PRIVATE R&D INVESTMENT IN U.S. AGRICULTURAL INDUSTRY: MARKET DEMAND, TECHNOLOGICAL OPPORTUNITY, AND APPROPRIABILITY.

by

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STATEMENT BY AUTHOR

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ABSTRACT

This study uses new, recently available data to undertake an econometric analysis of the determinants of private R&D investment in five U.S. agricultural industries – agricultural chemicals, farm machinery, food products, plant breeding, and veterinary pharmaceuticals – from 1961 to 1995. Four major results come from the analysis. First, econometric results generally suggest that complementary relationships exist between public and private agricultural R&D investment in all industries except farm machinery. Second, the complementarity between public and private R&D was the strongest and most robust in the plant breeding industry. Third, results are consistent with Schmookler's "demand pull" hypothesis as market demand (measured by industry sales) had a strong positive effect on R&D investment in all industries. Fourth, based on a growth decomposition exercise, growth in public R&D was the major factor contributing to private R&D growth in the plant breeding and agricultural chemicals industries between 1961-95. Sales growth was the major contributing factor to private R&D growth in the other three industries.

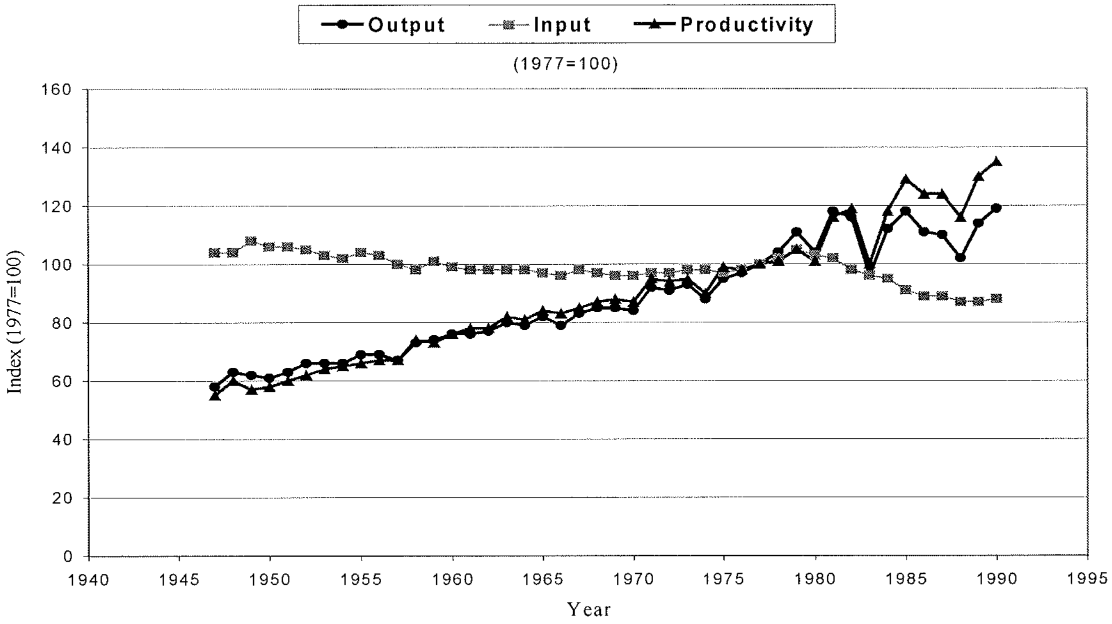
CHAPTER ONE: INTRODUCTION

1.1 Introduction

Total factor productivity growth is the main source of agricultural growth in U.S. agriculture. Productivity can be measured in different ways. Partial productivity measures are expressed as ratios of output to a single input. For example, land productivity measures output per acre while labor productivity measures output per unit of labor. Total factor productivity (also called multifactor productivity) is a ratio of total outputs to total inputs, where both inputs and outputs are measured as aggregate indexes. Thus, improvements in the quality of inputs and technological progress increase agricultural productivity growth, obtaining more outputs from a given input level. As Figure 1.1 shows, from 1948 to 1993 aggregate U.S. agricultural output doubled, while aggregate input use decreased by -0.1% a year (USDA 1999).

Agricultural productivity growth plays an important role in the U.S. economy. First, if productivity levels in one sector of the economy rise, resources will be released for use by other sectors. Second, increased productivity lowers the real prices of goods and services. Agricultural productivity gains are then passed on to consumers in the form of lower food prices. In addition, lower real prices for agricultural products have contributed to the advantageous U.S. trade position in international agricultural markets (Ahearn et al. 1998). In 1997, U.S. agriculture experienced a trade surplus of $32 billion, while the overall trade balance had a deficit of $110 billion (USDC 1999).

Figure 1.1 Index of Farm Output, Input, and Productivity in the United States, 1947-1990



Source: USDA (1999)

Research and development (R&D) is one of the most important sources of productivity growth in U.S. agriculture. Research can be divided into basic research, applied research and product development. Genetics, molecular biology, pathology, physiology and general mathematical sciences are examples of basic research. Plant breeding for specific traits would be an example of applied research, while adapting seed varieties to local conditions would be an example of development. These combinations of R&D activities produce higher yielding crop varieties, better livestock breeding practices, more effective fertilizers and pesticides, and better farm management practices (Ahearn et al. 1998).

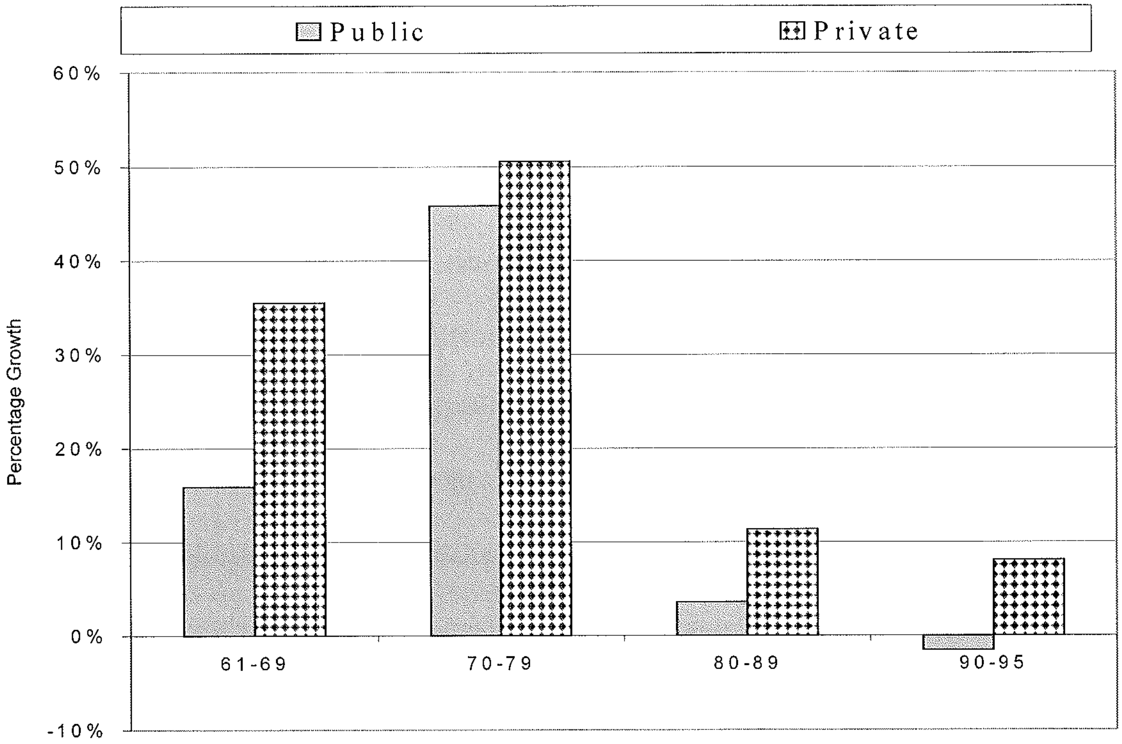
Thus, understanding R&D's role in productivity growth is important for understanding agricultural growth. Huffman and Evenson (1993) estimated multifactor productivity (MFP) growth during the period of 1950-1982 in the crop and livestock sectors. They estimated that crop sector MFP grew by 62.6% between 1950-82. Public agricultural R&D was the largest contributor to crop sector MFP growth, accounting for a 22.5% increase in MFP. Private R&D accounted for a 15.1% increase in MFP. In the livestock sector, MFP grew by 51.3% between 1950-82. Private R&D accounted for a 45.7% increase in MFP. Public R&D accounted for a 7.2% increase in MFP.

In the U.S., private R&D has grown in importance relative to public R&D. In 1960, the private sector accounted for 48 percent of U.S. agricultural R&D. By 1996, the private sector accounted for 60 percent of total agricultural R&D. Figure 1.2 compares growth rates of private and public R&D in the 1960's, 70's, 80's, and 90's. Private R&D growth rates exceeded public R&D growth in each period. This means that changes in private R&D have more of an impact on changes in agricultural productivity and overall agricultural growth in the United States.

1.2 Purpose of Study

This study describes trends and patterns in private R&D in agricultural input and food industries over the last 35 years, and tests a number of hypotheses from the economic literature that try to explain the level and intensity of private investment in agricultural R&D.

Figure 1.2 Public and Private R&D Growth, 1961-1995



Sources:

Public R&D: Huffman and Evenson (1993).

Private R&D: Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.

Note: Real Dollars (1996=1.00).

This study expands on work of Pray and Neumeyer (1989). Pray and Neumeyer econometrically estimated the influence of technology policies (i.e. pesticide regulation, R&D tax credits, and patent law) and public R&D on private R&D expenditure from 1958 to 1986. This study uses a new data set that covers private agricultural R&D from 1961 to 1995. The data set is used to examine factors that affect incentives for private R&D in agricultural input and food processing sectors.

1.3 Hypotheses Tested

The main focus of this study is to determine what factors influence agricultural private R&D at the industry level. Specifically, it will ask the following three questions:

1. Does market size influence private R&D investment (the demand-pull hypothesis)?

The demand-pull hypothesis means that inventive activity is responsive to changes in product demand. Schmookler (1966) emphasized the ability to make inventions is responsive to profit-making opportunities, and the larger market is, the more inventive activity will be directed toward it. Scherer (1982) explains this is because chance encounters between inventive talent and a problem needing solution are more frequent, the more productive activity there is devoted to meeting some demand. Schmookler tested demand-pull hypotheses by analyzing capital goods invention flows to particular industrial end uses. The more investment (measured by the amount of the goods purchased) there was in a technology-using industry, the more patented capital goods inventions directed toward that industry's needs (i.e. the greater the pull of technology-using industry demand). He found that the greater technology-using industry capital investment was, the larger the number of relevant capital goods invention patents from all sources was. Schmookler's study suggests that differences in R&D demand-pull effects cause differences in private R&D investment at the industry level.

2. Does public R&D complement or substitute for private R&D? Does it "crowd in" or "crowd out" private R&D?

A number of studies (Levy and Terleckyj 1983; Scott 1984; Mansfield 1984; Robson 1993) have demonstrated a complementary relationship between public and private R&D, which implies that increases in public R&D stimulate greater private R&D investment ("crowding in" effect). As Figure 1.2 shows, public and private agricultural R&D growth rates move up and down together. On the other hand, some studies (Carmichael 1981; Higgins and Link 1981; Lichtenberg 1984) have found a "crowding out" effect, meaning an increase in public R&D decreases private R&D.

Pray and Neumeyer (1989) examined the impact of public R&D on private R&D in agricultural input industries. They found that R&D carried out by USDA and State Agricultural Experiment Stations (SAES) increased private R&D investment. Their specification assumed that public R&D affected all private industry R&D in the same way. In other words, they assumed public R&D affected private investment in plant breeding and farm machinery in the same way. In this study, I use a more general specification that allows public R&D to affect different industries in different ways.

3. Does market concentration influence private R&D?

Several studies have tested the effect of market concentration on R&D spending and on innovative performance. Schumpeter's (1950) argument is that market concentration is a determinant of R&D spending and the rate of technological advance. Shumpeter emphasized that concentration reduces market uncertainty and provides the cash flow required for costly and risky R&D on an efficient scale. If this is true, it implies a trade-off between short-run price competition and long-run development of new technologies.

However, studies of the relationship between market concentration and private R&D intensity have had mixed results. Dasgupta and Stiglitz (1980) supported a positive relationship. Some (Scott 1984; Levin, Cohen, and Mowery 1985) found an inverted U relationship (i.e. R&D first increases, then decreasing with increasing concentration). Others (Scherer 1967; Mansfield 1983; Flaherty 1984; Pray & Neumeyer 1989) found no relationship or negative once control variables were included.

1.4 Organization of the Study

The organization of this study is the following. The next chapter reviews econometric studies of the determinants of private investment in R&D. The third chapter describes trends and patterns in private R&D in agricultural input and food industries over the last 35 years. Based on this information, my own econometric analyses and empirical results are presented in chapter four. The final chapter presents the summary and conclusions of this study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Factors Affecting Private R&D Investment

Empirical studies of factors influencing private investment in R&D have focused on demand-pull, technology-push, and appropriability effects. These studies have examined private R&D investment at the firm, industry, and aggregate level. I will introduce factors affecting incentives for private R&D. I will discuss the findings of demand-pull, technology-push and appropriability studies. In the final section, I review an R&D investment study of agricultural input industries.

2.2 Demand-Pull Studies

Jacob Schmookler (1966) argued that the private sector's ability to make new inventions was flexible and responsive to economic incentives. He also argued that because the profitability of an invention rises with market size, more inventive activity would be directed to larger markets. In contrast to others who emphasized the role of technological opportunities, Schmookler emphasized the importance of "demand-pull" in creating incentives for private R&D.

Griliches and Schmookler (1963) and Schmookler (1966) conducted some of the earliest econometric studies of demand-pull effects. Their studies divided industries into originating industries (industries that patented capital goods inventions) and technology-using industries (those that invested in capital goods). The hypothesis of these studies was that the more investment there was in a technology-using industry, the more capital goods inventions would be patented and directed to meet industry demand. Using data from the 1930s to 1950, they found that capital goods investment were highly correlated with capital goods investment patents and that the elasticity of patenting with respect to investment was close to 1.0.

