Impact of Biotechnology on Plant Breeding

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Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

ABSTRACT: The application of modern biotechnology to plant breeding is considered to be more efficient and quicker than conventional breeding techniques in the development of new and more resilient crop varieties. To test the impact that biotechnology is having on a industrial plant breeding activities, we relate firm level Plant Variety Protection Certificate (PVPC) applications to corresponding expenditure on research and development (R&D), agricultural biotechnology patents applications, field trials of genetically modified crops, firm structure, as well as industry specific characteristics. Regression results indicate agbiotech activities are directly related to PVP applications, hence the creation of new plant varieties.

I. Introduction

Prior to the twentieth century, most increases in agricultural production were due to increases in land devoted to crop production. As cities and industries took more land, the amount of open, farmable land became increasingly scarce. Farmers realized the importance of crop management and selection practices. For example, crops could be rotated to replace nutrients in the soil and selected for favorable traits given their environment, such as drought tolerance, resistance to pests, and higher yields.. However, as populations continue to expand, it has became increasingly important to push the threshold of crop production, i.e. to increase production yields.

Attaining greater yields requires selecting, developing and growing the most productive and durable crop varieties. At first, science contributed tools like the principles of Mendelian inheritance for trait selection and cross breeding. Such "conventional" breeding methods have led to significant increases in yield potential of crops, but they are limited by intra-special mating and the time it takes hybrid varieties to grow and exhibit the desired trait. With evidence now emerging that yield gains of major cereals is slowing down, conventional breeding may not be able to deliver the genetic gains required to achieve higher yields and meet rising food demand (Pingali and Heisey, 1999)

In this regard, advances in molecular biology, structural and functional genomics, bioinformatics and related fields have led to the development of biotechnology driven tools, methods, and products that promise to increase the productivity of plant breeding research towards increasing farming productivity. Biotechnology is a shortcut; biotechnological methods, such as genetic recombination and Marker Aided Selection (MAS), possess a number of advantages over conventional breeding techniques.

Using biotechnological techniques, genetic material can be manipulated or altered in such a way as to induce an organism (crop plant) to exhibit the desired phenotype by either introducing foreign DNA encoding a desired trait to the organism (recombination) or by changing or manipulating the genetic signals or material within the organism. The genetic element that corresponds to a given trait is the genotype; thus, scientists are now capable of physically introducing desired genotypes into a crop line without mating. In this way, genetic recombination speeds up the process. Furthermore, scientists are able to draw traits from a larger pool of genotypes because intra-species mating will no longer be a limitation as in conventional cross breeding. By allowing scientists to directly introduce genes corresponding to desired traits as opposed to conventional crossbreeding practices, recombinant techniques will cut costs and time in the creation of new and desirable varieties.

Another use of biotechnology is Marker Aided Selection (MAS). Once a trait has been linked to a genotype(s), crop lines (wild type and GMO) can be selected for desired traits without having to actually grow them and look for the expression of a desired trait; scientists can just score the genotypes using molecular diagnostic tools. Using MAS, science can assist farmers in selecting a crop variety for their given needs prior to even growing the selected variety. (Drehr et al, 2000) identify a number of applications where marker aided selection techniques offer considerable cost savings compared to conventional selection methods. Most of these cost savings are due to the fact that with conventional breeding the breeder has to rely on observable differences of the underlying genetic characteristics within their product, which is both time consuming and since the advent of molecular diagnostic screens, inefficient. Biotechnology-based tools allow the breeder to identify desired genes of interest quickly, reliably and efficiently. As a direct consequence of these cost savings one would expect that a firm's propensity to innovate would increase, *ceteris paribus*. Further, given that biotechnology tools shorten the time needed to develop new varieties vis-à-vis conventional breeding methods, one would also expect that new varieties will be developed and introduced at a much quicker pace than before. However, it is likely that the costs and benefits of biotechnology-based breeding programs are a function of the breeding objectives of the researcher, the organizational structure and research capacity of the breeder, and other site and environmental specific characteristics.

In this paper we examine and document the impacts of agricultural biotechnology on the productivity of overall plant breeding. We hypothesize that a firm's investment in the development of biotechnology tools and techniques specific to plant breeding research, (1) is a 'lumpy' investment, but will (2) lower the marginal costs of conducting research; and (3) lead to more plant variety innovations (i.e. more PVPCs). We expect firms engaged in large amounts of plant biotechnology research activities (as proxied by agbiotech patents and number of field trials) to also have higher levels of plant breeding activities. A failure to find such a relationship would suggest that plant biotechnology has, as yet, not played a significant role in a firm's breeding program.

