin and Reiss includes advertising as one of the firms' decision variables, where advertising serves to shift industry demand to the right. We omit advertising primarily because we do not have adequate data. The focus here is the impact of policy on R&D therefore we concentrate on the derivation of the R&D intensity equation. Given the firms' unit cost $c_i = c(x_i, Z)$ and inverse demand $p = p(Q)$, the firms profit maximization problem is:

$$\max_{q_i x_i} \Pi_i = [\ p(Q) - c(x_i, Z)\ ]\ q_i - x_i$$

assuming cournot conjectures on output, the first order conditions give us:

i) $p\ (\ 1 + \frac{s_i}{\varepsilon}\ ) = c$ where $1/\varepsilon$ is $(P/Q)(dp/dq_i)$ and si is the i^{th} firms market share,

ii) $q\ (\ \frac{dc}{dx_i} + \frac{dc}{dZ}\ \theta_i) = 1$ where $\theta_i = \frac{dZ}{dx_i}$

assuming free entry and that a symmetric equilibrium exits with n firms, by the zero profit condition at equilibrium:

$$[\ p(Q) - c(x, Z)\ ]\ q = x$$

summing over n firms and dividing both sides by pQ we obtain:

$\frac{p-c}{p} = R$ where the left hand side is the Lerner index of monopoly and the right side is R&D intensity

From (ii), multiplying both sides by x/pq, the lefthand side by c/c:

$\frac{c}{p}\ (\ \frac{x}{c}\frac{dc}{dx} + \frac{x}{c}\frac{dc}{dZ}\ \theta\ ) = R$, multiplying the second term on the left hand side by n/n yields:

$\frac{c}{p}\ (\ \alpha + \frac{\tau\theta}{n}i\ ) = R$, recall $\frac{p-c}{p} = R$ and $\frac{c}{p}$ 1-R therefore: $\alpha + \frac{\tau\theta}{n}$ is R&D/sales.

Constant elasticity cost and inverse demand functions of the form $C(x,Z) = \beta x^{-\alpha} Z^{-\tau}$ and $p(Q) \grave{o}^{1/}\varepsilon Q^{-1/\varepsilon}$.

$$RDINT = \alpha + \frac{\tau \theta}{n} \qquad (2)$$

where RDINT is the ratio of research expenditures to value of shipments
α is the elasticity of unit cost with respect to own R&D
n is the number of firms in the industry
τ is the elasticity of unit cost with respect to industry R&D
θ is the conjectural variation of R&D

Levin and Reiss interpret the first term (α) as a measure of technological opportunity facing the firm and the second term as a measure of appropriability. Their formulation of appropriability has three components: the technological, represented by the elasticity of cost reduction with respect to industry R&D (τ); the behavioral dimension measured by the R&D conjectural variation (θ)[3]; and the structural dimension represented by market share which in the case of a symmetric equilibrium is 1/n. From equation (2) if conjectural variation is positive (ie. $\theta > 0$), R&D intensity increases as market concentration increases.

Technological opportunity is described by equation (3), the variables are described in Table 1.

$$(3) \qquad \alpha = b_0 + b_1(RDGENERIC) + b_2(RDAPPLIED) + b_3(BIOTECH) + b_4(REGUL) + b_5(DTAX) + b_6(AGE) + b_7(AGESQ)$$

The first two variables in equation (3) are public sector research. Our hypothesis is that publicly funded research creates opportunities for firms to make commercial innovations[4]. We consider three categories of public R&D, basic R&D, generic R&D and applied R&D. Investments in basic research will

[3]The sign of θ is unrestricted since it is possible that if one firm increases its R&D efforts and other firms respond by reducing their R&D investment, if this negative effect is sufficient the net effect could be a reduction in industry R&D.