Scherer (1982) re-examined the importance of demand-pull factors on technological invention tested by Schmookler (1966). Scherer noted that Schmookler's findings were based on a small sample of industries that might not have been representative and that he used different samples to classify patents developed by originating industries and patented inventions embodied in the capital investments of the using industries. Scherer used a new and more comprehensive patent data sample to address these problems. Scherer also found a correlation between capital good patenting and user industry investment, although the link was weaker than in Schmookler's work. The elasticity of patenting with respect to capital investment was in the range of 0.4 to 0.7. Scherer found that originating industry sales tended to be a better predictor of patenting activity. [1]

In addition, Scherer ran regressions using industry level dummy variables to control for effects of industry-specific technological opportunities. Scherer found that

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[1] Scherer regressed the log of the number of patents on the log of capital investment (*CI*) and other variables. The regression coefficient β provided the estimate of the elasticity of patenting with respect to capital investment,

$$\frac{\partial \log(Patents)}{\partial \log CI} = \beta.$$

adding industry effects greatly increased the explanatory power of the regressions, but that the elasticity of patenting with respect to originating industry sales remained robust at about 0.9 whether industy effects were included or not.

Jaffe (1988) explored influences in R&D intensity including technological opportunity, market demand and R&D spillovers. A firm's level of R&D investment was estimated as a function of its sales, capital stock, its sales-weighted average market share, and the pool of spilled research potentially available to the firm, which affect the cost and benefits of R&D:

$$\text{Log}\ (\text{r}) = \beta_0 + \beta_1 \log\ (\textit{Sales}) + \beta_2 \log\ (\textit{Capital stock}) + \beta_3 \log\ (\textit{Market share}) + \ldots$$

where r is the annual R&D of the firm. Jaffe considered R&D as a fixed cost. Greater sales imply a greater return to R&D, from which we can assume the relationship between sales and R&D investment should be positive. The elasticity of firm research with respect to sales can be written as

$$\frac{\partial \log(r)}{\partial \log(Sales)} = \beta_1 \quad > 0$$

The sales variable was statistically significant and positive in all his specifications, with the elasticity of firm research with respect to sales (β_1) ranging between 0.88 and 0.98.

2.3 Technological Opportunity

Technological opportunity is a measure of a firm's ability to make use of new scientific knowledge or information to create innovations. Technological opportunities may arise because of scientific breakthroughs at a basic level or from information from new inventions by a firm's rivals or from other industries. Technological opportunities reduce the costs of conducting private R&D. Pray and Neumeyer (1989) divide factors influencing a firm's technological opportunity into a physical component and a price or market component (Table 2.1). The physical component consists of factors that improve a firm's technical efficiency in the research process. For example, policies concerning the accumulation of scientific knowledge -- specifically when new knowledge leads to technological innovations -- will positively affect the firm's technological opportunity. Breakthroughs in basic biological science and biotechnology and new institutions to encourage public-private collaboration all increase technological opportunity by increasing a firm's efficiency in R&D activity. The price or market component relates more directly to factors that affect the costs of conducting R&D, such as the prices of inputs. These include tax credits and increased R&D costs from regulation.

Table 2.1 Factors Affecting Technological Opportunity

Physical component	Price or Market component
• Public research • Technological Innovation	• Regulations • Tax credits

Based upon this definition, several factors affecting technological opportunity emerged in the 1980s. These factors included R&D investment tax credits legislation to encourage collaboration and information sharing (Table 2.2), biotechnological breakthroughs and a trend toward deregulation.

Table 2.2 List of Acts Related to Public-Private R&D Collaboration

Year	Acts
1982	**Small Business Innovation Development Act** Established the Small Business Innovation Research Program within major federal R&D agencies to increase government funding of research with commercialization potential in the small high-technology company sector.
1984	**National Cooperative Research Act** Encouraged U.S. firms to collaborate on generic, pre-competitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures.
1986	**Federal Technology Transfer Act** Authorized cooperative research and development agreements (CRADAs) between federal laboratories and other entities, including state agencies. Corporations are able to provide funding to USDA for research projects.
1988	**Omnibus Trade and Competitiveness Act** Established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies.
1989	**National Competitiveness Technology Transfer Act** Allowed government-owned, contractor-operated laboratories to enter into cooperative R&D agreements

Source: NSF (1998)

2.3.1 Industry Classification Measures

Levin and Reiss (1984) used firm-level survey data to measure the importance of technological opportunity to firms' R&D. They used their own survey data to classify industries based on the importance of technological opportunity. This classification system was used to create dummy variables in R&D intensity regression equations. The results showed that this industry-level effect was significant. In particular, chemical-processing industries had the largest technological opportunities.

Bernstein and Nadiri (1988) estimated the effects of inter-industry R&D spillovers. They investigated the difference of technological opportunity in five hightech industries by treating each industry as a separate spillover source in order to estimate the sources and beneficiaries of each inter-industry spillover. The inter-industry spillover was measured by how much the variable cost of the labor, physical capital, and material cost shares in one industry were reduced by new products or processes brought from other industry. Their results suggested that a one-percent rise in the spillover rate caused the variable cost in the chemical production industry to decline by 0.21% in 1961 and by 0.09% in 1981. As a result, demand for physical capital increased due to the spillovers. Demand for labor and materials declined since these factors were partly substituted by the R&D capital spillover.

Jaffe (1988) also found that the effects of spillovers and market structure measured by Herfindahl index were significant in explaining R&D intensity. The Herfindahl Index, H is the sum of squared percentages of market share of all firms in an industry. Let S be total industry sales and S_i be the share of total industry sales by the ith firm. The Herfindahl Index can be written as:

$$H = \sum_{i=1}^{N} \left[\frac{S_i}{S} \right]^2$$

2.3.2 Public R&D

Government intervention encourages private R&D in two ways. First, the patent system increases firms' abilities to capture short-run monopoly gains from their R&D investments. Second, government funded-public knowledge (basic research) is one of the most important sources of knowledge for private R&D. Excluding defense-related industries, agriculture has traditionally received a larger share of public R&D support than other industries. A number of studies have shown how public R&D can encourage private R&D (Levy and Terleckyj 1983; Scott 1984; Leyden and Link 1993).

The relationship between private and government-financed R&D has been examined in firm, industry and aggregate private sector level studies using a variety of econometric methods and over a range of different time periods (e.g., Globerman 1973; Buxton 1975; Goldberg 1979; Lichtenberg 1984; Levin and Reiss 1988). David, Hall and Toole provide a recent survey of this literature. They find that most industry-level and aggregate studies suggest that public R&D complements (encourages) greater private R&D investments. However, they also note that several studies based on firm-level data have found evidence that public R&D "crowds out" private R&D (Shrieves, 1978; Carmichael, 1981; Higgins and Link, 1981; Lichtenberg, 1984; Lichtenberg, 1988; Wallsten, 1999). Crowding out can occur if the public sector conducts R&D that the private sector already has an incentive to conduct.

Using NSF industry level data over the period 1963-79, Lichtenberg (1984) regressed the change in private R&D investment on the change in contemporaneous and lagged pubic R&D, industry dummies, and time dummies. The coefficient on present federal-funded R&D was positive, but insignificant. However, the coefficient on federal-funded R&D with one-year lag was positive but insignificant only when the time dummies were excluded; and the coefficient on federal-funded R&D with two-year lag was negative and significant.

Levin and Reiss (1984) found that public R&D intensity (measured as the ratio of public R&D to industry sales) had a positive and significant effect on private R&D intensity. In addition, the studies by Lichtenberg and Siegel (1991) and by Link (1981) suggest that private investment in basic research generated much higher returns than other components of private R&D. Robson (1993) focused on impacts of federal R&D expenditure on private expenditures on basic research. Robson conducted aggregate time-series analyses using NSF data and found evidence of significant positive relationship between federal spending on basic research and private basic research.

2.3.3 Environmental Regulation

Environmental regulations governing registration of pesticides increase the private costs of pesticide research and commercial development. Beginning in the 1970s, agricultural chemical firms were required to conduct additional tests on the environmental impacts of pesticides they wished to develop and sell. Before a new pesticide can be registered for use in the United States, firms must report results of tests concerning a compound's toxicity and efficacy relative to existing compounds. They must also conduct tests concerning fate and transport in soils and water, impacts on microbes and animal species, and potential human health impacts. Both Pray and Neumeyer (1989) and Ollinger and Fernandez-Cornejo (1995) have examined the impacts on environmental regulations on pesticide R&D. These studies suggest that environmental regulations have discouraged overall spending on pesticide R&D, but have caused private firms to devote a higher percentage of their R&D funds to the study of environmental and health impacts of new pesticides.

2.3.4 Tax Credits

To promote private R&D, some governments provide tax credits for private R&D expenditures. In the United States, the Economic Recovery Tax Act of 1981 provided a 25 percent tax credit on incremental R&D expenditures. Tax credits have been renewed six times since then, although the credit rates have been adjusted down, then up (Table 2.3). In the United States, current expenditures are fully deductible in the year in which they are incurred. In addition, companies receive a 20% income tax credit on the amount that eligible R&D current spending exceeds a base amount in a year; the incentive for basic research is a 20% flat rate. This credit may be used to reduce otherwise payable corporate income taxes. Unused credits may be either carried back three years or carried forward 15 years. The deduction for eligible R&D current expenditure is reduced by the amount of incremental credit claimed in a year.

Table 2.3 Tax Credit Legislation and Rates in the United States

Economic Recovery Tax act of 1981	25%
Tax Reform Act 1986	20%
1988 The Technical and Miscellaneous Revenue Act (TAMRA)	16.6%
1989 The Technical and Miscellaneous Revenue Act (TAMRA)	13.2%
The Revenue Reconciliation Act of 1989	20%

Source: Leyden and Link (1993)

To examine the effects of tax credits on private R&D, Mansfield (1986) surveyed top executives of firms in three different countries that provide tax credits. The effects of tax incentives were estimated based on executive responses to questions about the importance of tax credits in R&D investment decisions. The results showed the R&D tax incentives seemed to have increased R&D expenditures by about 1 or 2 percent, particularly in the first few years after the introduction of the tax incentive.

2.4 Appropriability Studies

Appropriability is the ability of the company that invents a new technology to capture the economic benefits from the technology (Pray and Neumeyer 1989). An important part of appropriability is the ability to prevent rivals from simply imitating the innovating firm. Because imitation costs can be much lower than developing a new process or product initially, individual firms may be discouraged from initiating research. Appropriability may be affected by market structure (imitation may be more difficult or costly in more concentrated industries) or by intellectual property rights (patents). The patent system grants inventing firms a short-run monopoly on a new product or process. Short-run monopoly rents are meant to provide economic incentives to innovate. Patents also require firms to disclose information about an innovation. This encourages inter-industry spillovers and creates technological opportunities for other firms in the long run.

2.4.1 The Patent System

Intellectual property rights reduce the spillover problem by enabling inventors to capture a greater share of the benefits from new technologies, which encourages more investment in research. To examine how firms appropriate gains from innovation, Levin and Reiss (1988) conducted a firm-level survey. Firms were asked about the relative importance of different mechanisms to appropriate gains from invention. These mechanisms included patents to prevent duplication, patents to secure royalties, trade secrecy, lead time, moving quickly down the learning curve, and superior sales or service efforts. Based on this data, Levin and Reiss measured the extent of process and product R&D spillovers. They found R&D intensities to be higher (controlling for other factors) in industries where the patent system was said to be important.

In agriculture, intellectual property protection for biological innovations such as plant and animal breeding have been weak historically compared to chemical and mechanical inventions (Frisvold and Condon 1998). Prior to the 1970s, private investment in biological inventions had been very limited in the United States, except where use of hybrids prevented easy replication of commercial seed varieties (Fuglie et al. 1996). Fuglie et al. (1996) found that private investments in plant breeding were higher for crops where hybrid varieties are important.

The Plant Variety Protection Act, approved in 1970, provided for a system of protection for sexually reproduced varieties of plants for which protection was not previously provided; it requires that this system be under the administration of a Plant Variety Protection Office within the Department of Agriculture. Plant Variety Protection allows owners of new varieties to maintain control over the purity and the marketing of their varieties. With such protection, companies or individuals that develop new varieties are more likely to obtain fair and equitable returns (USDA 1997). Several studies have found evidence that the PVPA has encouraged private plant breeding investment (see Fuglie et al. (1996) and Knudson (1999) for summaries of these studies).

2.4.2 Market Concentration

The Schumpeterian hypothesis (1950) posits that firm size determines R&D spending and the rate of technological advance. Several theoretical studies have focused on the degree to which market concentration determines technological opportunity and appropriation (Loury 1979; Dasgupta and Stiglitz 1980; Flaherty 1980; Lee and Wilde 1980; Levin and Reiss 1988). Schumpeter emphasized that market concentration reduces market uncertainty and provides the cash flow firms need to engage in costly and risky R&D on an efficient scale. Market concentration may increase firms' abilities to appropriate gains from their R&D investments. If this is true, there may be a trade-off between less short-run price competition in concentrated industries and greater innovation (price reductions and product improvements) in the longer run. High degrees of concentration, on the other hand, could discourage both price and technological competition.

Scott (1984) investigated the effects of market concentration on R&D intensity at the industry level. To measure industry concentration, he used the industry four-firm concentration ratio. The four-firm concentration ratio (CR4) is the share of sales of the top four selling firms in an industry. Let N be the number of firms in an industry, S_i be the share of total industry sales by the $_i$th firm and S_j be the share of total industry sales by one of the top four selling firms. CR4 may be written as:

$$CR\ 4 = \frac{\sum_{j=1}^{4} S_j}{\sum_{i=1}^{N} S_i}$$

Scott regressed CR4 and CR4-squared on variables measuring R&D intensity using line of business data [Federal Trade Commissions (FTC), Line of Business (four-digit FTC industry)]. The concentration variables were statistically significant in simple regression equations. However, when Scott controlled for company-specific and two-digit industry level effects, the concentration variables became statistically insignificant. Scott explained this result by positing that firms face different opportunities other than those inherent in concentration.

Levin, Cohen, and Mowery (1985) re-examined the Schumpeter's hypothesis at the industry level, using new data on R&D appropriability and technological opportunity collected in their survey of R&D executives in 130 different industries. As dependent variables, they used measures of R&D investment intensity and patenting intensity. In the R&D intensity equation, coefficients for CR4 and CR4^2 were both significant at the 0.01 level, with R&D intensity maximized at a CR4 of 52 percent. This implies an inverted U relationship between concentration and innovation. In the case of patent intensity measure, the concentration coefficients were again significant and suggested an inverted U relationship. However, when measures of technological opportunity and appropriability were included in the regressions, the coefficients for concentration became statistically insignificant.

