PROPERTY RIGHT PROTECTION OF REPRODUCIBLE GENETIC MATERIAL

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The duplicating of purchased materials has raised property right protection issues with copyrighted publications (with the advent of photo-copying machines); audio and video recordings; and computer software. In agriculture, genetic materials of plants and animals are duplicated through reproduction, especially with pure-line variety crops such as soybeans and wheat. The harvest of a pure-line variety is genetically similar to the parent plant. Thus, a farmer's harvest is a copy, but not identical as some loss in genetic purity occurs, to the original seed.

Preservation of property rights is important from an efficiency standpoint. A socially suboptimal level of research and development (R&D) results when property rights are not protected (Arrow; Loury; Novos and Waldman).[1] Property rights allow firms to obtain short-run economic rents that motivate successful R&D.

Property right protection of plant genetic material is both a national and an international issue. The International Union for Protection of New Plant Varieties (UPOV) and the 1970 Plant Variety Protection Act (PVPA) (following standards of UPOV) provide varietal property rights to the parent firm by prohibiting other firms from selling the seed of the protected variety.[2] The debate on the protection of the PVPA and UPOV centers around farmers' rights to use their harvests as seed.

Some argue that there is no need to eliminate farmer-produced seed because seed firms indirectly capture or appropriate all economic rents through the prices charged for seed of parent varieties. That is, when a variety's harvest can generate economic rents as farmer-produced seed, firms recognize and capture these rents indirectly through charging a high enough price on the parent seed.[3]

Others argue for reducing/eliminating farmers' rights to use their harvest as seed. This group correlates losses in varietal development incentives (economic rents) with use of farmer-produced seed. However, if indirect appropriation exists, then use of farmer-produced seed cannot be correlated with losses in development incentives. As of yet, there has been no empirical test for indirect appropriation perhaps because prices of farmer-produced seed are not observed.

The objective of this study is to provide a workable framework for testing the hypothesis of no indirect appropriation. The framework is applied to the soybean seed industry using cross-sectional field-level data on yields, prices, and

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[1]There are other potential reasons why the private sector's research and development expenditures may not be optimal (e.g., duplicate research activities, monopolies, excess resources spent in copying the new innovation, early release of technology to capture rent, etc. (Dasgupta and Stiglitz; Loury; Swan; Besen and Kirby; Anderson and Hill)) that are not examined here.

[2]The United States is a signatory country of UPOV, and therefore must develop property rights following the guidelines of UPOV.

[3]The indirect appropriation of the value of genetic material is analogous to the indirect appropriation of rents for copyright protected material (Besen and Kirby; Liebowitz; Johnson) and to Alcoa's (possible) indirect appropriation of the value of the aluminum scrap (Swan).

levels of input use. If the hypothesis of no indirect appropriation is rejected, then arguments for increasing the PVPA (and UPOV) limits on farmer-produced seed may not be justified.

Background

Before the PVPA, there was little restriction on the reproduction of seed from seed crops. New pure-line varieties were developed through public plant breeding programs. These varieties were public goods with farmers or seed firms free to reproduce them or use them in a breeding program.

Since passage of the PVPA, the public sector has decreased real R&D expenditures in this area; whereas, the private sector has increased its role (Frisvold, Yee, and Day). The seed industry is now a major industry. In 1988, the value of seed planted worldwide exceeded $51 billion; expectations are that this value will increase in the future (Kidd).

The significant growth in private sector seed development since passage of the PVPA indirectly indicates success of the Act (Butler and Marion; Perrin, Kunnings, and Ihnen). Until recently, the farmer exemption clause of the PVPA preserved the farmer's right to use his/her harvest as seed as long as revenue from seed sales did not exceed 50 percent of total gross income. A 1995 change in the PVPA allows farmers to use but not sell farmer-produced seed of varieties granted protection under the 1995 change.

Use of farmer-produced seed is significant. Data used in this analysis indicate that nearly 30 percent of the U.S. soybean acres in 1988 and 1989 were planted with farmer-produced seed. Farmer-produced winter wheat seed was used on over 30 percent of the Pacific Northwest and Corn Belt acres and over 70 percent of the Plains states' acres in 1986 and 1987 (Knudson and Hansen).

The Yield-Price Relationship

Across all major commodities, farmers have many varieties from which to select. Some varieties are recent releases while others have been marketed for several years. Seed companies recognize that farmers, as profit maximizers, pay more for seed of higher-yielding varieties. Higher prices that higher-yielding varieties provide the economic incentive for plant varietal research.

