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THE EFFECTS OF THE U.S. PLANT VARIETY PROTECTION ACT ON WHEAT GENETIC IMPROVEMENT

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ABSTRACT

The U.S. Plant Variety Protection Act (PVPA) of 1970 was meant to strengthen intellectual property protection for plant breeders. A model of investment under partial excludability is developed, leading to the hypotheses that any increase in excludability or appropriability of the returns to invention, attributable to the PVPA, would lead to increases in investment or efficiency gains in varietal R&D, improved varietal quality, and enhanced royalties. These hypotheses are tested in an economic analysis of the effects of the PVPA on wheat genetic improvement. The PVPA appears to have contributed to increases in public expenditures on wheat variety improvement, but private-sector investment in wheat breeding does not appear to have increased. Moreover, econometric analyses indicate that the PVPA has not caused any increase in experimental or commercial wheat yields. However, the share of U.S. wheat acreage sown to private varieties has increased–from 3 percent in 1970 to 30 percent in the 1990s. These findings indicate that the PVPA has served primarily as a marketing tool with little impact on excludability or appropriability.

Key Words**:** Intellectual property rights; wheat; genetic improvement

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1. INTRODUCTION

> Even in the case of really valuable inventions, useful to the whole community, how rarely do inventors permanently benefit by them. The speculator, the dealer, is constantly on the watch, to appropriate them, and realizes a large fortune, while the inventor is usually left to starve (Mill, p. 386).

The U.S. Plant Variety Protection Act (PVPA) of 1970 was intended to give private plant breeders stronger incentives to develop superior varieties. Under the PVPA, patent-like certificates of protection (PVPCs) may be obtained for varieties of self-pollinating crops, such as cotton, soybeans, and wheat. However, the effectiveness of the PVPA is thought to have been limited by the lack of a utility principle, an extremely narrow scope of protection based on measuring phenotypic differences, high enforcement costs, and a farmer exemption.

Economic analyses of the PVPA have been sparse. Knudson and Pray estimated the effect of the PVPA on public investment in the development of improved varieties of

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cotton, soybeans, and wheat, but their results were inconclusive. While investment in varietal research and adoption of private varieties increased relatively rapidly for soybeans after 1970 (Huffman and Evenson), these changes may have been in response to industry growth, as the acreage and real price of soybeans increased in the 1970s.

The few studies that have tested the effect of the PVPA on varietal improvement found that the estimated effect of the PVPA on yield improvement generally was not statistically significant (Perrin, Kunnings, and Ihnen; Babcock and Foster). These studies were limited by their few years of relevant observations. For each crop, it remains unknown whether the PVPA has led to superior varieties or merely to a proliferation of varieties that differ in little more than name. We do not know the quantitative implications of the PVPA for private and public investments, nor whether the practice of obtaining PVPCs enhances, slows, or otherwise changes the nature of genetic improvement. This study documents the effects of the PVPA on genetic improvement in the U.S. wheat industry. Wheat is the leading U.S. cereal grain, and second to soybeans in the total number of PVPCs. Sufficiently detailed data are available on wheat to allow definitive results to be obtained, for the first time, on several aspects of the PVPA.

GENESIS OF THE PLANT VARIETY PROTECTION ACT

Self-pollinating plants are homozygous, so their genotypes remain virtually unchanged across generations, so that growers may purchase seeds one year and, in subsequent years, replant seeds from previous harvests without discernible loss in performance. As a result, inventors of a new variety receive royalties on only a fraction of the acreage planted to the variety. Consequently, prior to the passage of the PVPA, few firms invested in the development of new varieties of nonhybrid crops. Instead, reliance was placed on public agencies such as the United States Department of Agriculture (USDA) and State Agricultural Experiment Stations (SAESs) (Huffman and Evenson; Pardey et al.).