Although market concentration has been hypothesized to be a positive and significant to R&D intensity, other econometrics studies examining the relationship (e.g. Flaherty 1984; Pray & Neumeyer 1989) showed a negative or statistically insignificant relationship.

2.5 Agricultural Industry Study

Pray and Neumeyer (1989) conducted one of the first econometric studies specifically focusing on private R&D in agriculture-related industries. Pray and Neumeyer adapted Levin and Reiss's model of R&D inter-industry spillovers that included technological opportunity and appropriability equations. They used this model to develop reduced-form regression equations explaining R&D intensity (the ratio of research expenditure to value of sales). Pray and Neumeyer used industry level data for the seed, agricultural chemical, farm machinery, and the veterinary medicine industries from 1960 to 1986. Their technological opportunity variables included expenditures on basic research and applied research conducted by USDA and State Agricultural Experiment Stations (SAES), and industry-level dummy variables. Their public R&D stock variable was measured as a moving 20-year average of past public R&D expenditures. A dummy variable was also included to test the impact of technological opportunity brought about by recent biotechnology breakthroughs beginning around 1982. They included a dummy variable for years 1982-6 for the agricultural chemical, seeds, and veterinary medicine observations. Effects of regulation were measured as the number of months' delay time from the discovery of a new agricultural chemical (pesticide) to the time it was registered. Age variables were also used to capture differences due to the "maturity" of the industry. Age was measured as the number of years since major scientific and technological breakthroughs important to the industry took place. To estimate the degree of appropriability, the four-firm concentration ratio was used as a proxy of market structure. To account for effects of changes in intellectual property rights, they included a dummy variable for years 1970-86. The Plant Variety Protection Act was passed in 1970. A dummy variable capturing the beginning and continuation of R&D tax credits was also included.

Their results showed public R&D had a positive and significant influence on research intensity in agricultural industries. They found that their measure of the impacts of pesticide regulations had a negative impact upon private R&D intensity. The dummy variables indicating years with changes in R&D tax credits, changes in patent laws and breakthroughs in biotechnology were not significant.

2.6 Summary

Several studies have identified factors that significantly influence U.S. private R&D. The main approach to determining the factors of private R&D is to consider market demand, technological opportunities, the appropriability of technology and knowledge, and market concentration.

Market demand was measured in terms of industry or firm sales. To measure technological opportunity, a popular technique is to create technology class dummy variables into the regression. Most studies used industry dummy variables to account for inter-industry differences in technological opportunity. Public R&D is also an important variable that influences technological opportunity of a firm. The public R&D variable was created in the form of lagged public R&D expenditure, public R&D intensity (the government share of industry sales), or moving averages of past R&D expenditures. The effect of tax credits on private R&D expenditure has been examined by a survey of firm executives (Mansfield 1986) or by using a dummy variable to account for years when tax credits were in effect (Pray and Neumeyer 1989).

To measures the degree of appropriability, researchers have examined the effect of patent system and market concentration ratios. The four-firm concentration ratio or Herfindahl index of concentration from Bureau of the Census has been used as a proxy of market structure. Market concentration may increase the degree of appropriability and in theory encourage private R&D. However, industry concentration has been found to be insignificant in several studies.

CHAPTER THREE: DATA AND TRENDS OF AGRICULTURAL R&D IN THE UNITED STATES

This chapter presents data on the trends and the changing characteristics of U.S. private agricultural R&D. The first section introduces different R&D categories and explains how they relate to each other. The second section reviews trends in aggregate R&D expenditures by the private and public sectors from 1961 to 1995. The third section discusses the relationship between the market concentration of U.S. agricultural industries and R&D intensity. The last section includes tables and documentation of the data used in the regressions presented in Chapter 4.

3.1 R&D Categories

R&D can be divided into three categories: basic research, applied research, and development. "Basic research advances scientific knowledge, but does not have any direct commercial objectives. In contrast, applied research discovers new scientific knowledge with specific commercial objectives concerning specific products, processes, and/or services. Finally, development is the systematic use of the knowledge or understanding gained from research (both basic and applied), and is directed toward the production of useful materials, devices, systems, or methods, including the development of prototypes and processes" (NSF 1998, p. 9). Agricultural basic research is funded and conducted by mainly the public sector, while the private sector concentrates on agricultural applied research and development. The public sector allocates 47.3 percent of expenditures for basic research and 45.4 percent for applied research and 7.3 percent for development. The private sector devotes only 15 percent of its research expenditures to basic research, instead spending 43.5 percent on applied research and 41.5 percent on development (Fuglie et al. 1996). Although basic research is fundamental to creating innovations, the economic returns from investments in basic research do not attract firms because the output from basic research often cannot be patented. Because of this public goods aspect of scientific knowledge, firms have difficulty excluding rivals and appropriating gains from basic research. Therefore, although basic research is valuable to private firms, they have turned their attention more toward applied research and development projects. This gap between public and private investment has become known as the "underinvestment problem" (Fuglie et al. 1996).

3.2 Expenditure Trends in Agricultural R&D

In 1992, about 60 percent of federal agricultural research expenditures went to USDA in-house research. USDA spent $952 million on in-house research and the rest went to state institutions.[2] State governments provided an additional $981 million to state institutions. Additionally, state institutions received $381 million from non-governmental sources. This consisted of $143 million direct grants from the private sector, $116 million from product sales and patent license fees, and $121 million from other sources such as grants from nonprofit foundations (Fuglie et al. 1996). For this

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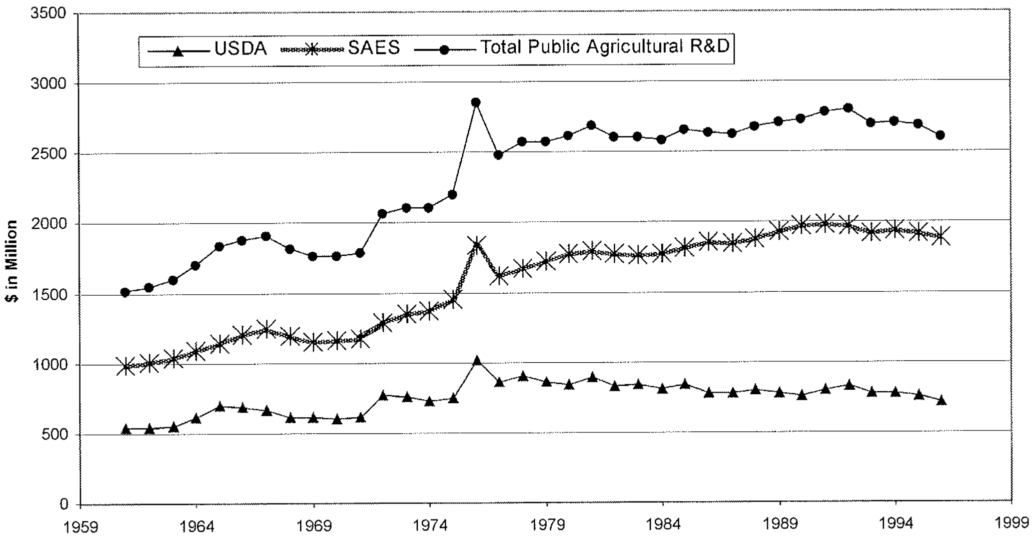
[2] State institutions include state agricultural experiment stations, the 1890 schools, forestry schools, and veterinary schools.

study, the public R&D expenditure data were obtained from Huffman and Evenson (1993), who compiled data on agricultural research expenditures by USDA and State Agricultural Experiment Stations (SAES) from 1888-1990. The data collected by various federal reports were converted into 1984 dollars using their own research price index. I converted their data once again into 1996 constant dollars using the Fuglie-Klotz research and development deflator (Klotz, Fuglie, and Pray 1995, 1998). Huffman and Evenson's data show that SAES spending surpassed USDA spending on agricultural research in 1949. By 1995, SAES R&D expenditures accounted for 72% of total public agricultural R&D expenditures, while USDA accounted for just 28%.

Figure 3.1 Public R&D Expenditure (1996 = 1.00)

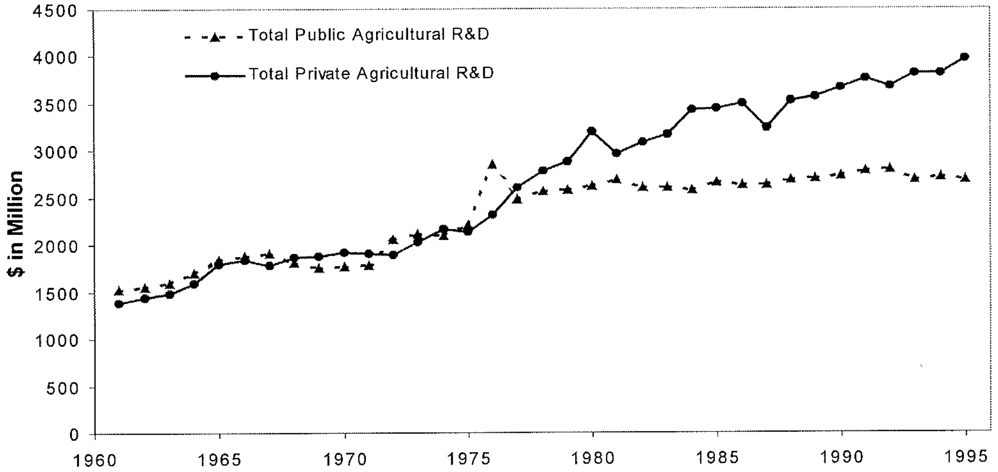


Source: Huffman and Evenson (1993)
Note: Real Dollars (1996=1.00).

The USDA and SAES R&D expenditures in 1992 were allocated mainly to activities to: reduce the production costs of food and forest products (30%); protect forests, crops, and livestock from pests and disease (24%); manage natural resources (15%); develop new products and enhance quality (10%); and improve community services and the environment (10%) (USDA 1997).

Private agricultural R&D expenditures have been showing interesting trends. Private R&D data from 1960 to 1992 were collected from the Economic Research Service (ERS) based on a study by Klotz, Fuglie, and Pray (1995). Updated figures for the years 1993-96 were obtained from Klotz and Fuglie (1998). As can be seen in Figure 3.2, private companies have surpassed the public sector as the major sponsors of agricultural R&D.

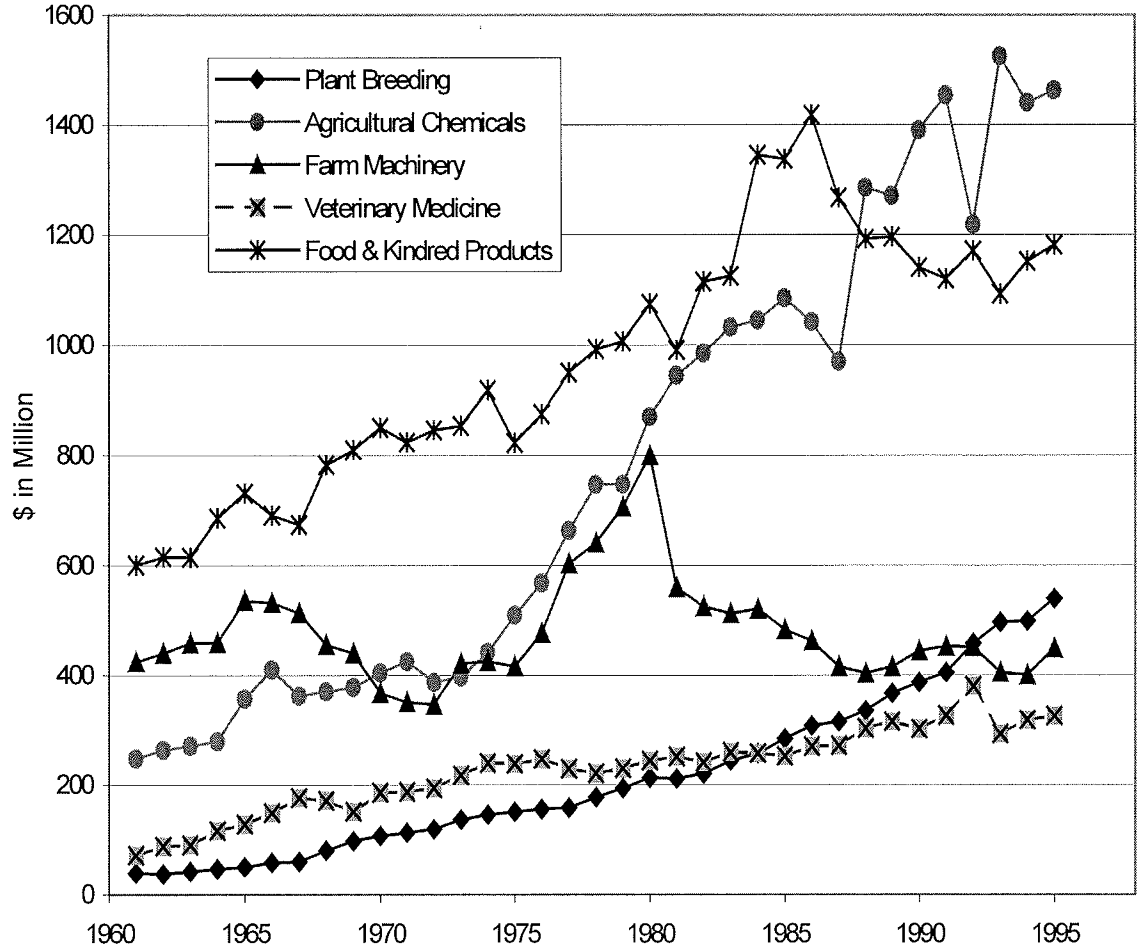
Figure 3.2 Total Private Agricultural R&D and Total Public Agricultural R&D (1996 =1.00)



Sources:
Public R&D From : Huffman and Evenson (1993).
Private R&D From: Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.

The private sector spent at least $3.8 billion for agricultural and food research in 1995, compared with $2.6 billion from the public sector. More than 40% of total private agricultural R&D expenditures are for product development research, whereas less than 7% of public agricultural research goes for product development. By 1996, nearly 60% of private research concentrated upon increasing crop and livestock yields by supplying farmers with improved crop varieties and various pharmaceuticals (Fuglie et al.1996).