If varieties are competitively priced, then farmers' expected per-acre profits, θ, should not vary across varieties. With direct appropriation, each varietal price, P(V), is set to satisfy:

$$Y(V) * P_O - P(V) * S(V) - KX = \theta, \qquad (1)$$

where P_O is the current value expected commodity price; Y is the expected per-acre yield; P is the seed price; S is the per-acre seeding rate; and K and X are unit price and per-acre use rate vectors, respectively, of other inputs. Y, P, and S are all functions of seed variety, V.[4]

Differentiating equation (1) with respect to V generates:

$$\frac{dY}{dV}P_O = \frac{dP}{dV}S(V) + \frac{dS}{dV}P(V), \qquad (2)$$

where the marginal revenue product associated with the difference in varietal yields equals the difference in varietal costs.

Profit maximization with farmer-produced or bin-run seed expands from equation (1) by including the competitive value of the seed of a variety V, W(V), and its expected yield so that:

$$Y^{BR}(V)P_o - W(V)S(V) - KX = \theta, \qquad (3)$$

where $Y^{BR}(V)$ is the expected yield of first-generation bin-run seed of variety V.[5] Other variables are as defined in equation (1).[6]

[4]The linear specification of equation (1) does not provide for the effect that a variety may have on use of other inputs. While the specified model is supported by the available data, future research should continue to test more complex yield specifications.

[5]Impurities in bin-run seed greatly reduce the quality of its harvest as seed. Thus, the harvest of bin-run seed is less competitive as seed. Note that the model can be extended to any number of generations.

[6]One exception is that KX includes cleaning, treating, and storing costs (e.g., the costs of preparing for harvest for next season's seed). These costs are independent of variety, and thus need not be included in W(V) (see Appendix).

Farmers expect Y(V) to exceed $Y^{BR}(V)$ for two reasons. First, **real** quality differences may exist if large-scale production allows firms to maintain genetic purity, minimize contamination by foreign seed, and ensure high germination. Second, **perceived** quality differences may exist if farmers feel more confident about the quality of seed from seed firms.

Unless W(V) exceeds P_O, it is more profitable to sell the harvest in the commodity market. For varieties where $W(V)>P_O$, seed firms indirectly appropriate economic rents by charging the competitive price, P(V), so that:

$$Y(V) * W(V) - P(V) * S(V) - KX = \theta. \quad (4)$$

Testing the Hypothesis of No Indirect Appropriation

To date, no data on seed price, yield, seeding rate, bin-run yield, and bin-run price are available by variety to allow direct testing of equations (1), (3), and (4). Data are not likely to be available as W(V) is implicit to the farmer who produces his/her own seed. This lack of data eliminates one approach for testing the hypothesis of no indirect appropriation.

However, equations (1), (3), and (4) can be used to construct a yield model to test the hypothesis of no indirect appropriation with farm production data. That is, the relationships associated with direct appropriation are derived based on those of equation (1) so that:

$$Y(V) = \frac{S(V) * P(V)}{P_O} + \frac{(KX + \theta)}{P_O}. \quad (5)$$

By simplifying equation (5), yield is written as a function of $SEED_D$:

$$Y = \beta_0 + \beta_1 SEED_D + \mu_D, \quad (6)$$

where β_0 is an intercept, $SEED_D$ equals $S*P/P_O$, β_1 is a coefficient expected to equal 1 across varieties where direct appropriation holds, and μ_D is an error term. Y, S, and P are the observed yield, seeding rate, and seed price. An important simplification is that the actual variety need not be known.

Similarly, for indirect appropriation, equation (3) is solved for W(V), substituted into equation (4), and simplified so that:

$$Y = \beta_2 + \beta_3 SEED_I + \mu_I, \quad (7)$$

where β_2 is an intercept, $SEED_I$ equals $[P*S^2/P_0 + (KX + \theta)*S/P_0 + ¼(\delta - (KX^{BR} + \theta)/P_0)^2]^{0.5}$, β_3 is a coefficient expected to equal 1 when indirect appropriation applies, δ is the yield decline of first generation bin-run seed, and μ_I is an error term (see the Appendix).