The PVPA was meant to encourage the private sector to develop new varieties of sexually reproductive crop species.[1] New legislation was required because the 1930 Plant Patent Act applied only to asexually-reproductive, or clonally-propagated, species of plants, and living organisms were not subject to utility patents until 1980. Under the PVPA, an applicant must demonstrate that a new variety is distinct, uniform, and stable if it is to qualify for a certificate of protection (PVPC).[2]

Several provisions of the PVPA meant that the protection afforded to a certificate holder was only partial, and weaker than patent protection. A "research exemption" granted crop breeders the right to use and reproduce a protected variety for plant breeding or other bona fide research (7 U.S.C. 2544, Sec. 114). In contrast, while the details of a patent are revealed when it is recorded, U.S. patent law requires that the patent-holder's permission must be obtained for research use. The right-to-save-seed exemption, or "farmer exemption," enabled growers to replant and sell seed of protected varieties for

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[1] The advantages of market-based incentives for inventions were noted by Mill (pp. 928-929): "…an exclusive privilege, of temporary duration is preferable; because it leaves nothing to anyone's discretion; because the reward conferred by it depends upon the invention's being found useful, the greater the usefulness, the greater the reward; and because it is paid by the very persons to whom the service is rendered, the consumers of the commodity."

[2] Distinctness is a measure of the differences in the variety's phenotype, or physical traits, compared with all other protected varieties. Uniformity is a measure of similarity

replanting as long as the grower's primary occupation was the growing of crops for sale for other than reproductive purposes (7 U.S.C. 2543, Sec. 113). The PVPA Amendments of 1994 ended the "farmer exemption." Growers may no longer legally sell seed of protected varieties for planting, yet growers may continue to replant seed of a PVP variety for their own use without obtaining permission from the owner of the PVPC. High enforcement costs have further reduced the ability of wheat breeders to exclude growers and seed companies from freely using their varieties. It is difficult to monitor the vast area sown to wheat, and to determine the source of a grower's seed. Litigation is expensive and lawsuits against growers may harm public relations.

The PVPA and U.S. utility patent law differ in their requirements for disclosure, novelty, and utility. The disclosure requirement of the PVPA is not as strict as that of U.S. utility patent law, and is satisfied with "a description of the genealogy and breeding procedure, *when known*" (7 U.S.C. 2422, Sec. 52, emphasis added). Consequently, in the Grain Genes database, a comprehensive public database of wheat varieties, the pedigrees of many PVP varieties remain concealed by the description "Bulk selection from unpublished crosses" (Grain Genes 1997). Novelty, an inventive step, is also a requirement for an invention to qualify for a utility patent, but not for a PVPC. Utility, or the usefulness of an invention (which may also include aesthetic value), is an additional requirement for an invention to qualify for a utility patent that is not required for a PVPC. Instead, a variety may qualify for a PVPC if the phenotype of the variety is different from the phenotypes of all protected varieties, even if the physical differences are of little or no value.

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among individual plants of the same variety. Stability refers to the degree to which

Consequently, PVPCs have been obtained for many varieties with similar or virtually identical genotypes.[3] This reduces the incentive to develop improved varieties, since rents are soon dissipated with the release of varieties that are genotypically similar. While the PVPA Amendments of 1994 defined an “essentially derived variety” (EDV) as a variety that is genetically similar yet not identical to another variety, the concept of an essentially derived variety remains unclear and has no effect on whether a variety qualifies for a PVPC (Hunter, p.96). The “distinctness” criterion is still based solely on phenotypic differences.

These features of the PVPA mean that the protection provided to plant breeders has been at best partial. The question that remains is whether the improvement in intellectual property protection conferred by the PVPA had significant economic effects. To address that question, we develop a theoretical model of invention under partial excludability and partial appropriability of returns. Hypotheses derived from that model are tested with new data on U.S. wheat varieties.

THEORETICAL MODEL: INVENTION WITH PARTIAL APPROPRIABILITY AND EXCLUDABILITY

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individual plants of a variety remain similar across generations.

[3] “You have the freedom to breed with each other’s materials–everybody still breeds with the same materials. With hard red or soft winter wheats, for example, everyone breeds with the two or three most successful varieties. Although you may have many different companies selling many different names of soft red winter wheat, you look at the pedigrees and they’re all very related” (Duvick, p. 25). For example, in the 1994 Iowa public experimental trials, a single soybean genotype was represented by 30 different varieties. This genotype was easily recognized by its unique leaf shape. Also, of the 18 highest-performing entries in the trial, 10 were selected from the same parental lines (Voss 1996, personal communication). In one case, a soybean variety was apparently granted protection based on a different flower color, a characteristic that has no relationship to economic performance (Lesser).

