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Examination of Winter Wheat Yield Response to Seed Source

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The incentive for private sector seed development is examined by looking at market forces in the seed industry. Differences in yield between private sector developed seed and bin run seed (grain from a previous harvest) were assessed to determine yield advantages of purchased seed and potential markets for seed firms. Winter wheat (*Triticum aestivum* L.) yield differences between bin run and purchased seed were estimated through regression analysis on field level data. In many cases, the estimated yield differences indicate that seed firms and farmers both could gain by substituting purchased seed for bin run seed. While a seed firm can expect to sell more seed by producing a more effective variety, providing the farmer more information on seed performance, either through increased advertising or encouraging their retailers to work more closely with farmers, could also increase the use of purchased seed. Some state and federal policy changes can also provide incentives for private sector seed development, including increased extension services, increased public promotion of purchased seed, better Plant Variety Protection Act enforcement, increased funding for public research and development (R&D) that complements private R&D, tax incentives, and commodity trade enhancement.

THE SEED INDUSTRY is big business in the USA. In 1979, the market value for private seed sales was approximately $3.9 billion (Butler and Marion, 1985). The seed industry can be credited for providing agriculture with higher yielding, hardier, cleaner, and better germinating seed. However, these rewards are not without costs. For 56 firms, R&D expenditures for varietal and hybrid development went up from $23.85/$1000 of sales in 1960 to $37.74 in 1979 (Perrin et al., 1983). For the entire private sector, R&D expenditures on varietal and hybrid development increased from approximately $8.4 million in 1960 to approximately $87.5 million in 1986 (1972 dollars) (Pray and Neumeyer, 1989). The public sector, also heavily involved with varietal development, raised expenditures from $32.2 million in 1970 to $79.8 million in 1979. Research and development has helped increase the number and quality of varieties or hybrids released (Butler and Marion, 1985).

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The Plant Variety Protection Act (PVPA), passed in 1970 and amended in 1980, recognizes the potential social gains from private seed development. It provides patent-like protection for 18 yr to a plant breeder for sexually reproducing varieties that the breeder produces. By establishing property rights, the PVPA increases the ability of a firm to appropriate returns on its investment in varietal development, which, in turn, provides an incentive to develop more and better varieties.

Before the PVPA, a seed firm could see much of the market for a seed variety it developed lost to other seed companies or to farmers who purchased the variety and sold the harvest as seed. With the PVPA, farmers are limited primarily to seed from their harvest, seed purchased from private firms, or seed purchased from state certification agencies. However, the PVPA still allows farmers to sell seed to others as long as the farmer's primary source of income comes from farming. Furthermore, the PVPA allows farmers to barter seed for services or other seed.

With the PVPA, an important question seed firms face is "How competitive is bin run seed (grain from a previous harvest)?" In particular, how much of the seed market does the private sector capture and why is the private sector capturing (or not capturing) a larger portion. One way to answer this question is to assess the yield response differences between private sector developed seeds and bin run seed. If yield differences between bin run and purchased seed are not significant, then seed firms cannot expect to expand their market without such measures as improving their market strategies or better market protection. For example, firms may benefit from increased advertising. A revision to the PVPA, such as prohibiting farmers from selling seed from their harvest, may help firms increase their seed sales. However, if a significant yield difference exists, then seed firms must search for reasons other than yield advantages for their reduced market share.

To answer these questions, this paper estimates winter wheat yield functions using field level data from the Cropping Practices Survey (CPS) of the USDA. Yield differences by seed source are estimated for the Plains, Corn Belt, and Pacific Northwest states for the growing seasons of 1986-1987 and 1987-1988.