To test the hypothesis of no indirect appropriation, equations (6) and (7) are combined to produce the generalized yield function:

$$\begin{aligned} Y = {} & \beta_0 + \beta_1 SEED_D * (1 - LIM) \\ & + (1 - LIM)_{\mu_D} + \beta_2 LIM \\ & + \beta_3 SEED_I * LIM + LIM * \mu_I, \end{aligned} \quad (8)$$

where LIM is a qualitative variable that equals 1 for observations on varieties where $W(V)>P_O$ and 0 otherwise. LIM is not observed, but when there is indirect appropriation, can be estimated because there will be a Γ such that $P*S>\Gamma$ for observations where LIM=1. The value Γ (and thus observations where LIM=1) is estimated by maximizing the likelihood function of equation (8) across incremental values of Γ (Judge et al. (1985) and Goldfeld and Quandt).

Thus, the hypothesis of no indirect appropriation is tested by constraining LIM=0 for all observations. That is, the maximum likelihood estimate of equation (8) is tested against the model where LIM is constrained to equal 0 for all observations (no indirect appropriation).

An Application to the Soybean Seed Industry

This framework is used to test for indirect appropriation by soybean firms. The soybean seed industry is significant – nearly $0.6 billion is spent annually for soybean seed in the United States alone (United States Department of Agriculture). The variables of equations (7) and (8) along with other explanatory variables are included in the analysis. Variables are listed in Table 1 along with definitions and sources. However, more details on variables and data sources are provided below.

The $SEED_i$ variables (i=D,I) are derived from the reported seed price, P, and seeding rate, S, of the Cropping Practices Survey (CPS). The May futures price for July soybeans is used as the expected output price, P_O.[7] The relationships of equations (7) and (8) reflect profit maximization behavior; they are expected to hold across all areas where soybeans are produced. The mean and standard deviation of variables in equations (7) and (8) are given in Table 2A.

Additional CPS variables as well as variables from three other sources are included in this analysis. The 1988 and 1989 Cropping Practices Surveys (United States Department of Agriculture) identify other farm production practices. The CPS is a random sample of acres in soybean production in major producing states. For this analysis, the 14-state sample is split into Northern (Illinois, Indiana, Iowa, Minnesota, Nebraska, and Ohio) and Southern (Arkansas, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, and Tennessee) regions to allow for differences in marginal impacts on yield.[8] There are 1,669 and 1,244 observations in the Northern and Southern regions, respectively. The CPS identifies the county where an observation is located.

Data on soil and land characteristics are from the National Resource Inventory (NRI) and the associated Soils-5 profile. County-level soil productivity factors are derived for each CPS observation.

Weather data are provided by the National Oceanic and Atmospheric Administration (NOAA) (United States Department of Commerce). Monthly precipitation and temperature data are provided by multi-county weather districts. The Northern observations lie within 53 and the Southern within 43 weather districts. Climate variables are included to serve as proxies for farm production adaptations to expected growing season weather (see Hansen for more on agricultural production estimation across differing climate regimes). In this analysis, climate is measured with 30-year averages of weather.

Given that yield is a function of daylight and daylight is a function of latitude, latitude can serve as a reduced form measure of daylight. Since the CPS does not include observations' latitudes, the mean latitude of the relevant county is used as a proxy (United States Forest Service).

Weather, soil, and other factors affecting yields are included in equation (8) by replacing β_0, the intercept, with:

$$\begin{aligned}
&\alpha_1 + \alpha_2 HMGROWN_j \\
&\quad + \alpha_3 IRRIG_j + \alpha_4 CORN_j \\
&\quad + \alpha_5 SOYBEANS_j + \alpha_6 ERODE_j \\
&\quad + \alpha_7 LOWTIL_j + \alpha_8 NOTILL_j \\
&\quad + \alpha_9 LNDCLSS_j + \alpha_{10} PLDATE_j \\
&\quad + \alpha_{11} SLPLGTH_j + \alpha_{12} TFACT_j \qquad (9) \\
&\quad + \alpha_{13} WTRAVG_j + \alpha_{14} PREJUL_j \\
&\quad + \alpha_{15} PREJULSQ_j + \alpha_{16} TMPJUL_j \\
&\quad + \alpha_{17} TMPAUG_j + \alpha_{18} PAVGJUL_j \\
&\quad + \alpha_{19} PAVGJULSQ_j + \alpha_{20} TAVGJUL_j \\
&\quad + \alpha_{21} LATIT_j + \alpha_{22} LATITSQ_j,
\end{aligned}$$

where the α_1 is the (new) intercept, and the remaining α's are the coefficients on the associated variables. Since observations on farmer-produced seed have no seed price or seeding rate variables, a zero-one dummy variable, HMGROWN, is used to approximate the yield affect of the variety of the bin-run seed. The HMGROWN coefficient represents the average value of PS/P_O across the bin-run observations. This dummy specification leaves bin-run observations with an error correlated with the actual value of PS/P_O (when HMGROWN=1), but independent of other model variables. Thus, estimates of other variables and the hypothesis tests are not affected.