Intellectual property rights may enhance excludability but might not confer complete excludability. Accordingly, a theoretical economic model of investment in research under partial excludability is needed. Here, we develop a model of a single invention in which market conditions and the degree of excludability and appropriability influence investment and hence the quality of the invention. In this model, an inventor develops a new (unique) wheat variety in one period, and authorizes seed propagators to market seed of that variety to growers over another period, τ periods later, in exchange for royalty payments.

The inventor acts as a Stackelberg leader, taking into account the subsequent responses of the seed companies that produce and market the seed, and pay royalties to the inventor. In the initial period, the inventor chooses research effort (the quantities of research inputs), which determines the quality of the seed to be produced and sold in period t.

$$z = z(s; K, X) \tag{1}$$

In equation (1), varietal quality, z, depends on the research effort, s, spent to develop the new variety, the stock of relevant knowledge used in its development, K, and other factors, X, that influence the demand for the new variety (such as the yield and commodity price of the most profitable alternative variety, the total acreage of wheat, and other input prices).

In period t, the total demand for the new variety, in price dependent form, is

$$r = r(Q, z) \tag{2}$$

where r is the royalty rate, which is a function of the total quantity of seed of the new variety, Q, and its quality, z, determined in the initial period.

If the inventor were a monopolist, he would appropriate all of the profits attributable to the new variety as royalties, and would authorize seed producers to reproduce and sell that quantity of seed that would equate his marginal royalty revenue and marginal cost. Since the genotype of the variety is assumed to be a nonrival good, the marginal cost of reproduction is zero (i.e., the cost of reproducing an additional unit of seed of one variety is assumed to equal the cost of reproducing one unit of seed of another variety). Hence, the inventor would seek to operate where marginal revenue from royalties is zero (i.e., where $r + r_Q Q = 0$, with $r_Q < 0$ representing the slope of the demand in equation (2)).

However, wheat varieties are only partially excludable. If there were no barriers preventing new seed producers from entering into the production and sale of the variety, through competition, the royalty rate would be driven to zero. In order to represent the market with partial excludability, first, it is assumed that seed producers incur a fixed cost, F. This fixed cost will prevent entry of firms from eliminating all of the returns to invention. It could represent the costs of obtaining information on the new variety, as well as any other lump-sum costs involved in going into production and marketing a new variety. Second, it is assumed that the quantity of seed sown to the new variety that earns its inventor royalties is equal to a fraction, α, of the total quantity of seed sown to that variety. This outcome could reflect either a situation where the inventor is able to detect (and collect royalties from) only a fraction of the total number of seed companies producing and selling the new variety, or a situation where seed producers report only a fraction of their sales to the inventor.

We wish to solve for the equilibrium rate of investment by the inventor, which affects the quality of the invention and the royalty rate, which together determine the rate of adoption as a function of the parameters of the model. To do this, first we solve the second-stage problem for the Nash equilibrium in seed quantities under Cournot competition among seed-producing companies (all of which earn zero marginal profit and zero total profit), who take as given the seed quality, which is determined by the inventor in the first stage. Thus, we obtain solutions for the total number of seed companies, the total quantity of seed, and the royalty rate paid by seed buyers, as functions of seed quality and other parameters. Next, we take the results from the model of the seed industry with given varietal quality, and incorporate them into the first-stage optimization decision of the inventor, who, as a Stackelberg leader, determines how much to invest in invention, given the anticipated responses of buyers and sellers of the new seed.

Seed Market Equilibrium for Given Quality

In period τ, given a variety of quality z, the *i*th seed producer chooses to produce the quantity of seed, q_i, that will maximize profits, π, where

$$\pi(q_i) = (1-\alpha)r(Q; z)q_i - F \tag{3}$$

In this equation, $Q = \Sigma_i q_i = nq$ is the total quantity of seed supplied by n symmetric firms, each of which chooses its own quantity of production taking into consideration the effect of that choice on the industry-wide royalty rate.[4] Since each firm takes the output of the others as fixed (i.e., $¶Q/¶q_i = 1$), the first-order necessary conditions for a maximum, $(1\text{-}\alpha)(r + r_Q q_i) = 0$, imply that $(r + r_Q q_i) = 0$. Combining this with the zero-profit condition $(1\text{-}\alpha)rq_i – F = 0$, we can solve for the equilibrium values for the quantity produced by each firm, $q_i^* = q^* \; \forall \; i$, and the royalty rate, r^*. Noting that $r_Q < 0$ means that the term inside the square-root is positive, the solutions are