Figure 3.3 Private R&D Expenditure in Agricultural Industries, 1961-1995 (1996 =1.00)

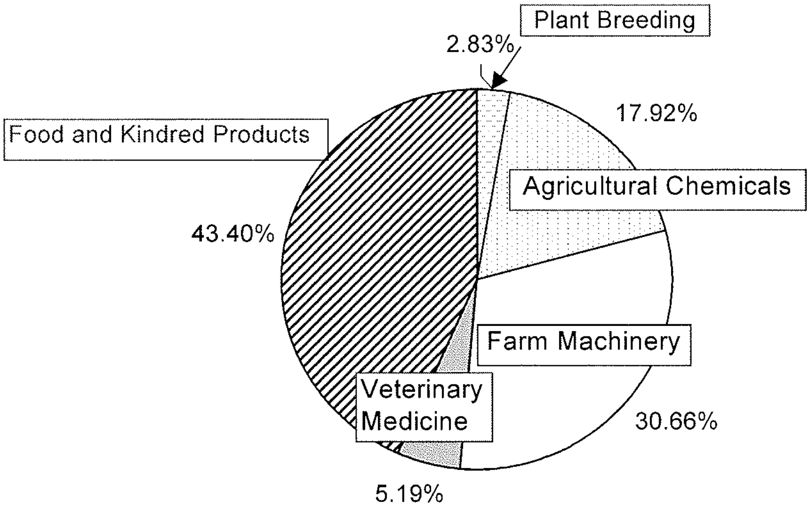


Sources:
Private R&D From: Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.

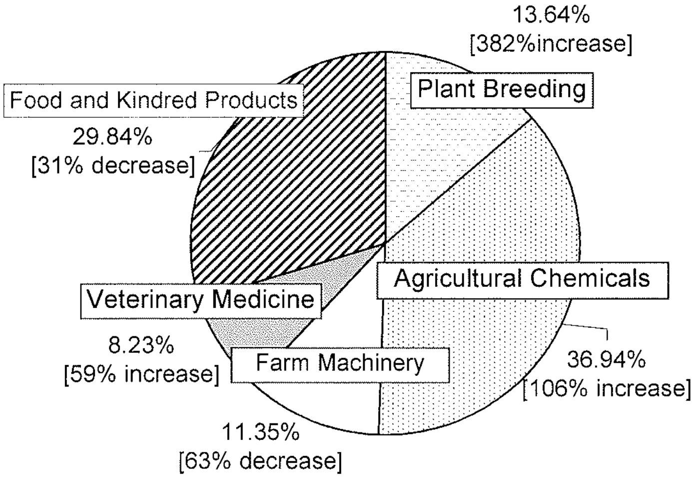
Figure 3.3 shows private R&D expenditures in the following industries: plant breeding, agricultural chemicals, farm machinery, veterinary medicine, and food and kindred industries from 1961-95. Additionally, Figure 3.4. demonstrates the share of R&D by industry has changed significantly over the last three decades.

Figure 3.4 The Share of Total Private R&D by Industry in 1961 and1996

1961



1995



Sources: Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.

R&D conducted by the plant breeding, agricultural chemicals, and farm machinery industries. The plant breeding R&D share of total private agricultural R&D accounted for 2.8% in 1961 and increased to 13.6% in 1995 (Figure 3.4). In the 1970s, the growth of R&D expenditures by private firms coincided with the passage of the Plant Variety Protection Act (PVPA). The PVPA strengthened intellectual property rights for private plant breeders. The PVPA has been credited with increasing private investment in plant varieties since then. For example, although both the public and private sector began contributing almost equal amounts of expenditure on both corn and soybean improvement, since 1975 private seed companies have become a significant source of development. By 1984, 24% of soybean variety development was carried out by the private sector. By 1990, the private sector received certificates for 85% of 503 separate soybean varieties. The private sector also began to increase R&D expenditures on small grain cereals (wheat, barley, oats, rye, and rice) after 1970.

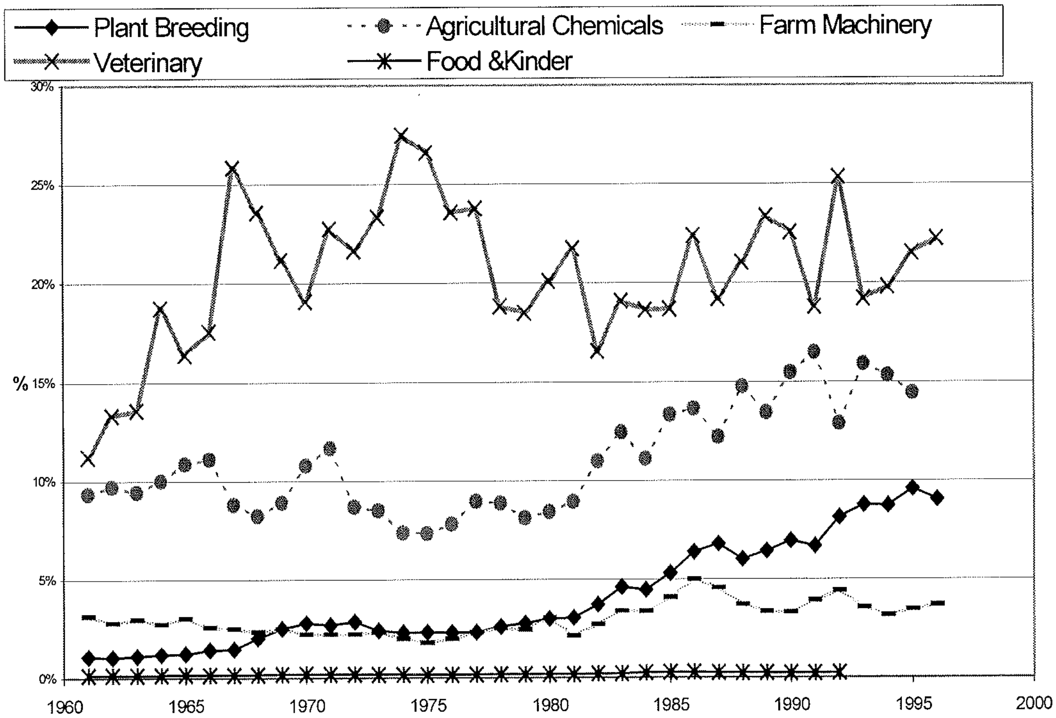
However, some surveys revealed the PVPA did not necessarily increase R&D investment for individual firms. According to a survey of 84 private plant-breeding firms conducted by Pray, Knudson, and Masse (1993), only six firms responded that they had increased their research expenditures because of the availability of utility patent protection, although most reported that utility patents increased profitability. Over a third of the firms felt that utility patents limited germplasm exchange both between private firms and between the public sector and private firms(Pray, Knudson, and Masse 1993).

The invention of various farm machines has lead to the replacement of human labor in agricultural production and helped to increase production efficiency. This efficiency, in turn, is a direct result of R&D investment in automation and improved mechanical efficiency and quality (USDC 1985). R&D expenditures have paid off in the production of self-propelled combines, rotary combines, row crop tractors, big round balers, and other new types of equipment. These products have been a major factor increasing U.S. production (USDC 1985). The farm machinery R&D expenditures have declined since the 1980s (Figure 3.3) and farm machinery's share of private agricultural R&D has decreased sharply. Overall, the farm machinery industry's share of private agricultural R&D has fallen from 30% in 1961 to 11% in 1995 (Figure 3.4).

The U.S. livestock farms that produce beef cattle, hogs, and sheep occupy 53% of the total acres on farms and livestock production accounts for 23% of total U.S. agricultural sales (Sommer 1994). Veterinary medicine R&D is important to livestock production, as it prevents diseases of livestock, prevents infections, and maintains health status. The increasing importance of veterinary medicine R&D can be seen in its share of the total agricultural private R&D, which increased from 5 % in 1961 to 8% in 1995 (Figure 3.4). In 1995, company-financed R&D expenditures for veterinary use pharmaceuticals were $0.32 billion. By 1998, they were estimated to be $0.5 billion (PhRMA 1999).

In addition, to investigate recent private R&D expenditure intensity in each agricultural industry, I derived ratios between R&D expenditure and sales. The primary source of data concerning the value of shipments of agriculture-related industries was the "Census of Manufactures" published by the USDC, Bureau of the Census (See Table 3.7). From this source I obtained data on four industries -- agricultural chemicals (SIC code: 2879), veterinary medicines (SIC code: 2834), farm machinery (SIC code: 3523), and the food and kindred industry (SIC code: 20). For the plant breeding industry, seed sale values were collected from the table "Cost to Farm Operators" in the Agricultural Statistics compiled by USDA in the "Annual Survey." Based on this data, Figure 3.5 provides a time series of the R&D sales ratio in different industries.

Figure 3.5 The Private R&D Intensity by Industry



Sources:
Private R&D From: Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.
Value of Shipments Data From: USDA. NASS. *Agricultural Statistics*. 1955-1997; U.S. Department of Commerce. Bureau of Census. *Census of Manufactures*. 1955-97.

The food and kindred products industry has had the lowest R&D intensity over the last three decades. The ratio of veterinary medicine's private research expenditures to its sales is the highest among the other agricultural industries; it was 22% in 1996 (Figure

3.5). This may be because of the nature of discovery and development of new medicines. They take an average of 12 to 15 years and cost an average of $500 million (PhRMA 1999). This may also explain why market concentration in the pharmaceutical industry has been increasing as some companies have left the market. For example, at least 6 drug companies were among the top 25 largest R&D performing companies in 1994. Ten years earlier, only 1 of those firms was in the top 25 (NSF 1998).

3.3 R&D Intensity and Market Concentration

According to the Schumpeterian hypothesis, market concentration has an important influence on the level of private R&D. The data for the four-firm concentration ratio (share of industry sales by the top four firms) came from Census of Manufactures, Bureau of the Census. The data for pharmaceutical preparation are available from 1947 to 1992 (collected every 4-5 years), and the data for agricultural chemicals and farm machinery and equipment industries is available from 1972 to 1992 (collected every 5 years). The concentration ratio data show that the four largest companies occupy about a half of the industry sales in the agricultural chemicals and farm machinery and equipment industries.

Table 3.1 presents levels of concentration and R&D intensities for each industry from 1972-1992. The most concentrated industry is the farm machinery and equipment industry. However, the R&D/Sales ratio is the lowest. The agricultural chemicals industry showed the greatest change in both sales concentration and R&D intensity during the period. The pharmaceutical preparations industry has the high R&D intensity and the least concentrated market.

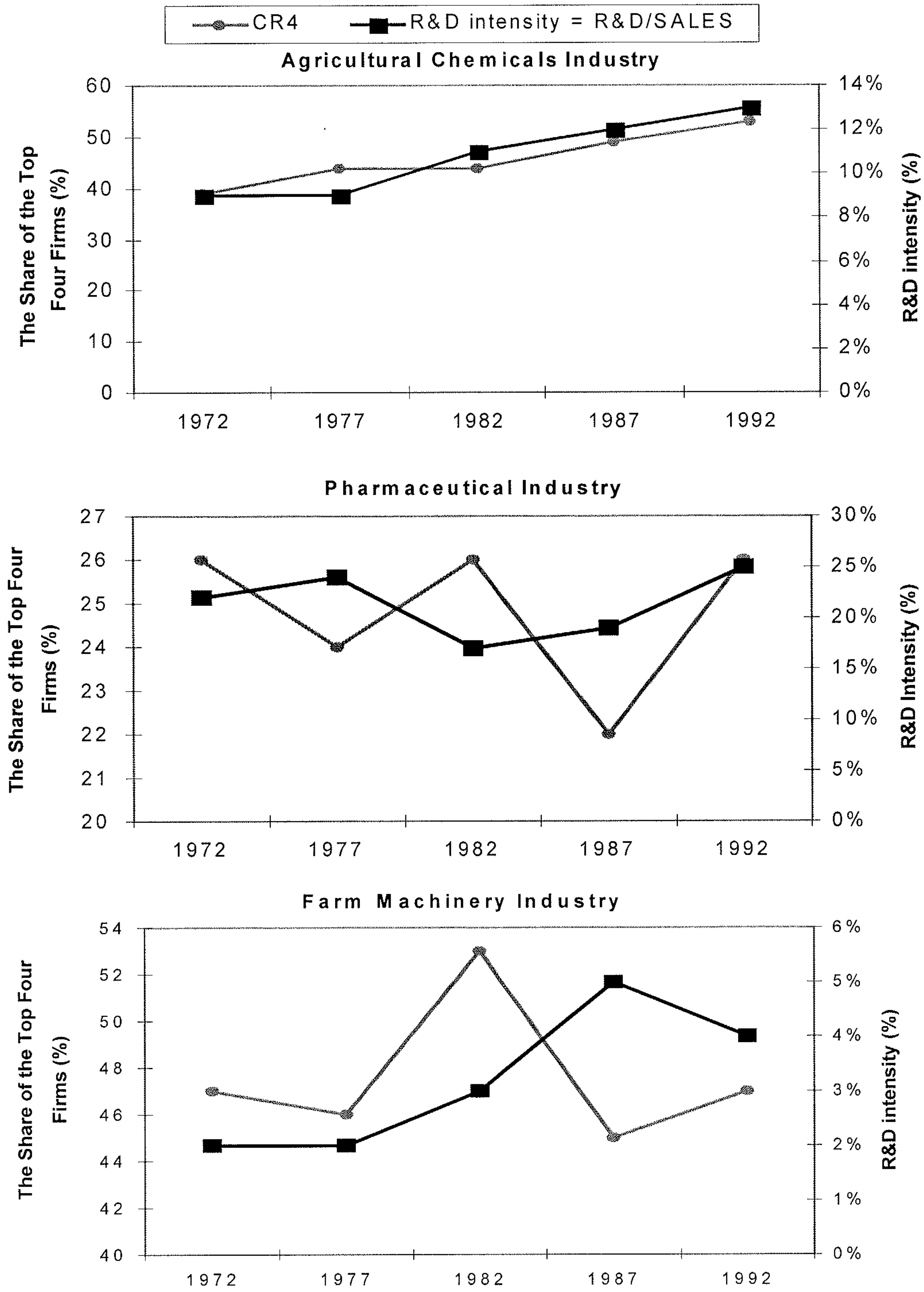
Table 3.1 Average Concentration Ratio & Average R&D Sales Ratios, 1972-1992

	Farm Machinery and Equipment (SIC code: 3523)	**Agricultural Chemicals, n.e.c.** (SIC code: 2879)	**Pharmaceutical Preparations** (SIC code: 2834)
Four-firm concentration ratio	45-53%	39-53 %	22-26%
R&D/Sales ratio	2-5%	7-16%	17-27%

Source: U.S. Department of Commerce. Bureau of Census. *Census of Manufactures*; Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.