Other zero-one dummy variables are: IRRIG=1 when irrigation was used; CORN=1 when corn was the previous a year's crop;

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[7]Derivation of $KX+\theta$ is provided in the Appendix.

[8]Northern and southern models were estimated separately and little or no change in any of the estimated coefficients were found – including the coefficients on the seed variables. Results are available from the authors.

Table 1. Variable Definitions and Sources

Variable	Definition	Source[a]
YIELD	soybean yield (bu per acre)	CPS
$SEED_D$	constructed yield-price factor, direct appropriation	CPS
$SEED_I$	constructed yield-price factor, indirect appropriation	CPS
HMGROWN	= 1 if seed used was home grown	CPS
IRRIG	= 1 if the field was irrigated	CPS
CORN	= 1 if corn was grown on field in previous year	CPS
SOYBEANS	= 1 if soybeans were grown on field in previous year	CPS
LOWTIL	= 1 if crop residue covers 30 percent or more of soil surface	CPS
NOTILL	= 1 if there were no tillage since harvest or the previous crop	CPS
PLDATE	planting date (numeric day of the year)	CPS
ERODE	= 1 if > 50 percent of county farmland is classified as having a soil erosion problem	NRI
LNDCLSS	= 1 if > 50 percent of county farmland is classified in class 1 or 2 (the highest capability classes)	NRI
SLPLGTH	average slope length (in feet)	NRI
TFACT	average soil loss tolerance used in the USLE (tons/acre)	NRI
WTRAVG	the average water-holding capacity of local soils (inches of water in top foot of soil)	NRI
PREJUL	actual July precipitation (inches)	NOAA
PREJULSQ	PREJUL squared	NOAA
TMPJUL	average of actual July daily temperatures[b] (°F)	NOAA
TMPAUG	average of actual August daily temperatures (°F)	NOAA
PAVGJUL	30-year average of July precipitation (inches)	NOAA
PAVGJULSQ	PAVGJUL squared	NOAA
TAVGJUL	30-year average of July temperature (°F)	NOAA
LATIT	estimated latitude of field (°north)	USFS
LATITSQ	LATIT squared	USFS
Const-shft	shift in the intercept for the south	

[a]CPS = Cropping Practices Survey (United States Department of Agriculture); NRI=National Resources Inventory (United States Department of Agriculture); NOAA = National Oceanic and Atmospheric Administration; USFS = United States Forest Service.

[b]Reported daily temperature are the average of the high and low temperature of the day.

Table 2A. Appropriation Test Variables' Means and Standard Deviations Not Region Specified

Variable	Mean	Standard Deviation
YIELD	24.3	12.6
$SEED_D$[a]	1.50	1.17
$SEED_D$[b]	2.11	0.687
$SEED_I$[b]	47.9	4.83
LIM	0.0106	0.103
No. observations	2,913	

[a]Mean of $SEED_D$ in the direct appropriation model derived from observations on purchased seed.

[b]The $SEED_D$ and $SEED_I$ of the indirect appropriation model. Means and standard deviations are derived from observations where the $SEED_I \neq 0$.

SOYBEANS=1 when soybeans was the previous year's crop; ERODE=1 when over half of the farmland falls into an NRI subclass indicating that erosion is a problem; LOWTIL=1 when at least a 30 percent residue cover remained after tillage (see Bull for the methodology applied to residue estimation); NOTILL=1 when all crop residue remained on the field surface after planting; and LNDCLSS=1 when over half of the farmland is of NRI class I or II. Continuous variables on production and land characteristics are: PLDATE, the planting date (numeric day of year); SLPLGTH, the slope-length (in feet); TFACT, the soil's erosion tolerance (derived for use in the Universal Soil Loss Equation); and WTRAVG, the soil's water-holding capacity. The weather variables are: actual July precipitation, PREJUL; PREJUL squared, PREJULSQ; actual July temperature, TMPJUL; and actual August temperature, TMPAUG. The climate variables are: the 30-year average of July precipitation as one characterization of climate, PAVGJUL; PAVGJUL squared, PAVGJULSQ; and and the 30-year average of July temperatures, TAVGJUL.[9] Because the amount of sunlight that plants receive varies by latitude, the approximate latitude of the field, LATIT, and LATIT squared, LATITSQ, are included as independent variables. Variable definitions can also be found in Table 1.