$$q^* = [-F/(1\text{-}\alpha)r_Q]^{½} \tag{4a}$$

$$r^* = [-r_Q F/(1\text{-}\alpha)]^{½} \tag{4b}$$

By combining (4b) with (2), we can solve for the total quantity, Q^* and total royalty revenue, $R^* = r^*Q^*$, and using (4a), we can solve for the number of seed-producing firms, $n^* = Q^*/q^*$. It can be seen how these solutions, for a given varietal quality, z, depend on (a) the entry cost, F, which can be thought of as a measure of excludability, and (b) the fraction of royalties returned to the inventor, α, which can be thought of as a measure of appropriability. Specifically, assuming a linear demand, so that r_Q is constant, in (4b) an increase in either F or α will result in a higher equilibrium royalty rate, r^*, and, in turn, a smaller adoption rate of the new variety, Q^*. Further, so long as the total quantity exceeds the monopoly optimum (i.e., marginal revenue is negative), an increase in the equilibrium royalty rate, r^* (from an increase in appropriability or excludability holding quality constant) must result in a larger total royalty revenue.[5] These

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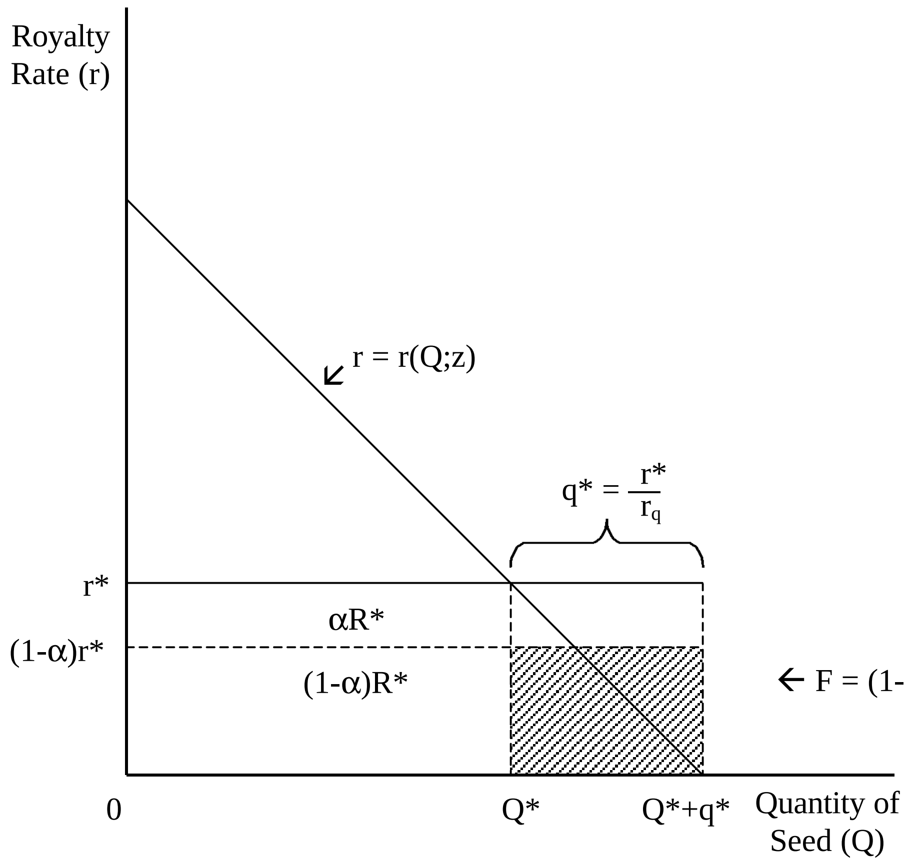
[4] We ignore integer problems and admit fractional firms.

[5] It can be shown that, if the second-order conditions for a maximum are met, then the same result applies generally, not just for linear demand equations.

relationships can be seen in Figure 1, which shows the equilibrium values of r* and Q* for given values of z, F, and α.