MARKET FORCES IN THE SEED INDUSTRY

The seed industry is comprised of a public and private sector. Each develops varieties for commercial release. To ensure a standard of seed quality and purity, each state has a seed-certifying agency which "establishes the procedure by which each class of seed may be produced and the standards of purity for each class of each crop within their state" (Poehlman, 1979, p.450). The procedure is the certification process and varies between states. The Association of Official Seed Certifying Agencies (AOSCA), a national agency, sets minimum standards to which each state seed-certifying agency is subject. Public varieties must go through the certification process before they are commercially distributed. Private varieties, however, do not have to go through this process although the Federal Seed Act requires all seed sold interstate to be labelled for purity and germination rate, but not necessarily certified. Those varieties that go through the certification process are labelled as certified seed and will meet the purity and germination standards of the AOSCA. Although not all private seed varieties (or hybrids) are certified, they need to be of sufficiently high quality to gain and keep the farmer's trust, and hence, market approval. Therefore, the certification process may provide a standard against which all seeds, including noncertified ones, are measured.

Until the PVPA, the public sector was the principal developer of pure-line varieties, and the private sector concentrated on developing hybrids. A pure-line variety is produced via 4 to 7 generations of self-crossing, whereas a hybrid is the first generation seed from a cross between two genetically unlike parents. The first method takes advantage of those crops that reproduce principally through self-fertilization, including wheat. The second is used on crops that outcross easily. A major distinction between these two types of seeds is that a pure-line variety is genetically similar between generations and a hybrid is not.

A farmer who chooses to plant a pure-line variety that has been introduced in earlier years has the option of purchasing the seed from a seed dealer, using seed from another farmer, or using grain he/she has grown. However, a farmer who intends to plant a newly released pure-line variety of winter wheat must purchase the seed from a dealer. The harvest of a pure-line variety can be used as seed and should provide yields similar to the parent seed when the harvest is properly cleaned and stored. This seed and farmers' own seed is called bin run seed, since it has been stored in a farmer's bin. However, few on-farm grain storage facilities have adequate control of moisture, insects, or rodents which can result in a reduced seed germination rate. Also, the cost of the equipment capable of removing most foreign material and weed seeds can be prohibitive for individual farmers. Hence, purchased seed is expected to provide higher yields than a farmer's own bin run seed.

Before the 1970 PVPA, firms were not likely to capture adequate returns on pure-line varieties and thus were reluctant to develop pure-line varieties. Since 1970, the private sector has increased its investments in pure-line varietal development, as evidenced by the number of private wheat varieties that were used on at least 500 000 acres. This number jumped from four in 1979 to 10 in 1984 (Dalrymple, 1988). Typically, the time it takes from the start of R&D on a new variety or hybrid until its market release is 10 to 15 yr. Hence, the impact of private sector varieties has just commenced.

With adequate protection of property rights, seed firms can develop varieties that offer the farmer production advantages over previous varieties and can ensure seed sales and, therefore, capture adequate returns. New varieties offer short and semi-dwarf stature, disease resistance, and early maturity (Dalrymple, 1988). Wheat yields improved from an average of 10 bu/acre in 1940 to an average of 35 bu/acre in 1980, with approximately half of this increase being attributable to genetic improvements (Dalrymple, 1980).

Seed firms also develop market strategies to ensure that information about their varieties is spread throughout the adopting population (e.g., farmers). Information is transferred via advertising, use of extension services, and seed dealers. The last two forms of communication in particular advise the farmer of specific advantages of new varieties and changes in production practices that may be required. Furthermore, the extension agent and seed dealer may serve as consultants to the farmer on production questions. Thus, seed dealers are an important part of a firm's marketing strategy.

Seed certifying agencies also play a role in transferring information regarding newly certified varieties and of certified varieties, in general. In particular, these agencies try to convince farmers of the advantages certified seed has over other seed varieties. The demand and supply of new varieties, coupled with good communication, help seed firms gain market space.