The linear relationship in equation (9), with second-degree and interactive terms, is the most common specification of yield functions when data are disaggregated (Houck and Gallagher; Knudson and Hansen; Menz and Pardey; Butell and Naive; Lin and Davenport; Reed and Riggins; Schroder, Headley, and Finley; Sundquist, Menz, and Neumeyer). However, to allow for differences in farming technologies of the north and south, the variables of equation (9) are specified by region. Their means and standard deviations can be found in Table 2B.

The dependent variable, YIELD, in approximately 3 percent of the observations, was truncated at zero as weather (hail, drought, etc.) made harvesting uneconomical. To avoid the truncation bias that Ordinary Least Squares could generate, a tobit model was used (McDonald and Moffitt; Judge et al. (1980)). While other estimation approaches can also generate unbiased results (Heckman 1976, 1979), the tobit approach conserves degrees of freedom and is relevant in a case like this where the independent variables have a continuous effect on yield.

Results

The tobit estimation results of the direct appropriation model (e.g., LIM=0) and the two–price strategy model are listed in Table 1. estimates have been adjusted for heteroscedasticity following Maddala.[10]

[9]A month's temperature is the average of the day temperatures. Day temperatures are the average of a day's high and low temperature readings specified by region. Their means and standard deviations can be found in Table 2B.

[10]The variables of interest here were not a source of heteroscedasticity. With heteroscedasticity, tobit model estimates may not be efficient or consistent (Maddala and Nelson). Heteroscedasticity was tested for and adjusted by estimating $\delta_k^2 = (\tau + \theta Z_i)^2$ where Z is a vector of independent variables, θ is a vector of coefficients, τ is the homoscedastic component of the variance, and the k subscript denotes observation k (Rutemiller and Bowers). July temperature, average July temperature squared, and the inverse of the selection probability are significant. The variables adjust for a 3 percent variation in variance. Estimates were made using the Gauss statistical package GRBL. (GRBL is available from Daniel Hellerstein, United States Department of Agriculture/Economic Research Service, 1301 New York Avenue, NW, Washington, DC 20005-4788.)

Table 2B. Appropriation Test Variables' Means and Standard Deviations Not Region Specified

	North Variables		South Variables	
Variable	Mean	Standard Deviation	Mean	Standard Deviation
HMGROWN	0.292	0.455	0.317	0.465
IRRIG	0.0461	0.210	0.125	0.330
CORN	0.640	0.480	0.194	0.395
SOYBEANS	0.217	0.412	0.440	0.497
ERODE	0.394	0.489	0.259	0.438
LOWTIL	0.162	0.368	0.0105	0.102
NOTILL	0.0389	0.194	0.0579	0.234
LNDCLSS	0.763	0.425	0.547	0.498
PLDATE	139.00	14.9	160.00	20.5
SLPLGTH	210.00	120.00	197.00	83.8
TFACT	4.53	0.491	4.49	0.441
WTRAVG	0.211	0.0143	0.175	0.0474
PREJUL	2.33	1.56	4.39	3.45
PREJULSQ	7.87	10.3	31.2	35.6
TMPJUL	76.2	1.43	79.4	1.34
TMPAUG	74.6	3.01	79.8	1.96
PAVGJUL	3.89	0.313	4.61	0.875
PAVGJULSQ	15.2	2.38	22.0	8.83
TAVGJUL	75.1	2.21	80.1	1.55
LATIT	41.0	9.14	34.6	1.92
LATITSQ	1,690	168	1,200	131
No. observations	1,669		1,244	

The reported Pseudo-R^2 for the model of direct appropriation is 0.297 – about what one expects from cross-sectional data (Table 3).[11] The Pseudo-R^2 of the model of indirect appropriation is 0.325 which suggests that it better explains yield variation. However, a likelihood ratio test is necessary to determine the statistical significance of this difference.

The signs and magnitudes of coefficients on the seed variables are as expected (Table 3). Recall that from equations (6) and (7), $\partial Y/\partial SEED_i$ (i=D,I) should equal 1. From the tobit model, a change in $SEED_i$ (i=D,I) is given by:

$$\frac{\partial Y}{\partial SEED_i} = \beta_j * F(Z), \qquad \textbf{(10)}$$

where F(Z) is the cumulative normal probability density function, Z equals Xα normalized by the variance, X is a the vector of the independent variables, and α represents the vector of estimated coefficients. If $\partial Y/\partial SEED_i$ equals 1, β_j must equal 1/F(Z). In both models, at the mean value of Z, 1/F(Z) equals 1.02. Since 1.02 is within one standard error of each of the estimated B_j's, results are as expected.