Based on this data, I contrasted the four-firm concentration ratio (CR4) and R&D intensity for the three industries (Figure 3.6). Figure 3.6 shows that, in agricultural chemicals industry, the R&D intensity goes up as the market concentration increases. However, in the other two industries, there is no consistent correlation between R&D intensity and market concentration. The data also shows that the four-firm concentration ratios do not change much from year to year within an industry. However, there are bigger differences in R&D intensities and CR4 between industries. Therefore, the data may not be able to distinguish between CR4 and other industry-specific effects.

Figure 3.6 R&D Intensity and Market Concentration



Source: U.S. Department of Commerce. Bureau of Census. *Census of Manufactures*; Klotz, Fuglie, and Pray (1995); Updated by Klotz and Fuglie in 1998.

Table 3.2 Source of Data Used

Variables	Variable Description	Full Citation of Data Source	Years for Which Data are available
Private R&D Expenditure for Agricultural Chemicals, Farm Machinery, Veterinary Medicine, and Food and Kindred industries	Private Expenditure [$ in million]	Klotz, Fuglie, and Pray (1995); Updated by Klotz, and Fuglie in 1998.	1961-1996
Plant Breeding R&D Sales	Value of Shipments [$ in million]	USDA. "Agriculture statistics: Cost to firm operators." Various years.	1955-1996
Agricultural Chemicals Sales (SIC code: 2879)	Value of Shipments [$ in million]	U.S. Department of Commerce. Bureau of Census. "Annual Survey of Manufactures: Value of Product Shipments." Various years.	1958-1996
Farm Machinery Sales (SIC code: 3523)	Value of Shipment s [$ in million]	Same as above	1955-1996
Veterinary Medicine Sales (SIC code: 2834)	Value of Shipments [$ in million]	Same as above	1955-1996
Food and Kindred Products Sales (SIC code: 20)	Value of Shipments [$ in million]	Same as above	1955-1996
Public R&D Expenditure	Expenditures in R&D by USDA and SAES.	Huffman and Evenson (1993)	1888-1990
Concentration Ratios	The value of shipments of the top four firms.	Department of Commerce. *Census of Manufactures*	1947-1992 (SIC 2879) 1972-1992 (SIC 2879) 1972-1992 (SIC 3525)

Note: SIC code: The census has created a classification system called the Standard Industrial Classifications of Economic Activity, more commonly referred to as SIC codes.

Table 3.3 Data Used for Private R&D Expenditure by Agricultural Industries

	Plant Breeding		Agricultural Chemicals		Farm Machinery		Veterinary Medicine		Food & Kindred Products		
Year	Nominal	Deflated	Nominal	Deflated	Nominal	Deflated	Nominal	Deflated	Nominal	Deflated	Agricultural R&D Deflator
1961	6	39.2	38	248.1	65	424.5	11	71.8	92	600.8	0.15
1962	6	37.7	42	263.8	70	439.7	14	87.9	98	615.6	0.16
1963	7	42.2	45	271.3	76	458.2	15	90.4	102	615.0	0.17
1964	8	46.5	48	279.0	79	459.1	20	116.2	118	685.8	0.17
1965	9	50.2	64	357.2	96	535.8	23	128.4	131	731.1	0.18
1966	11	58.5	77	409.4	100	531.6	28	148.9	130	691.1	0.19
1967	12	60.4	72	362.1	102	513.0	35	176.0	134	674.0	0.20
1968	17	80.7	78	370.1	96	455.5	36	170.8	165	782.9	0.21
1969	22	97.8	85	378.0	99	440.2	34	151.2	182	809.3	0.22
1970	26	107.4	98	404.7	89	367.6	45	185.8	206	850.7	0.24
1971	29	113.2	109	425.4	90	351.2	48	187.3	211	823.4	0.26
1972	32	119.2	104	387.4	93	346.5	52	193.7	227	845.7	0.27
1973	39	136.9	113	396.7	120	421.3	62	217.7	243	853.1	0.28
1974	45	146.0	136	441.4	131	425.2	74	240.2	283	918.5	0.31
1975	50	150.8	169	509.6	138	416.2	79	238.2	273	823.3	0.33
1976	55	156.2	200	568.0	168	477.2	87	247.1	308	874.8	0.35
1977	58	158.4	243	663.5	221	603.5	84	229.4	348	950.3	0.37
1978	69	177.8	290	747.4	249	641.7	86	221.6	385	992.2	0.39
1979	81	194.1	312	747.7	295	707.0	96	230.1	420	1006.6	0.42
1980	97	213.7	395	870.1	363	799.6	111	244.5	488	1075.0	0.45
1981	105	211.6	469	945.0	278	560.1	125	251.9	492	991.3	0.50
1982	118	220.7	527	985.4	281	525.4	129	241.2	596	1114.5	0.53
1983	138	244.1	584	1032.9	290	512.9	147	260.0	636	1124.9	0.57
1984	154	258.0	624	1045.2	311	520.9	154	258.0	803	1345.1	0.60
1985	179	284.5	683	1085.4	304	483.1	159	252.7	842	1338.1	0.63
1986	204	307.8	691	1042.6	307	463.2	179	270.1	940	1418.3	0.66
1987	222	315.8	682	970.1	292	415.4	191	271.7	891	1267.4	0.70
1988	245	335.5	939	1285.8	295	403.9	221	302.6	871	1192.7	0.73
1989	283	367.5	979	1271.4	320	415.6	243	315.6	921	1196.0	0.77
1990	314	387.3	1127	1390.2	360	444.1	245	302.2	925	1141.0	0.81
1991	342	405.0	1228	1454.3	382	452.4	276	326.9	946	1120.3	0.84
1992	400	458.9	1062	1218.3	394	452.0	331	379.7	1021	1171.2	0.87
1993	453	497.3	1389	1524.9	369	405.1	267	293.1	995	1092.3	0.91
1994	470	499.5	1356	1441.0	377	400.6	300	318.8	1084	1151.9	0.94
1995	524	540.3	1419	1463.1	436	449.6	316	325.8	1146	1181.6	0.97

Source: Klotz, Fuglie, and Pray (1995); Updated by Fuglie and Klotz in 1998.
Note: in $ Millions

Table 3.4 Data Used for Public Research Expenditures, 1961-1995

	Public Agricultural R&D Expenditure		
Year	USDA	SAES	Total
1961	294.8	540.2	835.0
1962	295.3	555.4	850.8
1963	309.2	581.3	890.5
1964	343.8	605.0	948.8
1965	384.8	631.1	1015.9
1966	376.3	661.2	1037.5
1967	372.8	691.5	1064.2
1968	319.3	624.2	943.5
1969	345.2	649.6	994.8
1970	350.2	673.7	1023.9
1971	365.0	692.7	1057.8
1972	459.5	765.8	1225.3
1973	446.0	795.1	1241.1
1974	424.4	801.9	1226.3
1975	440.0	852.8	1292.8
1976	607.8	1091.5	1699.2
1977	507.7	948.7	1456.4
1978	524.3	974.9	1499.2
1979	495.1	991.8	1486.9
1980	510.8	1075.4	1586.2
1981	541.3	1091.8	1633.2
1982	508.6	1092.6	1601.2
1983	500.7	1046.8	1547.5
1984	482.5	1059.3	1541.8
1985	502.7	1088.2	1590.9
1986	471.2	1125.8	1597.1
1987	482.9	1141.9	1624.8
1988	522.0	1225.9	1747.9
1989	468.3	1170.3	1638.6
1990	459.0	1193.3	1652.2
1991	480.2	1199.5	1679.7
1992	497.9	1186.7	1684.6
1993	466.0	1152.8	1618.8
1994	465.8	1165.4	1631.2
1995	455.9	1154.8	1610.7

Source: Huffman and Evenson (1993 p 96)

Note: in $million deflated (1984 =1.00)

Table 3.5 20 Year Stock of Public R&D Expenditure

Year	20 year Stock of Public R&D Expenditure
1961	11926.9
1962	12243.6
1963	12595.3
1964	12983.8
1965	13465.4
1966	13993.2
1967	14536.6
1968	14980.5
1969	15212.2
1970	15593.0
1971	16095.2
1972	16642.9
1973	17324.8
1974	18020.4
1975	18650.6
1976	19319.6
1977	20405.1
1978	21172.7
1979	21891.5
1980	22587.8
1981	23376.0
1982	24174.2
1983	24924.6
1984	25581.6
1985	26174.6
1986	26749.6
1987	27309.3
1988	27869.8
1989	28674.1
1990	29317.9
1991	29946.3
1992	30568.3
1993	31027.6
1994	31405.4
1995	31810.3

Note: Created based on Huffman and Evenson's (1993 p 96) data.
Note: in $million deflated (1984 =1.00)

Table 3.6 Agricultural Industry Sales Data (deflated by GDP Deflator)

Year	Plant Bleeding[a]	Agricultural Chemicals[b]	Veterinary Medicine[b]	Farm Machinery and equipment[b]	Food Products[b]	GDP Deflator[c] [1984=1.00]
1961	1757.71	1311.67	315.70	6652.62	208212.67	0.31
1962	1861.13	1422.04	346.10	8175.75	220288.53	0.30
1963	2067.95	1592.56	368.82	8492.64	228732.61	0.30
1964	2242.76	1623.88	362.03	9748.69	242928.45	0.29
1965	2484.65	2030.17	484.51	10844.11	256223.94	0.29
1966	2657.33	2422.02	557.34	13521.29	278848.43	0.29
1967	2878.51	2889.12	478.81	14418.37	296957.62	0.28
1968	2925.94	3329.44	537.65	14357.16	307478.39	0.28
1969	3009.68	3287.49	554.94	13691.09	322667.24	0.29
1970	3121.63	3056.97	794.05	13402.13	331805.35	0.30
1971	3515.02	3064.82	691.86	13205.60	339799.42	0.30
1972	3586.88	3848.10	773.03	13329.37	370141.62	0.31
1973	5017.74	4116.59	824.81	15941.95	420728.25	0.32
1974	3831.53	3637.09	531.60	12921.20	319993.52	0.51
1975	3856.43	4145.39	535.71	13870.33	310529.94	0.55
1976	4032.03	4361.78	628.83	14349.99	308331.83	0.59
1977	3976.91	4329.14	565.64	15287.91	308853.83	0.62
1978	3936.26	4871.38	681.76	14742.77	322408.13	0.67
1979	3992.61	5279.07	713.28	16550.75	324433.16	0.73
1980	4051.42	5898.21	695.16	14913.36	321938.42	0.79
1981	3942.64	6020.35	661.44	14995.84	312995.58	0.87
1982	3431.44	5186.10	842.28	11218.16	303473.70	0.92
1983	3099.69	4866.93	799.57	8865.08	297792.78	0.96
1984	3447.00	5613.40	826.50	9219.50	300011.90	1.00
1985	3257.03	4954.57	822.62	7221.54	291539.37	1.03
1986	3003.35	4767.28	753.55	5776.44	290680.51	1.06
1987	2978.76	5099.97	909.10	5835.86	301381.56	1.09
1988	3579.53	5607.59	926.21	6967.71	309953.67	1.13
1989	3720.86	6157.46	880.54	8104.45	308354.09	1.18
1990	3662.87	5902.69	881.22	8814.15	317598.88	1.23
1991	3988.92	5810.16	1145.74	7585.53	310398.51	1.28
1992	3729.42	6244.34	991.36	6787.17	308966.16	1.32
1993	3818.26	6462.37	1029.03	7648.22	313071.62	1.35
1994	3881.25	6391.97	1094.77	8604.99	311340.20	1.38
1995	3857.44	6936.96	1037.43	8896.71	315563.80	1.42

Source:

a. USDA. National Agricultural Statistics Service. *Agricultural Statistics*. Various issues from 1955 through 1997;

b. U.S. Department of Commerce. Bureau of Census. "Annual Survey of Manufactures: Value of Product Shipments." Various years;

c. Economics Report of the President (1999)

Table 3.7 The Data Used for the Four Firm Concentration Ratios, 1972-1992

Year	**Agricultural Chemiclas, n.e.c.** (SIC code: 2879)	**Pharmaceutical Preparation** (SIC code: 2834)	**Farm Machinery and Equipment** (SIC code: 3523)
1972	**39**	**26**	**47**
1973	40	25.6	46.8
1974	41	25.2	46.6
1975	42	24.8	46.4
1976	43	24.4	46.2
1977	**44**	**24**	**46**
1978	44	24.4	47.4
1979	44	24.8	48.8
1980	44	25.2	50.2
1981	44	25.6	51.6
1982	**44**	**26**	**53**
1983	45	25.2	51.4
1984	46	24.4	49.8
1985	47	23.6	48.2
1986	48	22.8	46.6
1987	**49**	**22**	**45**
1988	49.8	22.8	45.4
1989	50.6	23.6	45.8
1990	51.4	24.4	46.2
1991	52.2	25.2	46.6
1992	**53**	**26**	**47**

Note: The bolded numbers came from U.S. Department of Commerce, *Census of Manufactures*. The other numbers are estimated.

The data that measures the market concentration, which is the share of the top four firms in the industry, is limited. The source of this concentration ratio of the top four firms for pharmaceutical preparation, agricultural chemicals n.e.c., and farm machinery is Bureau of the Census, Census of Manufactures. The survey for concentration ratio is conducted only every 5 years (1972, 1977,1982,1987, and 1992), which is published in the Census of Manufactures, Concentration Ratios in Manufacturing by the U.S. Census of Bureau. Assuming the relationship is linear between the 5 years, I interpolated in order to obtain the data for intermediate years.