THE MODEL

To test the significance in yield differences between purchased seed and bin run seed, we developed a yield model with the source of seed serving as one of the explanatory variables. Though a variety of yield functions have been proposed and tested on field, county, state, and national time series and cross-sectional data, there is no consensus on the correct functional form. There is, however, general agreement within, and across, disciplines that inputs are likely to show diminishing, and possibly negative, returns [e.g., with each additional acre-foot of water applied to a field, the subsequent increase in yield becomes smaller (diminishing returns) until yield begins to fall from too much water (negative returns)].

Linear yield functions (with non-linear measures of some independent variables) are the most common yield functions applied in economics (Houck and Gallagher, 1976; Lin and Davenport, 1982; Reed and Riggins, 1982; Menz and Pardey, 1983; Narayana and Parikh, 1987; Offutt et al., 1987) with the Cobb-Douglas the most common alternative (de Janvry, 1972; Huffman, 1974). The linear form with continuous variables modelled to show diminishing returns was found superior to the log-log and log-linear forms. Each variable in the model is included because it is expected to affect winter wheat yields. The estimated model is written as:

$$YIELD = b_0 + b_1BIN + b_2CORN + b_3LEG + b_4FAL + b_5LnN + b_6RATE + b_7RATESQ + b_8MAN + b_9NOTIL + b_{10}HERB \quad [1]$$

where YIELD is the bushel per acre yield of the sampled field. Other variables are defined in Table 1. Data limitations have prevented the inclusion of all factors that affect yield. We are most interested in the yield effect of the use of bin run seed instead of purchased seed and thus assume that BIN is orthogonal to the excluded variables. Three dummy variables, CORN, LEG, and FAL, indicate last growing season's field use and are included to account for their effect on soil productivity. The application of fertilizer N is measured in logarithmic values, lnN, to allow for effects of diminishing returns. A second degree value of the seeding rate, RATESQ, is included to allow for diminishing and negative returns to higher seeding rates. Dummy variables are also included to capture the yield affect of manure, MAN, and herbicide, HERB, applications. The effect on yield of planting without any tillage between the harvest of one season's crop and the planting of the next season's crop, NOTIL, has also been estimated.

Table 1. Estimation results on winter wheat yields.†

	Corn Belt		Plains		Pacific Northwest	
Variable	1986-1987	1987-1988	1986-1987	1987-1988	1986-1987	1987-1988
Intercept	64.1*	59.9	23.1	17.1	−43.1	−43.3
	(4.66)*	(5.86)**	(3.75)**	(5.91)**	(3.45)**	(2.22)*
BIN	−1.61	−2.13	−3.54	−1.17	−2.11	−6.14
	(0.94)	(1.41)	(2.56)*	(1.31)	(0.94)	(2.39)*
RATE	−0.25	−0.18	0.09	0.16	0.50	0.65
	(1.45)	(1.27)	(0.61)	(1.83)	(6.49)**	(3.49)**
RATESQ	0.0008	0.0005	−0.0008	−0.0007	−0.0006	−0.0015
	(1.25)	(1.04)	(0.77)	(1.14)	(5.43)**	(1.39)
CORN	8.53	5.53	4.74	10.6	15.3	12.4
	(2.58)**	(2.18)*	(1.30)	(2.64)**	(0.77)	(1.13)
LEG	9.78	4.06	10.1	4.24	22.2	48.7
	(3.74)**	(2.29)*	(5.43)**	(1.44)	(5.39)**	(2.37)*
FAL			11.6		0.90	−10.2
			(10.5)**		(0.22)	(3.26)**
LnN	0.23	0.91	1.46	2.64	13.6	12.6
	(0.14)	(0.93)	(1.98)*	(9.30)**	(6.11)**	(8.69)**
MAN	8.77	8.74				
	(2.48)*	(2.48)*				
NOTIL		−12.3		−17.1	8.31	12.8
		(2.88)**		(3.45)**	(2.95)**	(1.13)
HERB	−7.05					
	(2.41)*					
Adj. R-Sq	0.075	0.045	0.199	0.172	0.616	0.520
Observation	299	336	583	786	294	304