[4]The influence of public sector R&D in agriculture may require more careful modelling, our use of it here represents a first approximation to its influence on private sector research investments. In general it is felt that the majority of public sector research will enhance technological opportunity to the private sector however at least some exceptions are obvious. For example, some public sector research may be expected to reduce the demand for agricultural chemicals. Such as research pertaining to environmental quality which leads to reduction in the use of chemicals or fertilizer (generally but not always this effect will be felt through changes in regulation). Another example of this influence on demand is research directed towards input substitution such as pest resistant varieties which permit reduced pesticide use without yield losses. One other impact which is often discussed in the industrial literature is the possibility that public sector research directed at developing new technology acts as a substitute to private sector research.

increase the level of scientific knowledge upon which the technology of the industry is based thus increasing its technological opportunity. We would expect the impact to differ across industries due to the closeness of the link between the 'cutting edge of technology' in an industry and the 'cutting edge of the body of scientific knowledge' on which the technology is based[5]. Public research expenditures on basic science have resulted in new scientific discoveries which have influenced the technology of the agricultural input industries. For example research funded by the National Institute of Health (NIH) and the National Science Foundation (NSF) resulted in some fundamental breakthroughs in biotechnology. Basic research on computers and new materials funded by the Department of Defense and other government agencies has been incorporated into R&D on new farm machinery. To date we do not have a time series of public basic research of sufficient length to test its impact on private R&D. To pick up some of the effects of basic research we have included a shift dummy, BIOTECH to test the impact of biotechnology breakthroughs on private R&D in the agricultural chemical and veterinary medicine industries[6].

Researchers at the U.S.Department of Agriculture (USDA) and State Agricultural Experiment Stations (SAES) conduct generic research which applies knowledge from basic disciplinary research to specific plants, animals and machinery. Expenditure on this type of research is our RDGENERIC variable. Some USDA/SAES R&D is very applied, involving the development and testing of new products. Although such research may produce new products that compete with private products this research also facilitates private sector scientists in adapting private innovations to make the product more effective in farmers' fields.

The second type of policy variable in equation (2) is regulation. Environmental protection regulation and occupational health and safety regulations affect the productivity of R&D by: (i) increasing the cost of developing new technology by extending the time necessary to bring a product to market (in the case of stricter licencing requirements for new products);

[5] Nelson (1986) reports that firms in chemical based industries and industries based on biological sciences ranked university R&D very relevant to their own R&D.

[6] Although the R&D in seed industry is also expected to be influenced by new discoveries in biotechnology, data limitation in the seed industry do not permit testing its impact.

and (ii) requiring that firms direct R&D resources to develop new processes/products that meet the stricter standards.

Regulation has had its greatest affect on the agricultural chemical and pharmaceutical industries. The regulatory law regulating pesticides is the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) of 1947[7]. FIFRA was strengthened in 1967, 1970 and 1972. In 1972 Congress made significant amendments to FIFRA which increased EPA's ability to enforce regulations and also increased the number of pesticides covered. A 1978 amendment of FIFRA attempted to streamline the registration process because of "concerns that the regulatory process had become excessively restrictive" (Hatch 1982).

Tax policy may be used as an instrument to influence the incentives for private R&D through its impact on the cost of R&D. Accelerated depreciation rates on R&D capital and tax credits on R&D expenditures may reduce the cost of R&D. The Economic Recovery Tax Act of 1981 provided a 25 percent tax credit on incremental R&D expenditures and allowed more rapid depreciation of R&D capital. The Tax Reform Act of 1986 eliminated many tax breaks in the 1981 act, but it continued the R&D credit through 1988.

The age variables attempt to capture differences due to the maturity of the industry. The input industries in our sample were based on major breakthroughs which led to many opportunities for commercially profitable research in their early years but which are expected to diminish over time. There are signs that conventional agricultural chemical R&D and plant breeding are running into diminishing returns to R&D expenditure. This suggests a pattern of rapid growth in R&D intensity during the early period of the industry and slowly declining growth thereafter.

The industry dummies are included to pick up industry specific characteristics such as the specific science base that each industry's technology draws upon.