The balance of the paper proceeds as follows. In Section II we examine the methods of previous attempts to characterize the relationship between research inputs and outputs. In Section III we specify the reduced form-econometric model, the data and estimation procedures to be used. The regression results are presented in Section V, followed by some concluding remarks in Section VI.

II. Literature Review

There exists a significant body of research describing (or attempting to describe) the factors leading to innovation at the firm level. Specifically, the focus of much previous work has been to examine the relationship between research inputs and outputs, where patents are often used as a measure of research output (or innovation) and R&D expenditure used as measure of research input (e.g. Griliches; Hausman et al, 1984; Crepon and Duguet, 1997). Griliches et al, examining firm-level cross sectional data, finds a strong relationship between the number of patents granted and R&D expenditures, leading him to conclude that patents are a good indicator of differences of inventive activity. While the patent-R&D relationship is weaker when differences within firms and across time are examined, the relationship remains statistically significant (Griliches et al, 1990).

While a perfect proxy measure of technical change and competitive position, innovation, is yet to be found; patent statistics have proven adequate to that end. Unfortunately, patents as an innovation measure in the plant breeding industry may not appropriate for the simple reason that few new varieties are patented (or patentable)—notwithstanding the surge of variety patents that have been awarded to a few firms in recent years.[1] Rather Plant Variety Protection Certificates (PVPC) awarded to firms are a more appropriate measure of outputs of the research process in plant breeding. Enacted in the Plant Variety Protection Act of 1970 (amended in 1994), a PVPC is a legal award of intellectual property rights over a new, distinct, uniform, and genetically stable variety of plant for a period of 20 years. PVPCs are administered by the U.S. Department of Agriculture. Like patents, PVPCs grant a developer intellectual property rights over a new "invention," in this case a new, non-hybrid plant variety. However, unlike patents, PVPCs are static in their measure. They represent only the creation of a new, non-hybrid plant variety while a patent can represent any number of things. Also, unlike patents, R&D, and other inputs, PVPCs are relatively new (created in 1970) and unlikely to have contributed as much as an input to the process of innovation and therefore would not be viewed as an input. Moreover, PVPC are generally regarded as a weaker form of patent protection as the Plant Variety Protection Act allows farmers to save and replant proprietary seeds, and breeders to use the protected seeds in their research program without compensating the original breeder.

To our knowledge, no study has employed PVPC as an innovation measure to explore the research input-output relationship as it pertains to innovation in plant breeding. Rather the focus in this context has been to ask whether PVPCs are a useful mechanism to protect the innovator's property rights that would result in higher R&D expenditure. The evidence on this issue is mixed. Alston and Venner (2002) report that

[1] The patenting of plant varieties is a controversial and unresolved issue. For a discussion see Janis and Kesan.

for the U.S. the PVPA may have stimulated public (but not private-sector) investment in wheat varietal improvement. For Spain, however, Diez (2002) reports that the enactment of plant variety rights has had a positive incentive especially for the private sector. Kloppenburg argues that the increase in private breeding in the U.S. since the 1970 represents an extension of pre-existing technology, and not necessarily that the passage of PVPA has caused an increase in breeding activities. The lack of clear evidence to support the claim that PVPC have an impact on excludability or appropriability has led some to suggest that PVPC are simply a "marketing tool" (Janis and Kesan)

Regardless of whether the PVPCs are an effective tool to protect the property rights of the plant breeder, they represent the culmination of the plant breeding process. Given that PVPA imposes four substantive protectability requirements—that it be new, distinct, uniform and stable—each PVPC is an innovation that requires some level of research effort. As such, they can be used in estimating a knowledge production function in which the outputs of plant breeding research are primarily a function of research expenditure (current and lagged) and the state of technology. We shall use the knowledge production function approach to test the hypothesis that a firm's research activities in biotechnology has a spillover effect on its breeding program as argued in the introduction.

III. Econometric Model

We test our hypotheses using firm level panel data in the context of the productivity of plant breeding programs. We specify a plant breeding (knowledge) production function that relates the dependent variable (PVP applications) to other firm and industry specific variables as follows:

$$V_{i,t} = f\,(\boldsymbol{F}_{i,t}, \boldsymbol{S}_{i}, \boldsymbol{I}_{t}\,) \tag{1}$$

where $V_{i,t}$ is the number of PVP certificate applications for firm *i* at time *t*. $\mathbf{F}_{i,t}$ is a vector of firm specific characteristics (such as R&D expenditure, AgBiotech patent applications, number of GM crop field trials), *i* is a firm index and *t* is a time index. **S** is a variable specific to research focus. **I** is a vector of environmental specific characteristics (firm invariant), such as institutional changes over time (for example, changes in the PVP Act).