Where:

BIN – Dummy variable indicating the use of bin run seed.
RATE – The seeding rate measured in lb/acre.
RATESQ – The square of the seeding rate.
CORN – Dummy variable indicating corn as the previous crop.
LEG – Dummy variable indicating soybeans or alfalfa as the previous crop.
FAL – Dummy variable indicating the no crop raised the previous season.
LnN – The natural logarithm of the pounds of N applied per acre.
MAN – Dummy variable indicating the application of manure.
NOTIL – Dummy variable indicating no tillage of the previous crop stubble.
HERB – Dummy variable indicating herbicide use.

* significant at the 95% level
** significant at the 99% level
† t-statistic is in parentheses

DATA

Observations on cropping practices come from USDA's 1987 and 1988 Cropping Practices Survey (CPS), which is part of the USDA's Objective Yield Survey (USDA, 1983). The CPS is an area frame random sample of planted acres that gathers information on inputs used in production of winter wheat and other crops. Only the major producing states were surveyed, which in the case of winter wheat included Washington, Oregon, Idaho, Ohio, Indiana, Illinois, Missouri, Arkansas, Oklahoma, Texas, Nebraska, Kansas, Montana, and Colorado.

Information was gathered on yield, seed source, seeding rate, previous crop, tillage practices, fertilizer use, and herbicide applications. The CPS offers a unique opportunity to examine yield differences between seed sources because observations represent a random sample of the seed varieties and sources that farmers chose to use. In the 1987 CPS, the question on seed source allowed three responses: (i) homegrown or traded, (ii) purchased from farmer, and (iii) purchased from seed dealer. Because of the limited number of responses indicating the purchase of seed from a farmer and because some farmers who sold seed were seed dealers (and not selling their harvest), responses to the 1988 CPS question on seed source was consolidated into two responses: (i) homegrown or traded and (ii) purchased. Response 1 was used to indicate use of bin run seed in both 1986-1987 and 1987-1988 analyses.

The 13 winter wheat states surveyed were divided into three groups based on the principal type of wheat grown and the state's relative locality. These states, and their respective group, are; Washington, Oregon, and Idaho in the Pacific Northwest; Ohio, Indiana, Illinois, Missouri, and Arkansas in the Corn Belt; and Oklahoma, Texas, Nebraska, Kansas, Montana, and Colorado in the Plains. In 1987 and 1988, nearly all winter wheat was Soft Red Winter (SRW) in the Corn Belt, Hard Red Winter (HRW) in the Plains, and a mixture of 80 to 90% White with the rest HRW in the Pacific Northwest.

The number of observations varied by state but usually exceeded 100 for any one state. The total number of observations for 1986-1987:1988-1989 were 294:304 for the Pacific Northwest, 583:786 for the Plains, and 299:336 for the Corn Belt. Purchased seed was used on 63, 13, and 62% of the 1987 winter wheat harvested acres and on 64, 33, and 67% of the 1988 winter wheat harvested acres for the Pacific Northwest, Plains, and Corn Belt, respectively (Table 2).

RESULTS

Regression results are presented in Table 1. Some key points are:

1. the BIN coefficient has the expected negative sign in all cases and tested significantly different from zero in the Plains region in 1986-1987 and in the Pacific Northwest in 1987-1988.
2. the RATE and RATESQ coefficients are most significant in the Pacific Northwest in both seasons.
3. the signs for all the coefficients are as expected, except for RATE, RATESQ, and HERB in the Corn Belt in both seasons, and FAL in the Pacific Northwest in 1987-1988.

The BIN coefficients were negative in all cases but are only significantly different from zero in the Plains region in 1986-1987 and in the Pacific Northwest in 1987-1988. Negative coefficients suggested that bin run seed produced lower yields. The insignificant magnitude of those coefficients on BIN suggests that the average quality of the bin run seed used in those cases was higher than in cases where the coefficients are significant.