The signs and magnitudes of the other estimated coefficients of equation (9) are consistent with conventional wisdom with the exception of the sign on the coefficient LNDCLSS in the South (Table 3). While the source of this discrepancy is not clear, LNDCLSS is not correlated with $SEED_D$ or $SEED_I$ and thus does not affect coefficient estimates or hypotheses tests related to seed choice. The coefficients (α_i's) and F(Z) in Table 1 allow one to estimate yield changes around mean values of Z for other independent variables, $\partial Y/\partial \alpha_i = \alpha_i F(Z)$.

Additional variables to those specified in equation (9) were tested but none had t-statistics

[11] Veall and Zimmerman suggested the Pseudo-R^2 measure because it was found to be the closest to the OLS-R^2 of the underlying population in Monte Carlo experiments. Compatibility with the OLS-R^2 is given priority because the R^2 is primarily used to compare models within and across studies.

Table 3. Tobit Coefficients of Direct and Indirect Appropriation Models

	Direct Appropriation		Indirect Appropriation	
Variable[a]	Coefficient	Standard Error	Coefficient	Standard Error
$SEED_D$	0.734**[b]	0.376	1.12*	0.413
$SEED_I$			1.20	0.750
LIM		−60.7	38.4	
$HMGROWN_N$	0.806	1.06	1.63	1.12
$IRRIG_N$	8.25**	1.49	8.12**	1.49
$CORN_N$	3.53**	0.854	3.57**	0.855
$SOYBEANS_N$	−0.104	0.963	−0.0983	0.964
$ERODE_N$	−2.73**	0.649	−2.77**	0.648
$LOWTIL_N$	−2.14**	0.744	−2.14	0.743
$NOTILL_N$	−1.16	1.43	−1.19	1.43
$LNDCLSS_N$	1.07	0.775	1.07	0.774
$PLDATE_N$	−0.105**	0.213	−0.104**	0.0213
$SLPLGTH_N$	−0.00354	0.00270	−0.00353	0.00270
$TFACT_N$	4.67**	0.667	4.61**	0.667
$WTRAVG_N$	106.00**	24.3	106.00**	24.3
$PREJUL_N$	2.48**	0.971	2.48**	0.971
$PREJULSQ_N$	−0.466**	0.128	−0.464**	0.128
$TMPJUL_N$	−1.80**	0.441	−1.83**	0.441
$TMPAUG_N$	−1.54	0.205	−1.53**	0.206
$PAVGJUL_N$	68.7	22.9	68.5**	22.9
$PAVGJULSQ_N$	−8.42	2.98	−8.40**	2.98
$TAVGJUL_n$	−1.72**	0.403	1.75**	0.403
$LATIT_N$	−5.29	4.53	−5.71	4.54
$LATITSQ_N$	0.0555	0.0540	0.0609	0.0541
$HMGROWN_S$	1.64*	0.987	2.24**	1.02
$IRRIG_S$	5.33**	1.06	5.31**	1.05
$CORN_S$	0.420	1.05	0.339	1.05
$SOYBEANS_S$	−1.29*	0.963	−1.31*	0.784
$ERODE_S$	−1.84*	1.04	−1.97*	1.04
$LOWTIL_S$	−3.11**	1.50	−3.23**	1.49
$NOTILL_S$	−2.77**	1.19	−2.98**	1.20
$LNDCLSS_S$	−1.81**	0.874	−1.85**	0.875
$PLDATE_S$	−0.158**	0.0172	−0.156**	0.0172
$SLPLGTH_S$	0.00398	0.00432	0.00416	0.00431
$TFACT_S$	0.106	1.01	0.0216	1.01
$WTRAVG_S$	17.7	12.3	16.5	12.3
$PREJUL_S$	1.89**	0.610	1.81**	0.610
$PREJULSQ_S$	−0.156**	0.0486	−0.152**	0.0485
$TMPJUL_S$	−0.807	0.826	−0.783	0.825
$TMPAUG_S$	1.14**	0.556	1.04*	0.557
$PAVGJUL_S$	13.7**	5.82	14.3**	5.83
$PAVGJULSQ_S$	−1.27**	0.549	−1.33**	0.550
$TAVGJUL_S$	−0.738	0.908	−0.684	0.909
$LATIT_S$	−23.1**	7.30	−23.0**	7.31
$LATITSQ_S$	0.351**	0.108	0.349**	0.108
Constant	101.00	118.00	108.00	118.00
Const-shft	313.00*	183.00	304.00*	184.00
R^2 (MZ)[c]	0.297		0.325	
F(Z)[d]	0.983		0.980	
Variance	11.225		11.222	

[a]The N and S subscripts designate variables of the north and south, respectively.