To estimate the degree of appropriability (second term of equation (2)), we require market share, the conjectural variation on R&D for each industry as well as a measure of the technological component of appropriability. The four

[7] See Hatch 1982 for a detailed description of the evolution of pesticide regulation in the U.S.

firm concentration ratio (CR4) is used as a proxy of market structure[8]. Cournot conjectural variation are assumed ($\Theta = 1$). The technological component of appropriability is estimated by:

(4) $$\tau = c_0 + c_1(PVPA) + c_2(BIOTECH)$$

Appropriability is influenced by institutions affecting property rights. Over the study period new legislation, court decisions extending coverage of existing property rights and decisions by the U.S. Patent Office have strengthened intellectual property rights in the US.

In the area of biological inventions a number of changes in property rights occurred over the study period. The Plant Variety Protection Act (PVPA) was passed in 1970 providing patent-like protection to new plant varieties. In the 1980 Diamond v. Chakravarty decision the U.S. Supreme Court upheld patenting of living organisms. In 1985 the first plants were patented (prior to this they could only be protected under the Plant Variety Protection Act) and in 1988 the first animal patent was issued. These rulings primarily affect the seed industry and biotechnology R&D (much of which is done by firms in the agricultural chemical industry).

The veterinary medicine industry was also affected by changes in patent regulation. The effective life of pharmaceutical patents had been shortened due to product testing regulations. In 1984 the 'effective life' of these patents could be extended for up to five years (Grabowski and Vernon, 1986). No major changes have occurred in patent protection for farm machinery or agricultural chemicals that are not produced through biotechnology.

BIOTECH is included in the appropriability equation because breakthroughs in understanding of DNA now make it possible to genetically fingerprint plant varieties which enhances seed companies' power to enforce property rights on plants. However, since the fingerprinting technique was discovered after 1980 (last available data on the seed industry), it was excluded from our regressions.

Equation (5) is derived by substituting (3) and (4) into equation (2).

(5) $$RDINT = b_0 + b_1(RDBASIC) + b_2(RDAPPLIED) + b_3(BIOTECH) + b_4(REGUL) + b_5(TAX) + b_6(AGE) + b_7(AGESQ) + b_8(INDUSTRY\ DUMMIES) + \Theta CR4[c_0 + c_1(PVPA)]$$

[8] CR4 has been shown to be a good approximation to the Herfindahl index, see F.M.Scherer Industrial Market Structure and Economic Performance, Second edition, Houghton Mifflin Co.,1980, pp 58.

Estimates

Industry level data for the agricultural chemicals, farm machinery, veterinary medicine and seed industries, over the period 1960 to 1986, were used to estimate equation (5) using OLS. The sources of data[9] for each variable are shown in Table 1. The results are reported in Table 2.

The results support the hypothesis that public sector research in agriculture has increased technological opportunity of the input industries. Generic agricultural R&D (RDGENERIC) has a positive and significant influence on research intensity in all specifications of the model. The past stock of knowledge generated by USDA and SAES' R&D expenditures increases the opportunities for firms to benefit from R&D and they have responded by investing more in R&D.

Applied research (RDAPPLIED) could be either a complement or a substitute for applied private research. We hypothesize that it is a complement. The regression results support this hypothesis. The applied research coefficient is positive and statistically significant in most specifications. It is insignificant only when we drop the industry dummies.

Breakthroughs in biotechnology have induced many firms to invest in biotechnology research. We expected that pharmaceutical and agricultural chemical firms would increase their total research expenditure rather than simply shift funds from other types of research to biotechnology. The results to not support this hypothesis. The dummy variable for biotechnology is not significant in any specification and is consistently negative. Agricultural chemicals and veterinary pharmaceutical may in fact have decreased their research expenditure because they expect biotechnology will reduce demand for conventional chemical products in the future. Another explanation is that the data do not accurately reflect the increase in biotechnology research because new firms, which do much of the biotech research, are not included in the NSF, National Agricultural Chemicals Association and Pharmaceutical Manufacturers Association data which is the basis for the time series used here[10].

To our knowledge, this is the first study to show that USDA/SAES R&D has a

[9] The sources of R&D data and construction of the time series are described in detail in Pray and Neumeyer (1989).