The non-negative, integer nature of the dependant variable (PVP application counts) implies that the basic assumptions of OLS and linear panel data models, such as normality of the residuals are no longer satisfied, and appropriate count data models have to be employed (Srininvasan and Shankar). The most widely used of these is the Poisson regression model which imposes the restriction that mean and variance of the distribution are equal. However, studies of patent and R&D data have typically found the variance to exceed the mean of the distribution (e.g., Graff, Rausser and Small). Accordingly, to account for this over dispersion we shall use the Negative Binomial regression model to estimate the functional relationship between the number of novel plant varieties and the explanatory variables mentioned earlier.

IV. Data and Estimation

For this analysis we have pooled firm-specific data from 13 firms[2] involved in plant breeding over the period 1985 to 2001. The analysis includes total plant variety certificates applications from the indicated firms for the given years, the number of genetically modified organism field trials conducted by each firm, the number of agbiotech patent applications from each firm, total R&D expenditure for each firm, a dummy variable for firms with a multi-industry focus (for example, a firm conducting agbiotech research, chemical research, and pharmaceutical research). A dummy variable was also included to control for legislative change in the PVP Act (i.e. the 1994 amendment to the Act). The PVP application and field trial data were obtained from on-line databases, http://www.ars-grin.gov/cgi-bin/npgs/html/pvplist.pl and http://www.nbiap.vt.edu/ , respectively. The ag-biotech patent data used in this study is from Bennet et al (2002) who screened all patents filed with the U.S. patent office between August 1, 1982 and August 1, 2001 to search for ag-biotech patents. The screening process they used is based on queries using both international patent classification (IPC) codes and technology-related fields. A total of 4,313 patents were identified as being ag-biotech, but only those assigned to the firms of interest in this study are included. The R&D and sales figures for the publicly traded firms in our study comes from compustat, whereas for the two private firms (Asgrow and Holden's) are author's estimates based on publicly available news reports.

A perennial problem in using Compustat data to acquire R&D expenditure is that the data is not broken down by line of business. While this is not an issue for firms fully vested in the just one industry (i.e. the seed and ag-biotech industry in this case), it

[2] Asgrow, Calgene, DeKalb, Delta & Pineland, Holden's, Lubrizol, Novartis, Pioneer, Seminis, Monsanto, DuPont, Mycogen, Dow

becomes problematic for large diversified firms that have interests and investments in several industries and sub-industries (i.e. Dow, Monsanto, Novartis, DuPont). Therefore, to attain a measure of firm involvement in agbiotech R&D for firms with multi-industry focus, we applied a ratio of those firm's Agbiotech patent applications in a given year to its total patent applications over that same year (we assume that the firm's ratio of agbiotech patents to total patents represents the proportion that a firm is vested in biotech research) to that firm's R&D expenditures. Total patent count was obtained from U.S. Patent and Trademark Office's online database.

R&D was found to be highly correlated with Agbiotech patent applications, suggesting that agbiotech patents are just as good, if not better, predictor of a firm's PVP counts. This is in line with prior literature, which has tended to find that patents can be used to quantify the rate of innovation as either an input to the process or as an output. Comanor et al found (after adjusting for company size) significant correlation between patent applications and sales of new products (the output measure) but greater correlation between patent applications and total research employees (the input measure, leading them to conclude that patents may be a better index of research input than output.

The use of patents as an input makes sense. Patents are intrinsically tied to appropriability and market availability. In an open market, one "might expect competitive forces to stimulate innovation and intellectual property protection to induce even more of it" (Gould et al, 1996). In effect, protection of intellectual property stimulates innovation; therefore, patents might be a better input than output variable.

V. Results

Standard Poisson regressions were applied to combinations of the explanatory variables - agbiotech patent applications, deflated R&D expenditures, field trials, company focus, legislation - and the dependent variable – PVP applications. It was quickly apparent that whenever the patents and R&D variables are included in the same equation one or the other is insignificant; however, individually both are significant. Perhaps this is because R&D expenditure is to be considered an input to the research stream that generates patents and therefore part of the same process flow. Furthermore, empirical evidence from previous studies has indicated a direct and contemporaneous relationship between R&D and patents. Indeed a Pearson Correlation Coefficient Matrix between R&D expenditures and agbiotech patent applications demonstrates a high degree of correlation, 0.74306, at the 99% confidence level (N=170). See Table I for regression results.