CHAPTER FOUR: ECONOMETRICS RESULTS

This chapter discusses the models used to test hypotheses about factors affecting private R&D and presents regression results. In this study, I used a model based upon Pray and Neumeyer's (1989) model (introduced in Chapter 2), and an expanded data set collected from 1961 to 1995 for agricultural input industries and food and kindred industries. Pray and Neumeyer used an OLS specification, pooling all industry observations and using industry dummy variables. This specification assumes that the coefficients for regression variables (besides the intercepts) are the same across all industries. However, I test this hypothesis by using a Seemingly Unrelated Regressions (SUR) model, which accounts for the possibility that the set of equations have contemporaneous cross-equation error correlation. Pray and Neumeyer's model is just a special case of the more general model that I use. Tables 4.1 and 4.2 provide definitions and the sources of the data in this study.

Table 4.1 Dependent Variables & Descriptive Statistics for Private R&D Expenditures, 1961-1995

Dependent Variables	Description	Mean	Standard Deviation	Minimum	Maximum
PLANT	R&D expenditures by the plant breeding industry	138.0	151.2	6	524
AGCH	R&D expenditures by the agricultural chemicals industry	470.8	452.9	38	1419
MACHINE	R&D expenditures by the farm machinery industry	221.0	120.1	65	436
VET	R&D expenditures by the veterinary medicine industry	123.5	97.7	11	331
FOOD	R&D expenditures by the food and kindred products industry	504.4	355.3	92	1146

Note: in $million

Source: Klotz, Fuglie and Pray (1995); Updated by Klotz and Fuglie in 1998.

Table 4.2 List of Independent Variables

Demand-Pull Variables	Description
SALES	Value of shipments

Technological Opportunity Variables	Description
PUBLICRD	Stock of 20 year R&D expenditure on agriculture by USDA and the State Agricultural Experiment Stations (SAES) collected by Huffman and Evenson (1993).
PUBSALE	Public R&D expenditure divided by the total agricultural sales.
TAX	Percentage of tax credit on incremental R&D starting from 1982.
BIOTECH	Breakthroughs in biotechnology occurred in 1982 when the genetic fingerprint technique was introduced (Pray and Neumeyer 1989). D =1 from 1982 to 1995, otherwise zero.

Appropriability Variables	Description
PVPA	Plant Variety Protection Act, passed in 1970. Dummy = 1 from the year 1970, otherwise zero.
CR4	4-firm concentration ratio.
$CR4^2$	CR4 squared

4.1 Demand-Pull Private R&D Activities

In this section, I will test the demand-pull effects on private R&D investment in agricultural industries. Scherer (1982) and Jaffe (1988) treat R&D spending like a sunk cost. Greater expected sales imply a greater return to R&D. Current sales reflect expected future sales. Therefore, one would expect greater R&D investment in industries with larger markets. Five equations measuring demand-pull effects of private R&D in log form are:

$$\log RD_{it} = \beta_{0i} + \beta_{1i} \log SALES + \beta_{2i} \log PUBRD + \beta_{3i}\, TAX + \varepsilon_{it}\,, \quad i = 1,2..,5 \qquad (1)$$

where RD_{it} is private R&D expenditure (in constant $millions) by the *i*th industry in year *t*. *SALES* is the industry's sales (in millions of constant dollars), *PUBRD* is the stock of public R&D expenditure (in millions of constant dollars), and *TAX* is rate for the R&D tax credit. Following Pray and Neumeyer, the public research stock is measured as cumulative public agricultural R&D expenditures over the previous 20 years. The five equations from (1) were estimated as a seemingly unrelated regression system (Table 4.3) since contemporaneous correlation may exist among industries.

Table 4.3 Demand-Pull SUR Estimation (1)

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Agricultural machinery	Food
Intercept	-21.26**	-8.41**	-6.59**	0.32	-10.22**
	[-13.06]	[-5.04]	[-4.53]	[0.32]	[-8.54]
Log SALES	0.987**	0.42**	1.18*	0.47**	1.17**
	[4.76]	[3.17]	[7.202]	[5.76]	[10.09]
Log PUBRD	1.79**	1.10**	0.39**	0.09	0.18**
	[6.75]	[4.14]	[1.83]	[0.96]	[2.06]
TAX	0.81	0.66*	-1.33**	0.469	1.22**
	[1.29]	[1.67]	[-3.20]	[1.19]	[5.093]
R^2	.95	.96	.88	.54	.91

System R^2=.999, χ^2=251.05 with 15 d.f. N = 35 Breusch-Pagan LM Test = 53.97 with 10 d.f.

Note: [t-statistic]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test)

Based on the Breusch-Pagan LM test one can reject the hypothesis of a diagonal covariance matrix. Thus, SUR estimation yields more efficient parameter estimates than ordinary least squares applied separately to each equation. In this study, based on the Breusch-Pagan LM test the hypothesis of a diagonal covariance matrix was rejected for all the SUR models estimated.

The elasticity of R&D with respect to industry sales is positive and highly significant in all the equations. These elasticities range from 0.4-0.5 for agricultural chemicals and machinery to about 1.0 and higher for plant breeding, veterinary pharmaceuticals and processed food. Jaffe (1988) also estimated the elasticity of R&D with respect to sales for 573 firms across 19 industry categories. His firm-level elasticity estimates ranged from about 0.88 to 0.98.

The public R&D stock variable *PUBRD* also had a positive, complementary impact on private R&D in most, but not all industries. The elasticity of agricultural machinery R&D with respect to *PUBRD* was not statistically different from zero. The elasticities with respect to *PUBRD* are largest for plant breeding and agricultural chemicals. The elasticities for veterinary pharmaceuticals and food are much lower, though still significant. These results should not be too surprising given that USDA and SAESs devote less than 1% of their production-related research expenditures to machinery research. In contrast, USDA and SAESs devote a significant portion of their production-related research to improving the biological efficiency of plants and to protect plants from pests and diseases.

The tax credit variable *TAX* was significant and positive only for the agricultural chemicals and food industries. It was significant and negative for veterinary pharmaceuticals. Pray and Neumeyer (1989) got similar results (negative impact from the tax credit) in their study. The tax variable equals zero for all years before 1982 and does not change much from 1983-95. So *TAX* may just be acting like a dummy variable for unknown effects since 1981.

I used the results from estimation of equation (1) to estimate the contribution of the explanatory variables to private R&D growth from 1961 to 1995. The growth rate of private R&D in an industry in logarithmic form is $\log(RD_{i95}/RD_{i61})$. Based on (1), the growth rate can be rewritten as:

$$\log(RD_{i95}/RD_{i61}) = \beta_{1i}\log(SALES_{i95}/SALES_{i61}) + \beta_{2i}\log(PUBRD_{i95}/PUBRD_{i61})$$

$$+\,\beta_{3i}(TAX_{i95}/TAX_{i61}) + (\varepsilon_{i95}/\varepsilon_{i61}),\quad i=1,\ldots,5$$

where the β and ε terms are taken from the regression results in Table 4.3. The right side of the equation shows private R&D growth in an industry as a weighted average of different effects.

Table 4.4 Contribution of Factors to Private R&D Growth, 1961-1995

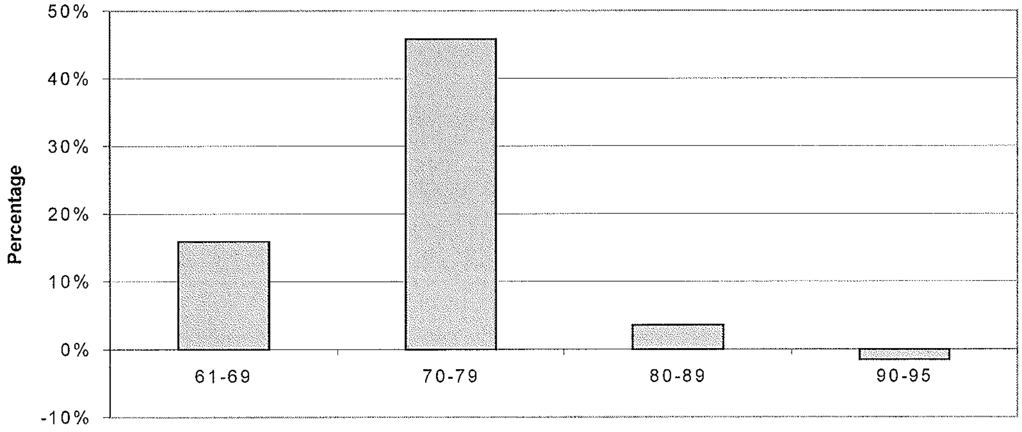
Industry	Total Growth Rate in R&D 1961-95	Sales Effect	Public R&D Effect	Tax Credit Effect	Residuals
Plant Breeding	1.28	0.34 [27%]	0.77 [60%]	0.20 [16%]	-0.03 [-3%]
Agricultural Chemicals	0.91	0.30 [33%]	0.47 [52%]	0.17 [18%]	-0.03 [-3%]
Veterinary Pharmaceuticals	0.80	0.61 [76%]	0.16 [20%]	-0.33 [-41%]	0.36 [45%]
Farm Machinery	0.17	0.06 [35%]	0.04 [24%]	0.12 [71%]	-0.05 [-30%]
Processed Food	0.44	0.21 [48%]	0.07 [16%]	0.30 [68%]	-0.14 [-32%]

Note: [Percentage of contribution to the total growth]

Table 4.4 shows that public R&D contributed to most of the private R&D growth in the plant breeding and agricultural chemical industries. Sales were relatively more important for the veterinary pharmaceutical, farm machinery and food industries. I included coefficients even though some were not statistically different from zero in the regression equations. Because of this, Table 4.4 overstates the importance of public R&D to private R&D growth in the farm machinery sector. Also, the role of tax credits may be overstated.

Figure 4.1 shows the slowdown in public agricultural R&D growth since the 1970s. The growth in the public research stock variable *PUBRD* has also slowed down. *PUBRD* grew at a 3% annual rate in the 1960s and at 3.8% annually in the 1970s. But in the 1980s, *PUBRD* grew by only 2.5% per year and in the first half of the 90s, the growth rate slowed to an annual rate of 1.5%. Results from the regression in Table 4.3 suggest that this slowdown would contribute to a slowdown of private agricultural R&D in the latter half of the 1990s and slower private agricultural R&D growth in the near future.

Figure 4.1 Growth in Public R&D Variable (1996 = 1.00)



Source: Huffman and Evenson (1993).

Table 4.5 Hypotheses Tested for Regression Equation (1)

Null Hypothesis	Test Statistic	Null Hypothesis Rejected?
Elasticity of private R&D with respect to public R&D stock *(PUBRD)* equal across industries $\beta_{21} = \beta_{22} = \beta_{23} = \beta_{24} = \beta_{25}$	$\chi^2(4) = 50.27$	Reject the null hypothesis
Elasticity of private R&D with respect to industry sales *(SALES)* equal across industries $\beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15}$	$\chi^2(4) = 40.63$	Reject the null hypothesis

Table 4.5 shows results of hypothesis tests concerning R&D elasticity estimated in equation (1). Using a Chi-squared test, I reject the hypothesis that the elasticity of private R&D with respect to public R&D stock *(PUBRD)* is equal across industries. I also reject the hypothesis that the elasticity of private R&D with respect to industry sales *(SALES)* is equal across industries. Based on these results, the specification of the type used by Pray and Neumeyer (1989)is rejected in favor of a more general one.

4.2 A SUR Model of Private Agricultural R&D Intensity

In this section I test how technological opportunity and approriability variables influence agricultural industry R&D intensity. Many econometric studies of private R&D investment use the ratio of R&D to sales (R&D intensity) as a dependent variable. Table 4.6 shows results of a SUR regression where the dependent variable is now:

$$(RD/SALES)_{it} = \beta_{0i} + \beta_{1i}\, PUBRD + \beta_{2i}\, TAX + \varepsilon_{it}, \quad i = 1,2..,5 \qquad (2)$$

Table 4.6 SUR Estimation of Equation (2)

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Farm Machinery	Processed Food
Intercept	-0.03** [-4.8]	0.07** [5.47]	0.13** [4.80]	0.02** [6.60]	0.0011** [3.56]
PUBLICRD	0.3E-05** [8.42]	.13E-05* [1.77]	0.46E-05** [3.08]	-0.83E-07 [-0.37]	0.43E-07* [2.402]
TAX	0.028 [1.19]	0.13** [3.00]	-0.24** [-2.69]	0.061** [4.55]	0.001 [1.09]
R^2	0.88	0.65	0.22	0.61	0.50

$R^2 = .942$, $\chi^2 = 100.23$ with 10 d.f. $N=35$, Breusch-Pagan LM Test = 36.59 with 10 d.f.

Note: [t-statistic]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test)

The results of regression (2) (Table 4.6) are similar to those from regression (1). The public research stock variable is positive and significant for all industries except farm machinery. Also like regression (1) the coefficient for processed food is much smaller than the coefficients for plant breeding, agricultural chemicals, and veterinary pharmaceuticals. The tax credit variable was significant and positive for agricultural chemicals and farm machinery but significant and negative for veterinary pharmaceuticals. The regression did a much poorer job predicting research intensity in the veterinary pharmaceuticals industry (R-squared only 0.22) than for the other industries.

Levin and Reiss (1984) used a specification that deflated the public R&D variable by industry sales as well. Following this approach, the regression is:

$$(RD / SALES)_{it} = \beta_{0i} + \beta_{1i}\,(PUBRD / SALES)_{t} + \beta_{2i}\,TAX_{t} + \varepsilon_{it}, \quad i = 1,2..,5. \qquad (3)$$

Table 4.7 shows the results of this regression. For all the specifications used thus far, the same qualitative results seem to hold. Public agricultural R&D appears to be complementary to private agricultural R&D for all industries except farm machinery, where it is neither a complement nor substitute. Public R&D appears to have a stronger affect on the other agricultural input industries than it does for the processed food sector.