[10]. See Pray and Neumeyer (1989) for an explanation of why biotechnology is underestimated in this data.

Table 1. List of Variables

Variable	Description
RDINT	Research intensity is R&D expenditure on a product field by the value of shipments of the product. Sources are applied R&D by Product Field for Agricultural Chemicals 1958-86 (NSF and NACA), applied R&D by Product Field for Farm Machinery 1958-1983 (NSF), seed R&D and sales 1960-80(Butler), veterinary pharmaceutical R&D and sales 1961-86(PMA) and value of shipments of agricultural chemicals and agricultural machinery (Survey and Census)
RDGENERIC	Stock of public sector basic research on agriculture by USDA and the State Agricultural Experiment Stations (Langston). The stock for any year is the sum of the previous twenty years' expenditure.
RDAPPLIED	Stock of USDA/State Agricultural Experiment Stations applied research. There are series on mechanization, plant protection, post harvest, animal disease and crop breeding/genetics. The stock for any year is the sum of the previous five years' expenditure. Data is based on categories of Huffman and Evenson.
CONS	Concentration ratios are the share of the top four firms from the Census of Manufacturers for ag. chemicals, farm machinery and veterinary medicine. For the seed industry the CR8 for the hybrid corn seed industry was used as a proxy for concentration in the seed industry.
CONSQ	Concentration squared.
AGE	Age is measured as the number of years since commercialization of major breakthroughs in the industry. For each industry the approximate date at which major breakthroughs occurred was 1955 in veterinary medicine, 1945 in agricultural chemicals, 1935 for seed, and 1925 for agricultural machinery.
AGESQ	Age squared
REGUL	Regulation is measured as the number of months delay time from the discovery of a new chemical to the time it is registered (Hatch and NACA)
BIOTECH	Impact of technological breakthrough represented by the new biotechnologies. This variable is a dummy variable for the agricultural chemical, seeds and veterinary medicine industries. The variable is an intercept dummy equal to 1 for these industries for 1982 onward and 0 otherwise.
PVPA	Impact of the effect of the PVPA on the seed industry. This variable is an intercept dummy equal to 1 in the post PVPA period (1970 onward) and 0 otherwise.
DTAX	Dummy variable for the R&D tax credit. It is on all industries and equals 0 before 1982 and 1 from 1982 onward.
D0,D1,D2	Industry dummies for veterinary medicine, agricultural chemical and seed industries respectively.

Key to Data Sources:

Butler Butler, L.J. and B.W.Marion, The Impacts of Patent Protection on the U.S.Seed Industry and Public Plant Breeding Madison: U of Wisconsin 1985.

Census U.S.Bureau of the Census Census of Manufacturers Washington D.C.:GPO.

Huffman Huffman, Wallace and Robert Evenson, The Development of U.S.Agricultural Research and Education : An Economic Perspective, unpublished manuscript, 1988.

Hatch Hatch, L.U. "Effect of Environmental Protection Agency Regulation on Research and Development in the Pesticides Industry," Ph.D. Dissertation, U. of Minnesota, St.Paul, Minnesota 1986.

Langston Langston, Jackie "Dynamic Strategies for Research Expenditures in Agriculture: Public and Private, Basic and Applied," Ph.D. Dissertation, U. of Georgia. 1988.

NACA National Agricultural Chemicals Association, unpublished survey of members.

NSF National Science Foundation, Research and Development in Industry Washington,DC:GPO 1957 to 1984

PMA Pharmaceutical Manufacturers Association.

Survey U.S.Bureau of the Census Annual Survey of Manufacturers Washington D.C.:GPO

Table 2. Regression Results: Input Industry R&D Intensity 1958-86.