Figure 1 Royalty rate and quantity of seed for given varietal quality (z), appropriability (α), and excludability (F)



THE INVENTOR'S OPTIMAL RESEARCH INVESTMENT

The total value of royalties is given by $R^* = r^*q^*n^* = r^*Q^*$, of which $(1\text{-}\alpha)R^*$ is spent by seed-producing firms on entry costs (n^*F), and the remainder, αR^*, is returned to the inventor in period τ. This result determines the incentives for the inventor to invest in research in period 0, which determines the varietal quality, *z* and, ultimately, the quantity and price of seed in period τ. Assuming a linear form for *r(Q, z)*, the optimized firm size, *q** from (4a) and royalty rate, *r** from (4b) do not depend on varietal quality, z. Hence, the inventor maximizes:

$$W(z) = e^{-rt}\alpha\, r^*\, Q^*(z) - c(z) \tag{5}$$

where W is the present value of profits of the inventor, ρ is the discount rate, and c(z) is the inventor's cost function (dual to the production function in (1)).

In equation (5), an increase in the inventor's research investment, *s* (and thus in varietal quality, *z*) implies an increase in both costs and revenue. The revenue increase is achieved by increasing the total quantity, *Q** demanded at the given price, *r** (and this expansion in demand is met entirely by an increase in the number of firms, *n** producing the given quantity per firm, *q**). Wealth is maximized by equating the present value of the marginal revenue product (αr^*Q_z) and marginal cost (c_z) of an increment to varietal quality.

It is useful to express this result in terms of elasticities

$$e^{-rt}\alpha r^*Q^*E_{Q,z} = c(z)E_{c,z} \tag{6}$$

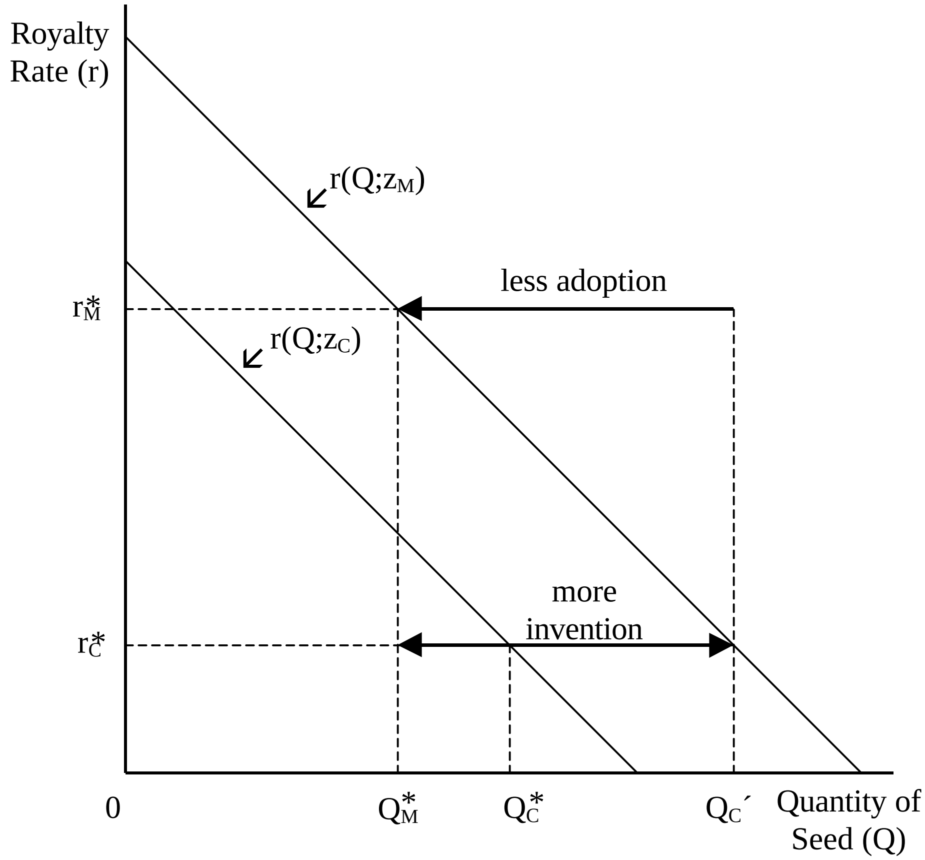
where $E_{Q,z}$ is the elasticity of the total quantity of seed demanded with respect to the variety's quality ($E_{Q,z} > 0$), and $E_{c,z}$ is the elasticity of research costs with respect to quality ($E_{c,z} > 0$). Anything that increases the royalties going to the inventor (αr^*Q^*) will encourage an increased research investment, leading to an increase in quality. Hence, the profit-maximizing research effort, *s**, and quality of the new variety, *z**, increase with increases in excludability, *F*, appropriability, α, and the size of the relevant market, and decrease with increases in the discount rate, r, costs of research, c, and development time, t.