In the Plains States in 1986-1987, the yields of bin run seed averaged 3.5 bu/acre less than the yields of purchased seed. Since only a small portion of the winter wheat acreage had been planted with purchased seed, it was not surprising that a statistically significant yield difference was found. Since the BIN coefficient estimates the average yield difference, purchased seed could have increased yields for some farmers substantially more than the 3.5 bu/acre suggested.

Table 2. Actual and percent of total winter wheat acres planted with purchased seed in the Corn Belt, Plains, and Pacific Northwest in 1986-1987 and 1987-1988.

	Actual		Percent	
Region	1986-1987	1987-1988	1986-1987	1987-1988
	thousand acres			
Corn Belt	2809	3960	62.0	67.0
Plains	4199	10148	13.0	33.0
Pacific Northwest	2230	2157	63.0	64.0

The loss in significance of the BIN coefficient for the Plains in 1987-1988 may be due to the increase in the portion of acres planted with purchased seed or the disease outbreak in this region. The greater use of purchased seed could have eliminated use of the lowest quality bin run seed. The amount of purchased seed planted rose from 4.2 million acres (13%) in 1986-1987 to 10.1 million acres (33%) in 1987-1988 as product price of HRW increased (Table 1).

Most Plains states saw yields fall 3 to 17 bu/acre in 1987-1988. A mild winter and idled land from conservation programs increased winter survival rates of insects, such as the mite that carries the wheat streak mosaic virus. As a result, the Plains reported an unusually high incidence of disease. The wheat streak mosaic virus hit Kansas and Nebraska particularly hard (USDA-ERS, 1988).

In the 1987-1988 results, the Pacific Northwest responded significantly to seed source. Yields of farmers using bin run seed averaged 6.15 bu/acre less than the yields of farmers using purchased seed. The average difference in yields in the Pacific Northwest was only 2.11 bu/acre in 1986-1987. It appears that the average quality of bin run seed was significantly lower in 1987-1988.

FACTORS INFLUENCING THE CHOICE OF SEED SOURCE

Three principal factors influence choice of seed source: profitability, costs of cleaning and storing seed, and information diffusion.

Profitability

Profit is the primary factor influencing farmers' choices between purchased and bin run seed. From the estimated coefficients, the cost-effectiveness of purchased seed is indicated by comparing the expected revenue from the greater yield to the higher costs of purchased seed. The most statistically significant yield differences are examined to determine the effect on profits of using purchased seed.

The value of the 3.5 bu/acre yield gain in 1986-1987 for the Plains, based on a conservative output price of \$2.17/bu, translates into a \$7.60/acre gain in revenue. The output prices used in the analysis were from September, since this was the last price farmers

Table 3. Winter wheat acreage planted and yields in the Corn Belt, Plains, and Pacific Northwest states in 1986-1987 and 1987-1988 (USDA, 1989).

Region	Acres planted		Yield	
	1986	1987	1986-1987	1987-1988
	— thousand acres —		— bu/acre —	
Corn Belt:				
Arkansas	930	1 120	41.0	53.0
Illinois	1 100	1 300	59.0	54.0
Indiana	750	840	58.0	50.0
Missouri	900	1 650	46.0	50.0
Ohio	850	1 000	58.0	50.0
Total acreage	4 530	5 910		
Weighted avg.†			52.4	51.4
Plains:				
Colorado	3 100	2 500	37.5	33.0
Kansas	10 700	10 200	37.0	34.0
Montana	2 300	2 450	36.0	19.0
Nebraska	2 200	2 300	44.0	36.0
Oklahoma	7 200	7 000	27.0	36.0
Texas	6 800	6 300	28.0	28.0
Total acreage	32 300	30 750		
Weighted avg.			33.3	32.1
Pacific Northwest				
Idaho	860	820	75.0	66.0
Oregon	780	700	66.0	71.0
Washington	1 900	1 850	57.0	62.0
Total acreage	3 540	3 370		
Weighted avg.			63.4	64.8

† Regional average is weighted by planted acres.