Table 4.7 SUR Estimation of Equation (3) (Public R&D intensity variable used)

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Farm Machinery	Processed Food
Intercept	-0.050**	0.035**	0.11**	0.019**	0.0009**
	[-5.50]	[2.43]	[3.22]	[3.93]	[2.26]
PUBSALE	8.71**	6.97**	11.06**	0.58	0.11**
	[8.20]	[4.19]	[2.72]	[0.98]	[2.32]
TAX	0.02	0.06*	-0.23**	0.046**	0.001
	[0.822]	[1.53]	[-2.4]	[3.30]	[1.00]
R^2	0.88	0.75	0.18	0.62	0.49

System R^2 =.944, χ^2= 100.94 with 10 d.f. *N*=35, Breusch-Pagan LM Test = 33.49 with 10 d.f

Note: [t-statistics]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test)

Table 4.8 Summary of Hypotheses Tested for Equations (2) and (3)

Null Hypothesis	Test Statistic	Null Hypothesis Rejected?
H_o: Technological opportunity variables (PUBLICRD, TAX) have no effect across industries $\beta_{11}= \beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}=\beta_{21}= \beta_{22}=\beta_{23}=\beta_{24}=\beta_{25}=0$	$\chi^2(10)=$ 323.05	Reject the null hypothesis
H_o: Technological opportunity variables (PUBSALE, TAX) have no effect across industries $\beta_{11}= \beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}=\beta_{21}= \beta_{22}=\beta_{23}=\beta_{24}=\beta_{25}=0$	$\chi^2(10)=$ 432.52	Reject the null hypothesis
H_o: The effects of Public R&D equal across industries $\beta_{11}= \beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}$	$\chi^2(4)=94.46$	Reject the null hypothesis
H_o: The effects of Public R&D intensity equal across industries $\beta_{11}= \beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}$	$\chi^2(4)=95.39$	Reject the null hypothesis

Table 4.8 summarizes hypotheses tested in the model above. The test statistics show that technological opportunity factors do influence industry R&D intensity. Also, the hypothesis that the effect of public R&D was equal across industries was rejected at high level of significance, confirming that the effect of technological opportunity differs across the industries.

Finally, two shift dummy variables (*BIOTECH* and *PVPA*) were added to the model. Pray and Neumeyer included these variables in their model to account for breakthroughs in biotechnology (that would affect technological opportunity) and changes in intellectual property rights (that would affect appropriability). *BIOTECH* is a dummy variable that equals one for years 1982-95 and zero otherwise. *PVPA* is a dummy variable that equals one for years 1970-95 and zero otherwise. The Plant Variety Protection Act (PVPA) was passed in 1970. Table 4.9 shows results when these variables are included in regression (2).

Table 4.9 Model Estimation with BIOTECH and PVPA Variables in Equation (2)

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Farm Machinery	Processed Food
Intercept	-0.026** [-3.00]	0.09** [6.37]	0.15** [4.02]	0.022** [4.26]	0.0009* [1.97]
PUBLICRD	.30E-05** [4.86]	.17E-05 [0.17]	0.21E-05 [0.80]	0.37E-06 [1.02]	0.56E-07* [1.74]
TAX	-0.13** [-2.05]	-0.27** [-2.6]	-0.25 [-0.93]	0.042 [1.14]	0.004* [1.37]
BIOTECH	0.04** [2.37]	0.10** [3.75]	0.015 [0.20]	0.002 [0.20]	0.88E-03 [-0.10]
PVPA	-0.006 [-1.19]	-0.008 [-1.10]	0.032* [1.54]	-0.007** [-2.47]	0.00001 [0.04]
R^2	0.92	0.79	0.27	0.69	0.52

$R^2 = 0.97$, $\chi^2 = 127.8$ with 20 d.f. $N = 35$, Breusch-Pagan LM Test = 25.06 with 10 d.f.

Note: [t-statistics]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test)

Table 4.10 shows results when they are included in regression (3).

Table 4.10 Model Estimation with BIOTECH and PVPA Variables in Equation (2)

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Farm Machinery	Processed Food
Intercept	-0.03**	0.06**	0.09**	0.020**	0.0004
	[-3.01]	[3.96]	[2.31]	[3.155]	[0.81]
PUBSALE	5.91**	3.91*	10.39**	0.92	0.16**
	[4.52]	[1.93]	[2.00]	[1.21]	[2.48]
TAX	-0.14**	-0.19*	-0.12	0.046	0.0053*
	[2.14]	[-1.96]	[-0.46]	[1.23]	[1.71]
BIOTECH	0.04**	0.07**	-0.038	0.0009	-0.0012*
	[2.37]	[2.79]	[-0.56]	[0.097]	[-1.49]
PVPA	0.007*	-0.010*	0.03**	-0.005**	0.0002*
	[2.37]	[-1.96]	[2.78]	[-2.79]	[1.44]
R^2	0.91	0.81	0.33	0.69	0.56

R^2 =.998, , χ^2=131.22 with 22 d.f. N=35, Breusch-Pagan LM Test = 25.53 with 10 d.f.

Note: [t-statistics]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test)

When more variables were added the coefficient of public R&D decline as do their level of significance. However, public R&D show robust results for plant breeding and food processing industries. Consistent to the results in the previous models, tax credits do not affect R&D intensity in plant breeding industry and affect the veterinary medicine industry negatively. *TAX* had a significant and positive effect in farm machinery and food processing industries. Biotechnology breakthroughs showed a significant positive effect on plant breeding and agricultural chemicals industries.

Some past studies (Pakes and Griliches1984; Stoneman 1987) have found that that patents are not a major factor in determining the level of R&D (as suggested by Pray & Neumeyer 1989). However, Knudson (1999) reports results specific to the plant breeding industry suggesting that PVPA has increased plant breeding R&D. The hypothesis that PVPA patent protections would have a significant effect upon the plant breeding industry was not supported by the results in Table 4.9, but were in the specification in Table 4.10. One should notice that I used two dummy variables, one for years after 1969 and one for years after 1981. In addition, the tax credit variable equals zero prior to 1982 and changes little in subsequent years. When these three variables are combined all together in the model, it might have caused a multicollinearity problem.

Table 4.11 Summary of Hypotheses Tested

Null Hypothesis	Test Statistic	Null Hypothesis Rejected
H_0: Technological opportunity variables (PUBLICRD, TAX, BIOTECH) have no effect across industries $\beta_{11}=\beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}=\beta_{21}=\beta_{22}=\beta_{23}=\beta_{24}=\beta_{25}=\beta_{31}=\beta_{32}=\beta_{33}=\beta_{34}=\beta_{35}=0$	$\chi^2(15)=321.30$	Reject the null hypothesis
H_0: Technological opportunity variables (PUBSALE, TAX, BIOTECH) have no effect across industries $\beta_{11}=\beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}=\beta_{21}=\beta_{22}=\beta_{23}=\beta_{24}=\beta_{25}=\beta_{31}=\beta_{32}=\beta_{33}=\beta_{34}=\beta_{35}=0$	$\chi^2(15)=398.54$	Reject the null hypothesis
H_0: The effect of biotechnology breakthrough equal across Industries $\beta_{31}=\beta_{32}=\beta_{33}=\beta_{34}=\beta_{35}$	$\chi^2(4)=16.84$	Reject the null hypothesis
H_0: The effect of Public R&D equal across industries. $\beta_{11}=\beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}$	$\chi^2(4)=27.30$	Reject the null hypothesis
H_0: The effect of PUBSALE equal across industries $\beta_{11}=\beta_{12}=\beta_{13}=\beta_{14}=\beta_{15}$	$\chi^2(4)=31.47$	Reject the null hypothesis

In this study, as opposed to other empirical studies of R&D, I assumed the effect of R&D differs among industries. SUR model allowed the estimation to capture the inter-industry differences of technological opportunities. Therefore, the joint significance of all the technological opportunity variables on the R&D intensity was examined. Wald chi-square statistics rejected the null hypotheses at a high level of significance as can be seen in Table 4.11. Also, the table shows that the effect of biotechnology breakthrough and public R&D differ across industries.

I also tried specifications where the PVPA variable was only included in the plant breeding equation (the one where you might expect the most direct effect). The BIOTECH variable was also excluded from the farm machinery equation, because biotechnology breakthroughs would be less likely to create technological opportunities for the farm machinery industry. Results are shown in Tables 4.12 and 4.13.

Table 4.12 SUR Estimation with BIOTECH and PVPA, Alternative Specification

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Farm Machinery	Processed Food
Intercept	-0.025** [-2.98]	0.10** [8.34]	0.12** [3.96]	0.026** [6.60]	0.0009** [2.32]
PUBLICRD	.29E-05** [5.00]	-.56E-06 [0.80]	0.48E-05** [2.65]	-0.83E-07 [-0.37]	0.59E-07* [2.74]
TAX	-0.13** [-2.06]	-0.28** [-2.89]	-0.19 [-0.79]	0.062 [4.55]	0.005* [1.60]
BIOTECH	0.04** [2.48]	0.11** [4.54]	-0.012 [0.19]	-	-0.99E-03 [-1.29]
PVPA	-0.004 [-0.85]	-	-	-	-
R^2	0.91	0.79	0.22	0.62	0.52

R^2 =0.97, χ^2= 127.8 with 20 d.f. *N*=35, Breusch-Pagan LM Test = 25.06 with 10 d.f.

Note: [t-statistic]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test)

Again, the results concerning the PVPA appear mixed, with no significant effect in Table 4.12, but a positive effect in the specification in Table 4.13. The complementary relationship between public R&D and private plant breeding research appears to be the most robust result from all the regression specifications that I tried.

Table 4.13 SUR Estimation with BIOTECH and PVPA, Alternative Specification (2)

Variables	Plant Breeding	Agricultural Chemicals	Veterinary Pharmaceuticals	Farm Machinery	Processed Food
Intercept	-0.03** [-3.03]	0.06** [3.88]	0.09** [2.09]	0.02** [3.93]	0.0004 [0.71]
PUBSALE	5.58** [4.5]	3.07* [1.5]	13.38** [2.49]	0.58 [0.99]	0.18** [2.81]
TAX	-0.14** [-2.14]	-0.20* [-2.05]	-0.07 [-0.28]	0.046** [3.30]	0.006* [1.81]
BIOTECH	0.04** [2.56]	0.07** [2.82]	-0.045* [-0.66]	-	-0.0013* [-1.56]
PVPA	0.009** [2.87]	-	-	-	-
R^2	0.91	0.79	0.19	0.62	0.53

R^2 =.998, , χ^2=131.22 with 22 d.f. *N*=35, Breusch-Pagan LM Test = 25.53 with 10 d.f.

Note: [t-statistic]. *significant at 0.1 level (one-tail test). **significant at .05 level (one-tail test) [Note] - : variable is omitted

4.3 Market Concentration and R&D Intensity

Previous empirical studies have examined the relationship between market concentration and private R&D intensity (Scherer 1967; Scott 1984; Levin, Cohen, and Mowery 1985). These studies all used the four-firm sales concentration ratio for an industry to measure market concentration (*CR4*). In all these studies there appeared to be a relationship between market concentration and R&D intensity in simple regression equations with only measures of market concentration as regressors. However, when these studies controlled for company-specific or industry-specific fixed effects, the results changed. Scherer (1967) found that introducing industry-specific dummy variables led to declines in the explanatory power of *CR4*. Both Scott and Levin, Cohen, and Mowery found that *CR4* and *CR4-Squared* variables became insignificant when industry-specific dummy variables were included in the regressions.

In this study, due to the limitation of data concerning concentration ratios, I was able to obtain the four-firm concentration ratios only for agricultural chemicals (SIC 2879), pharmaceutical preparation (SIC 2834), and farm machinery and equipment (SIC 3523) industries from the *Census of Manufactures* between 1972 and 1992. Thus, I only estimated the effects of market structure on the research intensity in the three industries. Because *CR4* measures were only available at four or five year intervals, I used linear interpolation to fill in missing data. First, I followed the approach of Scott (1984) and Levin, Cohen, and Mowery (1985) running a simple regression of R&D intensity on *CR4* and *CR4-Squared.*

Since independence of the concentration variables and the disturbance term is decisively rejected in OLS estimation, I employed a maximum likelihood (ML) estimation for models with first autoregressive error.[3] The use of the ML estimator improves the efficiency of the estimates compared to the ordinary least squares. The results are shown in equation (4). Numbers in brackets are t-statistics.

$$\underset{}{RD/SALES} = \underset{[7.47]}{1.03^{**}} - \underset{[-5.86]}{0.045CR4^{**}} + \underset{[5.13]}{0.0005\ CR4\text{-}Squared^{**}} \tag{4}$$

$N = 63, R^2 = .92$

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[3] The method is due to Beach and MacKinnon (1978). It is similar to the Cochrane-Orcutt procedure, but this estimator appears more efficient and yields better estimates.

Given that the sample values for *CR4* range from 0.22 to 0.53, the results from (4) mean that R&D intensity declines with market concentration at a decreasing rate. However, again I follow Scott and Levin, Cohen, and Mowery and add industry-specific dummy variables, where D_1 is a dummy variable for agricultural chemicals industry and D_2 is for veterinary medicine industry. Results are shown in equation (5).

$$\begin{array}{llllll} \mathit{RD/SALES} = & -0.10 & +\ 0.002\mathit{CR4} & +\ 0.16\text{E-}04\ \mathit{CR4\text{-}Squared} & +\ 0.08D_1^{**} & +\ 0.26D_2^{**} \\ & [-0.42] & [0.197] & [0.144] & [8.12] & [4.48] \end{array} \tag{5}$$

$N = 63$, $R^2 = 0.95$

When industry dummies were added to the model, the concentration variables were no longer significant. My results looking at the relationship between market concentration and private agricultural R&D intensity are limited by lack of data. They are, however, consistent with the findings of other studies that concentration is not a factor if one controls for industry-specific fixed effects. Recalling the figure of concentration ratios in Chapter 3, CR4 does not change much over the time series given. However, there is difference among industries. Given these data limitations, it may be that this regression specification cannot accurately separate market concentration from other industry specific effects.

4.4 Summary

Econometrics models investigating private R&D investment for five agricultural industries were discussed and explained. These models attempted to estimate how market demand, technological opportunity, appropriability, and market concentration influence R&D investment in different agricultural industries. By using the SUR model, I could account for differences in effects between industries.

The demand-pull hypothesis was tested using industry sales as a measure. I find that market growth is a driving force of private R&D especially for plant breeding, agricultural chemicals, and farm machinery industries. Firms increase their R&D as demand increases.

The stock of public R&D had a complementary effect on private agricultural R&D in all industries except farm machinery, where it had neither a complementary or substitution effect. Public R&D appeared to have the strongest and most robust complementary impact on private plant breeding R&D. The growth in the stock of public R&D was an important source of private R&D growth in the plant-breeding and agricultural chemical industries. Results suggest that the recent slowdown in public R&D spending could contribute to a slowdown in R&D growth in those sectors, other things constant.

Results for effects of tax credits, biotechnology breakthroughs and the effects of the Plant Variety Protection Act were not conclusive and were sensitive to the econometric specification that I used.