Table I. Regression Results

Equation	A	**B**	**C**
Intercept	1.9415*** (0.1749)	2.0162*** (0.1483)	1.9632*** (0.1752)
Patents	0.0097 (0.0061)	0.0132*** (0.0042)	-
R&D	0.0008 (0.0010)	-	0.0023*** (0.0006)
Field Trials	0.0025* (0.0013)	0.0025* (0.0013)	0.0025*** (0.0009)
Focus (dummy var)	-.4866* (0.2595)	-0.4290** (0.2232)	-0.6040** (0.2570)
Legislation (dummy var)	0.5093** (0.2391)	0.3975* (0.2155)	0.5717** (0.2387)
N	147	166	148

(Standard Error**)**
*Significant at the 90% level of confidence
**Significant at the 95% level of confidence
***Significant at the 99% level of confidence

Table I, comparison of equation A with equations B and C clearly shows no relationship between PVPs and both agbiotech patent applications and R&D expenditures when both terms are included, but high levels of statistical significance when each term is included separately. Equations B and C show that both agbiotech patent applications and R&D expenditures are positively linked to PVP applications; as R&D expenditures and patents represent inputs to the innovation stream in the form of investment and acquired knowledge, this is to be expected. Further analysis of equations B and C shows, with a high degree of confidence, that firms that do more agbiotech research as measured by field tests also have a positive relationship to PVPs. There is also some indication that legislative changes (i.e. the 1994 PVP Amendment) had a positive relationship with PVPs, which was expected. Companies with multi-industry focus as opposed to those concentrating on agricultural biotech and seeds produce less PVPs, ceteris paribus.

These results generally support our hypotheses. Biotech research as measured by field tests is positively related to our research output proxy, PVP applications even when total research is held constant. The PVP Amendment of 1994 acted to strengthen the PVP Act by extending protection to plant cultivars that are derived, naturally or through genetic engineering, from a protected variety. As this affords greater IP protection to plant cultivars, it encourages more productivity in creating new cultivars. This relationship is expected. The negative relationship between PVP applications and the large multi-industry focus of some firms suggests that firms which concentrate in agriculture are more efficient producers of agbiotech research output. This finding is evidenced by the recent decisions of a number of companies (Monsanto-

Pharmacia, Novartis, Zeneca, and Aventis) to split their agricultural sectors into companies that are separate from their pharmaceutical and other businesses.

VI. Conclusion

We undertook this project intent on documenting the impact of Biotechnological tools, methods, and techniques upon plant breeding programs in the U.S. This was accomplished by relating firm level Plant Variety Protection Certificate (PVP) application counts to corresponding expenditure on research and development (R&D), agbiotech patent application counts (Patents), field trials (Field Trials), and company structure (Focus) for an industry representative sample pool, and industry specific characteristics (Legislation).

Agbiotech patent application and R&D expenditure data proved to be significantly correlated. The two variables are therefore interchangeable as inputs to the innovation production function.

As we expected, the results demonstrated a significant and positive relationship between agbiotech patent applications/R&D expenditure, field trials, and the legislative Changes (i.e. the PVP Amendment of 1994) and the dependent variable, PVP applications. Agbiotech patents may be viewed as accumulated agbiotech knowledge stock which would logically lead to or spill over into the creation of additional Plant Varieties. R&D expenditures are a basic input to the innovation stream; more investment in agbiotech research activities would lead more agbiotech advancements. Field trials are a positive input in the agbiotech research process towards innovation. The PVP Act of 1994 strengthened the Act by protecting varieties created from varieties already under protection from 1994 on. By strengthening protection of new varieties, this Act made the act of creating new varieties more alluring to firms in the industry. The ramifications of the relationship between PVP applications and company focus suugests that firms which concentrate in agriculture are more efficient producers of agbiotech research output which may be part of the reason why large diversified firms are selling off their agriculture divisions.

A significant and direct relationship has been illustrated between PVP applications and agbiotech patent applications, R&D expenditures, and field tests, all integral inputs in the agbiotech research process. This agbiotech research process has led to the filing of more PVP applications. PVP applications are by definition indicative of the creation of new plant varieties. Thus, we conclude that the documented agbiotech activities have had a positive effect on the generation of new plant varieties thereby advancing the potential for increased agricultural productivity.

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