Table 4. Prices paid and prices received for winter wheat in the Corn Belt, Plains, and Pacific Northwest States in 1986-1987 and 1987-1988 (USDA, 1988).

Region	Prices paid for certified seed		Prices received for harvest	
	1986	1987	1986	1987
	$/bu			
Corn Belt:				
Arkansas	5.91	6.06	2.35	3.09
Illinois	7.36	7.55	2.27	2.50
Indiana	7.36	7.55	2.32	2.53
Missouri	5.81	5.83	2.24	2.45
Ohio	6.29	6.46	2.24	2.58
Weighted avg.†	6.55	6.60	2.28	2.61
Plains:				
Colorado	7.36	7.55	2.12	2.30
Kansas	7.46	7.65	2.14	2.38
Montana	5.91	6.06	2.32	2.57
Nebraska	7.46	7.65	2.32	2.30
Oklahoma	6.98	7.16	2.16	2.40
Texas	8.14	8.35	2.15	2.32
Weighted avg.	7.38	7.55	2.17	2.37
Pacific Northwest				
Idaho	6.69	6.86	2.40	2.63
Oregon	6.69	6.86	2.43	2.68
Washington	6.59	6.76	2.27	2.51
Weighted avg.	6.64	6.81	2.34	2.58

† Regional prices paid are acre-weighted averages based on acres planted in the current crop year. Regional prices received are acre-weighted averages based on acres planted in the previous crop year. Both prices paid and prices received are those observed by farmers at planting.

could expect for their crop. On the cost side, a seeding rate of about 1 bu/acre, and purchased seed and bin run seed of $7.38 and $2.17, respectively, translated into a per-acre seed cost difference of $5.21 ($7.38 − $2.17) for a $2.39/acre ($7.60 − $5.21) net gain (Tables 3 and 4). Bin run seed cost of $2.17 was conservative because it did not include any storage, cleaning, or treatment costs, which are discussed in more detail in the next subsection.

In the Pacific Northwest, given the $2.58/bu output price, the 6.15 bu/acre average yield difference in the Pacific Northwest translated to a $15.87/acre gain in revenue. The difference between the planting costs of purchased seed and bin run seed for the Pacific Northwest in 1987-1988 was $4.24/acre for an $11.63 ($15.87 − $4.24)/acre net gain.

Thus, given the average quality of the bin run seed used by farmers in the Plains in 1986-1987 and in the Pacific Northwest in 1987-1988, and assuming no decrease in price, it appeared that per-acre profits would have increased if all farmers had planted purchased seed. These results are especially important to the seed industry because it implies that farmers, in making use of bin seed, do not always make the best choice. Both the seed industry and farmers can gain by greater use of purchased seed providing grain prices do not decrease significantly.

The regional variations in the relative differences between grain and seed prices (and, thus, cost-effectiveness of purchased seed) can explain in part, the greater use of purchased seed in the Pacific Northwest and the Corn Belt (Tables 3 and 4). On average, farmers in those two areas paid lower prices for purchased seed and received higher prices for grain, which, together, decreased the cost difference between bin run and purchased seed. The higher the grain prices farmers expect, the greater the expected value of the yield gain offered by purchased seed. As a result, Pacific Northwest and Corn Belt farmers planted a greater portion of purchased seed than bin run.

Higher prices for the HRW wheat may explain the increased use of purchased seed between 1986-1987 and 1987-1988 for the Plains. Average prices increased from $2.17/bushel in September 1986 to $2.58/bushel by September 1987 and acres planted with purchased seed increased from 13% to 33% of the total wheat acres. Increased exports of HRW to the Soviet Union, China, and, potentially, Latin America, due to the Export Enhancement Program, could have contributed to this price increase. The previous two seasons saw 15-yr record lows in HRW wheat export activity (USDA-ERS, 1987).