	Generic R&D 20 Year Stock	Generic R&D 20 Year Stock (No fixed effects)	Generic R&D Distributed Lag Model
RDGENERIC	0.2036 *	0.0386 *	2.7312[1] *
RDAPPLIED	0.0025 *	-0.0004	0.0037 *
REGUL	-0.0019 *	-0.0013 *	-0.0026 *
DTAX	-0.0093	-0.0024	0.0046
PVPA	0.0080	-0.0198	0.0028
BIOTECH	-0.0078	-0.0118	-0.0038
CON	-0.0091	0.0052	-0.0093 #
CONSQ	0.0001 #	-5.4E-05	0.0001 *
AGE	-0.0382 *	-0.0008	-0.0306
AGESQ	-3.5E-05	-7.4E-05 *	-1.1E-05
D0	-1.1046 *		-1.3631
D2	-0.7254 *		-0.5145
D3	-0.6500 *		-0.6101 *
Adjusted R^2	.9004	.8820	.9096

1. This is the sum of the distributed lag weights.
* = significant at .05 % level, # = significant at .10 % level.

positive influence on private R&D in agriculture. Only two other econometric studies have examined the relationship between research in universities or public research institutions and private R&D in any industry (Levin et.al. andJaffe). They find positive, significant relationships.

The purpose of the R&D tax rebates was to stimulate private sector R&D expenditure. It does not appear to have occurred in the agricultural input industries. The tax variable, DTAX, is usually negative and sometimes statistically significant[11]. In a study of U.S. industries Mansfield (1986) obtains similar results. He finds that the 1981 tax credit had a small, positive impact. He also notes that the foregone revenue from the R&D provisions of the Act was about three times the increase in R&D.

The influence of regulatory changes is demonstrated by the negative impact of more stringent testing requirements on R&D investment in the agricultural chemical industry. The regulatory effect REGUL, proxied by the number of months required to register a new chemical, is consistently negative and significant. This is consistent with the findings of Hatch (1986) that the productivity of agricultural chemical R&D was reduced by more stringent regulation after 1967.

Changing intellectual property rights to increase the degree of appropriability of returns from new innovations was expected to increase research. However the impact of PVPA on the seed industry does not support this hypothesis. In our regressions we attempted to pick up the effect of the PVPA through a shifter dummy in the seed industry. This variable was consistently negative but generally insignificant. This contradicts the conclusions of the seed industry study from which the research intensity was taken (Butler and Marion 1985). It is, however, consistent with the conclusions reached by economists who have studied the impact of patents on R&D in industry that patents are not a major factor in determining the level of R&D (Griliches and Pakes 1987 and Stoneman 1987).

[11] In other work currently underway, with firm level data (in the agricultural chemical and farm machinery industries) we follow individual firms R&D investments over time, we are picking up a positive effect from tax changes. These preliminary results this may suggest that the tax effect is in fact positive for large firms (the sample used for this study tends to be large firms).

The degree of concentration present in an industry does not influence of research intensity in our study. The concentration variables are not significant except in the distributed lag model. Antitrust policy changed when the Reagan administration came into office and there has been consolidation in the pesticide and farm machinery industries. However, most of the consolidation took place after 1982 which is the last year in which we have concentration data.

The age of industry variable (AGE) is consistently negative and significant. This supports the hypothesis that as the industry ages the level of technological opportunity decreases.

5. Policy Implications

The paper provides some first quantitative evidence that technology policies do affect private sector agricultural research in the U.S. Generic R&D and applied R&D by USDA and SAES have a positive and significant influence on private R&D expenditure. Other policies have been less successful in promoting private research. There is no evidence that either the R&D tax credits of 1981 or increased patent protection had the expected positive impact on research. Stricter regulation of agricultural chemicals had a negative affect on private agricultural chemical R&D. Finally, the statistical evidence on the relationship between concentration and research does not support either the critics or the proponents of relaxed antitrust policies.

Although this paper did not address the issue of designing policies to obtain the optimal amount of private research, it does examine which policies do influence the level of private research in the agricultural input industries. From the findings of this paper, if the U.S. government does want to encourage private research, then investments in USDA and SAES research appears to be an effective way to do so. Other policy options do not look as promising. The negative or insignificant impact of patents and tax credits is supported by other studies in the industrial sector and suggests that policy makers should not expect large positive impacts from these policies. The message on antitrust policy is mixed.

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