Market concentration did not appear to have an effect on R&D intensity once dummy variables controlling for industry specific fixed effects were included. This was consistent with the findings of Scott (1984) and Levin, Cohen, and Mowery (1985). However, data limitations make it difficult to disentangle market concentration from other industry-specific effects.

CHAPTER FIVE: SUMMARY AND CONCLUSIONS

This study used a new industry-level data set to conduct an econometric analysis of the determinants of private R&D in agriculture-related industries. The industries examined were agricultural chemicals, farm machinery, food and kindred products, plant breeding and veterinary pharmaceuticals over the years 1961-95.

I reported results of a series of seemingly unrelated regression (SUR) equations that examined the role of variables intended to capture the effects of technological opportunity, appropriability, and market demand. The SUR specification allows one to test and adjust for contemporaneous correlation of errors across industry-level equations. It also allows regression coefficients to vary across industries. Most previous studies of the determinants of private R&D rely on simple ordinary least squares (OLS) regression that assumes that regression coefficients (besides the intercept) are the same across industries. I conclude by summarizing some of my major findings.

First, one of the main hypotheses of interest was whether or not public agricultural R&D was a complement to or substitute for private R&D. In general, the regression results suggest that public R&D is a complement to (i.e. encourages) private R&D in all industries except farm machinery. This complementarity was strongest and most robust for the plant breeding industry.

Second, the results give support to Schmookler's "demand-pull" hypothesis. Market demand (measured by value of industry shipments) had a positive and statistically significant impact on private R&D investment in all industries.

Third, I carried out a growth decomposition exercise to estimate the relative contribution of different factors to private R&D growth between 1961 and 1995. Results suggest that public R&D growth was the major source of private R&D growth in the agricultural chemical and plant breeding industries. Sales growth was the main source of growth in the farm machinery, food and kindred products, and veterinary pharmaceutical industries. One of the implications of this result is that the slowdown in the growth of public R&D spending may eventually contribute (all else constant) to a slowdown in the growth of private R&D investment, particularly in the agricultural chemical and plant breeding industries.

Fourth, the SUR models used in this study were more general specifications of the type of models used in Pray and Neumeyer's (1989) earlier study of private agricultural R&D. They used OLS models that assumed that the slope coefficients were equal across industries. This would imply that the degree of complementarity between public and private R&D would be equal across all industries. Their model is thus a special, restricted case of the SUR model that I use. I tested this restriction against the more general specification. The hypothesis that slope coefficients were equal across industries was strongly rejected. Also the hypothesis that the covariance matrix was diagonal was also rejected in all specifications. These two results suggest that a SUR specification is more appropriate than the simple OLS specification commonly used in private R&D studies.

The more general, SUR specification also allows one to capture the differences in complementarity across industries. The results are intuitively appealing. Public R&D

appeared to be neither a complement to nor a substitute for private R&D. USDA and SAESs devote very little research funding to machinery research. The degree of complementarity was strongest for plant breeding and agricultural chemicals, where the public sector does focus a large portion of its research effort. There was also generally a significant complementary relationship between public R&D and veterinary pharmaceuticals and food and kindred products. The degree of complementarity was weaker for these industries than for agricultural chemicals and plant breeding, however. The public sector spends less research effort on food products and veterinary medicine than it does on plant breeding and pest control.

I conducted other hypothesis tests to estimate the effects of tax credits, the Plant Variety Protection Act (PVPA), and technological opportunities created by recent breakthroughs in biotechnology. The results here were mixed. The regression coefficients often did not have the expected signs and they were sensitive to the specification used. This may be the result of data problems. The PVPA began in the early 1970s, coinciding with greater regulation of the agricultural chemicals industry. Breakthroughs in biotechnology in the early 1980s coincided with the initiation of R&D tax credits in the United States. Because the variables I use have large discrete jumps at similar points in time (and vary little after the jumps), they may be too crude to estimate the separate effects of different changes.

I also repeated the experiments of Scott (1984) and of Levin, Cohen, and Mowery (1985), by regressing the R&D – Sales ratio for industries on measures of market concentration. Because of data limitations, I could only run regressions for farm machinery, agricultural chemicals and veterinary pharmaceuticals. Scott (1984) and Levin, Cohen, and Mowery (1985) both found an inverted U relationship when they regressed the R&D – Sales ratio on the four-firm concentration ratio and its square. They also both found that the correlation between market concentration and R&D intensity disappeared when industry or firm specific dummy variables were included in the regressions. In my regressions, I also found a significant relationship between concentration and R&D intensity in a simple regression. In my regression, rather than an inverted U relationship, R&D intensity decreased at a decreasing rate as concentration increased. When industry-level dummy variables were added, the coefficients on concentration and concentration squared also became insignificant. As discussed in Chapter 3, market concentration within industries did not vary much over time, while there was much greater variation between industries. Given this pattern in the data, it may not be possible to distinguish between the effects of market concentration and other industry-specific effects.

In closing, the most important finding of this study is the strong and robust complementary relationship between public agricultural R&D investment and private R&D investment in plant breeding. My results suggest that the growth in the stock of public R&D accounted for more than half of the growth in private plant breeding R&D between 1961 and 1995. The growth in the public research stock variable has also slowed down considerably over the period covered by this study. The public agricultural research stock grew at a 3 percent annual rate in the 1960s and at 3.8 percent annually in the 1970s. But in the 1980s, it grew by only 2.5 percent per year and in the first half of the 1990s, the growth rate slowed to an annual rate of 1.5 percent. This suggests, that (all else constant) the decrease in the growth of the public R&D stock may be a constraint on the growth of private R&D in plant breeding over the near term.

REFERENCES

Ahearn, M., J.Yee, E. Ball, and R. Nehring, *Agricultural Productivity in the United States.* Washington DC: U.S. Department of Agriculture, Economic Research Service. Agriculture Information Bulletin No. 740, January 1998.

Beach, C., and J. MacKinnon. "A Maximum Likelihood Procedure for Regression with Autocorrelated Errors." *Econometrica* 46(January 1978):51-58.

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

Buxton, A.J. " The Process of Technical Change in UK Manufacturing." *Applied Economics* 7(March1975):53-71.

Carmichael, Jeffrey. "The Effects of Mission-Oriented Public R&D Spending on Private Industry." *Journal of Finance* 36(January 1981):617-627.

Dasgupta, P., and J. Stiglitz. "Industrial Structure and the Nature of Innovative Activity." *Economic Journal* 90(June 1980):266-293.

David, P., B. Hall, and A. Toole. "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence." *Research Policy*, in press.

Economic Report of the President. Transmitted to the Congress February, 1999. Washington DC, 1999.

Flaherty, T.M. "Industry Structure and Cost-Reducing Investment." *Econometrica* 48 (July 1980):1187-1210.

___________. " Field Research on the Link between Technological Innovation and Growth: Evidence from the International Semiconductor Industry." *American Economic Review* 74(May 1984):67-72.

Frisvold, G., and P. Condon. "The Convention on Biological Diversity and Agriculture: Implication and Unresolved Debates." *World Development* 26 (4)(1998):551-570

Fuglie, K., N.Ballenger, K.Day, C. Klotz, M.Ollinger, J.Reilly, U.Vasavada, and J.Yee. *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions.* Washington DC: U.S. Department of Agriculture, Economic Research Service. Agr. Econ. Rep. 735, July 1996.

Globerman, Steven. "Market Structure and R&D in Canadian Manufacturing Industries." *Quarterly Review of Economics and Business* 13(Summer 1973):59-68.

Goldberg, Lawrence. "The Influence Of Federal R&D Funding On The Demand For and Returns To Industrial R&D." Working paper, CRC-388 The Public Research Institute 1979.

Griliches, Z., and J. Schmookler. " Inventing and Maximizing." *American Economic Review* 53(September 1963):725-729

Higgins, R., and A. Link. Federal Support of Technological Growth in Industry: Some Evidence of Crowding Out, IEEE Transactions on Engineering Management EM-28, November 1981, 86-88.

Huffman, W., and R. Evenson. *Science for Agriculture: A Long-Tem Perspective.* Iowa: Iowa State Univeristy Press, 1993.

Jaffe, A.B. "Demand and Supply in R&D Intensity and Productivity Growth." *Review of Economics and Statistics* 70(August 1988):431-437.

Klotz, C., K. Fuglie, and C. Pray. *Private-Sector Agricultural Research Expenditures in the United States, 1961-92.* Washington DC: U.S. Department of Agriculture, Economic Research Service. Staff paper, AGES9525. October 1995. Unpublished Data 1993-96 provided by Klotz and Fuglie in 1998.

Knudson, M. "Agricultural Diversity: Do We Have the Resources to Meet Future Needs?" *Global Environmental Change and Agriculture.* George Frisvold and Betsey Kuhn eds., pp. 43-86. Cheltenham: Edward Elgar, 1999.

Lee, T., and L. Wilde. "Market Structure and Innovation: A Reformulation." *Quarterly Journal of Economics* 94(March 1980):429-436.

Levin, R., and P. Reiss. "Tests of a Schumpeterian Model of R&D and Market Structure." *R&D, Patents, and Productivity.* Zvi Griliches ed., pp.175-204. Chicago: The University of Chicago Press, 1984.

__________. "Cost-reducing and Demand-Creating R&D with Spillovers." *Rand Journal of Economics* 19(Winter 1988):538-556.

Levin, R., W. Cohen, and D. Mowery. "R&D Appropriability, Opportunity, and Market Structure: New Evidence on Some Schumpeterian Hypotheses." *American Economics Review* 75(May 1985):20-24.

Levy, D., and N. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: a Macroeconomic Analysis." *Bell Journal of Economics* 14(Autumn 1983):551-561.

Leyden, D., and A. Link. "Tax Policies Affecting R&D: an International Comparison." *Technovation* 13(1993):17-25.

Lichtenberg, Frank. "The Relationship between Federal Contract R&D and Company R&D." *American Economic Review* 74(May 1984):73-78.

___________. "The Private R&D Investment Response to Federal Design and Technical Competitions." *American Economic Review* 78(June 1988):550-559.

Lichtenberg, F., and D. Siegel. "The Impact of R&D Investment on Productivity--New Evidence Using Linked R&D-LRD Data." *Economic Inquiry* 29(April 1991): 203-29.

Link, Albert. "Basic Research and Productivity Increase in Manufacturing: Additional Evidence." *American Economic Review* 71(December 1981):1111-1112.

Loury, Glenn. "Market Structure and Innovation." *Quarterly Journal of Economics* 93 (August 1979):395-410.

Mansfield, Edwin. " Technological Change and Market Structure: An Empirical Study." *American Economic Review* 73(May 1983):205-209.

__________. "R&D and Innovation: Some Empirical Findings." *R&D, Patents, and Productivity*. Zvi Griliches ed., pp.127-148. Chicago: The University of Chicago Press, 1984.

__________. "The R&D Tax Credit and Other Technology Policy Issues." *American Economic Review* 76(May 1986):190-194.

National Science Foundation. "National Science and Engineering Indicators 1998 [Online]." Available HTTP: http://www.nsf.gov/sbe/srs/seind98/frames.htm (1998).

Ollinger, M and J. Fernandez-Cornejo. "Innovation and Regulation in the Pesticide Industry." Working paper, Center for Economic Studies. December 1995.

Pakes, A., and Z. Griliches. "Patents and R&D at the Firm Level: A First Look." *R&D, Patents, and Productivity.* Zvi Griliches, ed., pp.55-72. Chicago: The University of Chicago Press, 1984.

Pharmaceutical Research and Manufacturers of America (PhRMA). "Pharmaceutical Industry Profile 1999 [Online]." Available HTTP: http://www.phrma.org/publications/industry/profile99/index.html (1999).

Pray, C., and C. Neumeyer. "Impact of Technology Policy on Research in the Agricultural Input Industries." Unpublished. Department of Agricultural Economics and Marketing. Rutgers University, July 1989.

Pray, C., M. Knudson, and L. Masse "Impact of Intellectual Property Rights on US Plant Breeding R&D." Mimeo. Rutgers University, Brunswick NJ. 1993

Robson, M.T. "Federal Funding and the Level of Private Expenditure on Basic Research." *Southern Economic Journal* 60(July 1993):63-71

Scherer, F.M. "Market Structure and the Employment of Scientists and Engineers." *American Economic Review* 57(June 1967):524-531.

__________. "Demand-Pull and Technological Invention: Schmookler Revised." *Journal of Industrial Economics* 30(March 1982):225-237

Schmookler, Jacob. *Invention and Economic Growth.* Cambridge: Harvard University Press, 1966.

Schumpeter, Joseph. *Capitalism, Socialism, and Democracy.* 3rd ed. New York: Harper and Row, 1950.

Scott, John. "Firm Versus Industry Variability in R&D Intensity." *R&D, Patents, and Productivity.* Zvi Griliches, ed., pp.233-252. Chicago: The University of Chicago Press, 1984.

Shrieves, Ronald. "Market Structure and Innovation: a New Perspective." *The Journal of Industrial Economics* 26(January 1978):329-347.

Stoneman, Paul. *The Economic Analysis of Technology Policy.* Oxford: Oxford University Press, 1987.

U.S. Department of Agriculture, Economic Research Service. "National Productivity Accounts and Implicit Price and Quantity Indexes for Agriculture, 1948-1994[Online]." Available HTTP: http://www.phrma.org/publications/industry/profile99/index.html (1999).

U.S. Department of Agriculture. Economic Research Service. Natural Resource and Environment Division. *Agricultural Resources and Environmental Indicators 1996-1997.* Agricultural Handbook. Bull. No. 712, Washington DC, July 1997.

U.S. Department of Agriculture. National Agricultural Statistics Service. *Agricultural Statistics.* Various issues from 1955 through 1997.

U.S. Department of Commerce. Bureau of the Census. *A Competitive Assessment of the U.S. Farm Machinery Industry.* Washington DC, March 1985.

U.S. Department of Commerce. Bureau of the Census. *Census of Manufactures.* Washington DC, Various issues from 1955 through 1997.

U.S. Department of Commerce. International Trade administration. *U.S. Industry & Trade Outlook '99.* New York: The McGraw-Hill Companies, 1999.

Wallsten, Scott. "Do Government-Industry R&D Programs Increase Private R&D?: The Case of the Small Business Innovation Research Program." Working paper, Department of Economics, Stanford University, 1999.