Costs of Storing and Cleaning Seed

Another factor affecting seed selection, but not apparent in the price data, was regional differences in the costs of storing and cleaning seed. In the previous discussion on the profitability of seed source, we do not include storage and cleaning cost of bin run seed because we have no measure of these costs. Excluding these costs underestimates the profitability of purchased seed relative to bin run seed. However, there are storage and cleaning costs and they are likely to vary across regions. Farmers who produce wheat on a large scale, such as in the Plains, can spread costs of grain storage and cleaning facilities and seed germination tests across a greater quantity of seed, thus making bin run seed more competitive in those areas.

Information Diffusion

A third factor that affects a farmer's choice of seed was information diffusion. In the Pacific Northwest, state certifying agencies work hard at promoting the use of certified seed. In 1984, Washington State Extension agents examined 96 samples of winter wheat seed found in drill boxes, trucks, and bins. Twenty-five of the samples were certified seed and of good quality. The bin run seed, however, varied greatly in quality, and suffered from high levels of weed seed and seed from other small grain crops. In one sample, there were over 500 weed seeds in a pound of bin run seed. At a seeding rate of 60 lb/acre, this translates to 30 000 weed seeds planted per acre (Washington State Crop Improvement Association, 1986). Foreign seeds decrease yield and the quality of the harvest, and, in turn, decrease the return to the farmer. The Washington survey indicated, therefore, that the bin run seed was of considerably lower quality than certified seed. The BIN results in 1987-1988 in the Pacific Northwest support this finding. The Washington State Crop Improvement Association, uses these results to promote certified seed sales (Washington State Crop Improvement Association, 1986).

In the Corn Belt, an intensive communication system exists between the corn seed dealer and farmer. Corn hybrids are location specific, and, hence, vary considerably across areas as small as counties. Corn seed companies have set up a network of seed dealers in these locations to sell their seed and to act as an "extension agent" on behalf of the seed company. As a result, seed dealers and farmers have a close relationship. This relationship affords the seed dealer the opportunity to inform the farmer of the advantages of purchased seed while the farmers' familiarity with the seed dealer may encourage him to follow the dealer's advice.

IMPLICATIONS FOR SEED R&D

Results from this study suggest that the potential market for purchased seed depends on price trends and information diffusion. However, each region varies in its response to each of these factors. Farmers appear to be responsive to product price. Purchased seed acreage increased when product prices increased in the Plains. The high portions of purchased seed acreage in the Pacific Northwest and Corn Belt appear to result from both favorable prices and extension and seed dealer services.

Of the three regions, the Plains holds the biggest potential market growth. The Plains States not only have the lowest portion of acres planted with purchased seed, but they have the largest number of winter wheat acres (Tables 2 and 3). If product prices increase due to increased export or domestic demand, sales of purchased seed in the Plains could grow significantly. The Pacific Northwest and the Corn Belt already plant a large percentage of their acres with purchased seed and do not have as much room to expand as the Plains.

In light of tight federal and state budgets, it may be desirable to have more private sector seed development efforts. To assess this strategy, one needs to consider how the public can provide more incentive to the private sector and the benefits and costs of doing so. One apparent means would be to enforce the PVPA more strongly, since enforcement is currently seen as a weakness in the PVPA. Other options are to fund more public sector R&D that complements that of the private sector, or to increase R&D tax incentives. While looking at these incentives to R&D, one also needs to weigh the benefits and costs to the programs and compare these to what our public and private systems currently provide.

The provision of incentives for private R&D programs can encourage growth in seed technology. Greater private R&D should probably not be considered a replacement for public R&D programs, since the social returns to public R&D are quite high (Evenson et al., 1979; Ruttan, 1982). In fact, some basic and applied public R&D programs complement private R&D programs. Results of this study suggest that public efforts (e.g., extension) play a significant role in encouraging the use of purchased seed, which can increase farm incomes and incentives for private sector investment in new wheat varieties.