[b]Single and double asterisks indicate significance at the 90 and 95 percentiles, respectively.

[c]This Pseudo-R^2 has been suggested by Veall and Zimmerman (1994).

[d]F(Z) at mean Z. Estimation of marginal effects follow from equation (10).

greater than 1.0 in either region (a conservative cut-off), and hence were subsequently dropped. Variables tested and dropped include: the nitrogen application rate and rate squared; a Soil Conservation Service classification of the land as highly erodible; soil permeability; temperature and precipitation interaction terms; precipitation and temperature variables of other months; and second-degree values of the weather variables.

Hypothesis Test: Applying the Likelihood Ratio Test

As discussed earlier, the likelihood ratio test can be used to test the hypothesis of no indirect appropriation. Before estimating equation (8), $\beta_1 SEED_D*(1\text{-}LIM)$ is expanded to $\beta_1 SEED_D - \beta_1^* SEED_D*LIM$ generating a model of indirect appropriation that nests direct appropriation:

$$Y(V) = \beta_0 + \beta_1 SEED_D - \beta_1^* SEED_D * LIM + \beta_2 SEED_I * LIM + \beta_3 LIM + \mu. \quad (11)$$

Equation (11) is identical to equation (8) when $\beta_1^*=\beta_1$. The constraint $\beta_1^*=\beta_1$ was applied to equation (11); the likelihood function decreased by less than 0.06 which is not significant at any reasonable level of $\chi^2_{1,\alpha}$. Furthermore, the constraint caused little, if any, change in the model's coefficients.

The hypothesis of no indirect appropriation is tested by restricting $\beta_1^*=\beta_2=\beta_3=0$. This constraint reduces the likelihood function by 3.83 which is significant for $\chi^2_{3,90}$. Thus, the hypothesis of no indirect appropriation is rejected at the 90 percent confidence level in favor of the alternative hypothesis that some varietal prices reflect indirect appropriation.

Implications of Indirect Appropriation

These findings support the hypothesis that seed firms are indirectly appropriating economic rents associated with use of farmer-produced seed. This means that the level of bin-run seed use cannot be made analogous to the seed industry's loss in property rights, at least in soybean production. Thus, farmer-produced or bin-run seed can exist without decreasing incentives for varietal development. Results do not support arguments for the 1995 amendment or any additional reduction in farmers' rights to use their harvest as seed.

If indirect appropriation exists in the sale of soybean seed, it is possible that it can also exist in other pure-line variety seed markets (e.g., wheat). Obviously, the above framework can be applied to test this proposition.

A final note: Model results suggest that approximately 22 percent of all soybean seed will be bin-run while the actual figure is closer to 30 percent. Thus, farmers do not over-produce bin-run seed. The remaining bin-run seed may be produced from varieties where $W(V)=P_O$, and if some farmers are poor managers, from varieties where $W(V)<P_O$.

Summary and Conclusions

The reproductive capabilities of plants and animals complicate property right protection of genetic materials because the purchaser can reproduce the new genetic line without direct compensation to the developer. The Plant Variety Protection Act (PVPA) explicitly allows farmers to use their harvest as seed without direct compensation to variety developers.

The use of farmer-produced seed has led some to argue that incentives for plant varietal development are reduced because property rights are lost when farmer-produced seed is used. However, others argue that seed producers price the seed of each variety to reflect farmers' highest-valued use of the harvest, and therefore seed firms indirectly appropriate the value of varieties' harvests when used as seed.

The objective of this analysis is to develop a framework for testing the hypothesis of no indirect appropriation and thus provide empirical foundation for this debate. The framework is applied to the soybean industry where the hypothesis of no indirect appropriation is rejected at the 90 percent confidence level. Thus, firms appear to capture the economic rents associated with use of farmer-produced or bin-run seed. These results show that no additional property right protection is needed, at least in the soybean industry, where indirect appropriation is important as approximately 30 percent of the soybean acres are seeded with bin-run seed.

This empirical evidence of indirect appropriation is critical to the escalating international debate on the level of need for intellectual plant protection. More studies are needed to see how other industries are capturing rents both domestically and internationally. This study is significant as it is the first to offer direct empirical tests to what has been a philosophical debate.