OTHER FACTORS AFFECTING WHEAT YIELDS

The estimated yield model also provides insight on the yield effects of other factors. Seeding rates were only significant in the Pacific Northwest and had the expected signs. The coefficients on seeding rates indicate that farmers did not overseed, as seeding rates in the Pacific Northwest averaged under 89 lb/acre in Idaho and Oregon and around 65 lb/acre in Washington.

A previous crop of either corn (CORN) (*Zea mays* L.) or legumes (LEG) increased yields significantly in all three regions, and a season of fallow (FAL) increased yields significantly in the Plains. There probably are two reasons for the greater wheat yields on land previously planted to corn. First, corn is generally grown on higher quality land. Second, corn usually has a significant amount of N applied that can carry over and boost wheat yields. Legumes fix N, thus helping to increase yields. A season of fallow helps the land to build up its moisture level, which is important in the Plains. The negative coefficient on FAL for the Pacific Northwest in the 1988 season was unexpected.

Nitrogen also increased yields, either through chemical application (LnN), or through manure application (MAN). Nitrogen applications were particularly significant in the Pacific Northwest and the Plains in both seasons, but not in the Corn Belt. Nitrogen carryover after corn was not included in LnN, which, if significant, would have decreased the significance of LnN.

Herbicide (HERB) was only significant in the yield model of 1986-1987 corn. A reason for the negative sign could be that farmers waited to apply herbicide until weeds became a problem. By that time, yields may have been already reduced relative to a "no-weed" situation. But herbicide, in such cases, kept yields from falling lower than if no herbicide was applied.

No-till practices (NOTIL) appear to have improved yields in the Pacific Northwest, but showed no effect—or a loss in yields—in the other regions. Although there have been a number of studies examining the effect of no-till on yields, results have not been consistent (Holloway and Hoag, 1988, unpublished data). The results obtained here suggest that no-till can make a difference in yields, but the direction of the impact will vary by field location.

INTERPRETIVE SUMMARY

This paper reviews the protection of intellectual property rights afforded seed firms through the PVPA. In particular, we assess how well privately developed seed can compete in a market against home-grown (bin run) seed. We focus on two questions. First, do yield response differences affect the choice of purchased seed and how might seed firms increase their return to research by exploiting this response difference? Second, is agriculture's present level of purchased seed use cost-effective and, if not, how might seed firms change their market efforts?

Regression analysis of winter wheat yields suggest that use of purchased seed could have increased average yields in the Pacific Northwest, Corn Belt, and Plains states for both the 1986-1987 and 1987-1988 growing seasons, although yield differences were not always statistically significant. Depending on the year analyzed, the Plains and the Pacific Northwest showed a statistically significant yield response to purchased seed. Interestingly, purchased seed was used on a lower portion of the areas in the Plains than in the Corn Belt and Pacific Northwest. Hence, yield advantages do not always play a major role in the farmer's choice of seed.

Other factors influencing the choice of seed include relative prices, advertising, seed dealer and extension services, and costs of seed storage, cleaning, and testing. Seed firms might increase sales by increased advertising, encouraging their retailers to work more closely with farmers, or by encouraging state and federal policy changes. These policies include increased extension services and promotion of purchased seed. Other policies that could increase the use of purchased seed are better PVPA enforcement, funding public R&D that complements private R&D, tax incentives, and promotion of commodity exports.

Because the coefficients on BIN estimate the average yield differences between seed sources, the size of the estimated coefficients suggest that many farmers are not making a cost-effective selection of seed. Therefore, seed firms could expand markets in areas where the portion of purchased seed use is low, particularly if expected prices for grain increase as well. The Plains offer the most significant region for growth in seed sales because this area has approximately twice the winter wheat acreage of the other two regions combined, and the portion of acres planted with purchased seed is significantly lower than in the Corn Belt or the Pacific Northwest.

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