With respect to the 1995 amendment to the farmer exemption clause of the PVPA, bin-run seed can still be used but not marketed. Thus, bin-run seed will continue to be used. If these results hold for other pure-line variety seed grain crops, it is difficult to justify the 1995 amendment or any further restrictions on the useof bin-run seed.

When indirect appropriation exists, additional research areas related to efficiency become relevant. Probably most significant is that, with indirect appropriation, incentives for varietal development may or may not equal but could exceed or fall short of incentives that would exist without bin-run seed use (Liebowitz). Answering this question requires an estimate of what seed demands would be without any farmer-produced seed. Other efficiency questions related to the welfare impact of restricting copying and the social welfare loss due to underutilization (Hirshleifer and Riley; Novos and Waldman). There are two dimensions to underutilization: (1) more resources are used to produce the copies than to produce originals; and (2) consumers (in this case, farmers) are willing to pay the marginal cost for the good (seed) but do not obtain the good as price exceeds marginal cost.

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Appendix

Solving equation (3) for W(V), the value of a variety's harvest as bin-run seed, generates:

$$W(V) = \frac{Y^{BR}(V)*P_o - KX^{BR} - \theta}{S(V)}, \qquad \textbf{(A1)}$$

where expected yield, Y(V); seed price, P(V); and seeding rate, S(V), are specified by variety, V. Expected profit, Θ; other input costs, KX; and commodity price, P_O are independent of variety. The BR superscripts specify variables for bin-run seed. Substituting equation (A1) into equation (4):

$$Y(V) * \left(\frac{Y^{BR}(V)*P_o - KX^{BR} - \theta}{S(V)} \right) = P(V)*S(V) + KX + \theta. \quad \textbf{(A2)}$$

Define δ as the yield loss of bin-run seed due to loss in seed quality/genetic purity so that $Y(V)=Y^{BR}(V) + \delta$. Equation (A2) becomes:

$$Y(V) * \left(\frac{(Y(V) - \delta) * P_o - KX^{BR} - \theta}{S(V)} \right) = P(V)*S(V) + KX + \theta. \quad \textbf{(A3)}$$

Collecting the Y(V) terms produces:

$$Y^2(V) + Y(V)* \left(\frac{-\delta*P_o - KX^{BR} - \theta}{P_o} \right) = \left(\frac{P(V)*S(V) + KX + \theta}{P_o} \right) * S(V), \quad \textbf{(A4)}$$

Solve for Y(V) by adding:

$$\frac{1}{4}\left(\frac{-\delta * P_o - KX^{BR} - \theta}{P_o} \right)^2, \quad \textbf{(A5)}$$

to both sides of equation (A4) and taking the square root of both sides to generate:

$$Y(V) = \sqrt{ \left(\frac{P(V)S(V) + KX + \theta}{P_o} \right) S(V) + \frac{1}{4}\left(\frac{-\delta P_o - KX^{BR} - \theta}{P_o} \right)^2 } + \frac{1}{2}\left(\frac{\delta P_o + KX^{BR} + \theta}{P_o} \right). \quad \textbf{(A6)}$$

The first right-hand-side term indicates how seed characteristics of varieties priced for indirect appropriation should be specified in a yield function. Thus, $SEED_I$ is set equal to this term.

To generate $SEED_I$, the variables P(V), S(V), and P_O must be observed as in generating $SEED_D$. However, farmers' expectation of $KX + \theta$ must also be known. From equation (1), we know farmers expect $Y(V)P_O - P(V)S(V)$ (total revenue minus seeding costs) to equal $KX + \theta$ (other costs plus profits). Thus, an estimate of farmers' expectation of $KX + \theta$ can be derived using futures (harvest season) prices for the commodity and an average of yield (Y_A), seed price (P_A), and seeding rates (S_A).

Estimates of Y_A, P_A, and S_A for the analysis here are listed in Table A. The May futures price of July soybeans is used as an indicator of the expected output price of soybeans, P_O.

The yield loss of bin-run seed (δ) is assumed to equal 2 bu/acre based on opinions of those in the industry and the limited empirical evidence that is available.[12]

Table A. Values of Y_A, P_A, and S_A

Variable	North	South
Y_A	27.3	20.2
P_A	16.5	15.0
S_A	1.03	0.898

Y_A equals average yield.

P_A equals average price farmers paid for new seed.

S_A equals seeding rate.

[12]Research shows that bin-run seed yields approximately 1.9 bu/acre less than the parent seed (e.g., δ=1.9) (Kip Pendleton, Northrup King Company, personal communication). Knudson and Hansen found yield differences of 1.2 to 6.2 bu per acre between bin-run and purchased seed for winter wheat.