An improvement in intellectual property rights (IPRs) can be thought of as giving rise to an increase in excludability, appropriability, or both. The theoretical effects of improved IPRs on adoption of the new variety are ambiguous. On the one hand, an improvement in IPRs will lead to the development of a higher-quality variety, an increase in quantity demanded at a given royalty rate. On the other hand, an improvement in IPRs also will result in a higher royalty rate, and a smaller total quantity demanded of seed of a given quality (or acreage planted to it).[6]

An improvement in IPRs will increase the quantity of seed sown to the new variety, only if the increase in acreage resulting from a higher-quality variety outweighs the reduction in acreage resulting from a larger royalty per unit. These relationships are depicted in Figure 2. Figure 2 replicates the equilibrium shown in Figure 1 under partial appropriability, with a royalty rate of r^* and total quantity Q^*, and adds curves showing the outcome for a monopolist as would apply under complete appropriability. Complete appropriability, would imply a greater research investment and a higher quality of invention, and hence the demand would be greater (as shown by the curve $r(Q; z_M)$,

[6] This trade off between the effects on knowledge creation and the effects on diffusion means that the effects of improved IPRs on social welfare are ambiguous, even if the effects on inventor welfare are unambiguous. Perrin and Venner illustrate and discuss the welfare effects.

Figure 2 Ambiguous effects of improvements in appropriability on the rate of varietal improvement



where z_M is the quality of seed produced under complete appropriability). Holding the royalty rate constant at r^*, this increase in quality would result in an increase in total adoption to Q□. However, the monopoly optimum is for a quantity of Q_M and a royalty of r_M per unit of seed sold. In Figure 2, the "investment effect" (increasing the quality and thus the quantity demanded of the new variety at a given royalty rate) is outweighed by the "adoption effect" of the higher royalty rate occasioned by the increase in appropriability. Hence, an increase in appropriability meant that the new seed was of higher quality but, in this case, it was adopted on fewer acres. Even still, this might mean a faster rate of genetic improvement if the quality effect dominates the quantity effect. More generally, we might see an increase in both quality and quantity if the adoption effect does not outweigh the invention effect.

Testable Implications

The results from the theoretical model of plant breeding with partial appropriability are intuitive. An improvement in intellectual property rights should lead to an increase investment in research, the quality of new varieties, and royalties, but may or may not increase acreage sown to new varieties or the rate of genetic improvement in farmers' fields. Hence, if the PVPA effectively improved IPRs for wheat breeders, the theoretical model implies the following specific null hypotheses:

(a) The PVPA did not lead to an increase in the rate of investment in wheat breeding.

(b) The PVPA did not lead to higher per unit royalties received by wheat breeders.

(c) The PVPA did not lead to faster rate of genetic improvement in wheat varieties,

(d) The PVPA did not lead to a faster rate of growth in commercial wheat yields

These hypotheses are tested empirically below. Three types of evidence are presented. First, we consider evidence on the use of PVPCs for wheat, on scientist effort and investment in wheat breeding research, and on seed prices. This evidence relates relatively directly to the behavioral response to the passage of the PVPA. Second, we consider data on commercial wheat yield improvements, which is more comprehensive in nature, and relates more directly to the purpose of the law, but less directly to the response to it. Third, we consider data on improvements in experimental wheat yields. (Other dimensions for improvements in wheat varieties, such as reduced yield variability or increased protein content are thought to have been relatively unimportant, and useful data on these aspects are not available.)

2. DIRECT EVIDENCE ON WHEAT BREEDER RESPONSES TO THE PVPA: INVESTMENTS AND ROYALTIES

A total of 373 applications for PVPCs for wheat varieties were filed during 1971-95 that resulted in PVPCs by October 1996. Of this total, 69.7 percent were private and 30.3 percent were public varieties. The fact that PVPCs were obtained means that the PVPA was not perceived as totally irrelevant to wheat breeders, but it need not mean that the PVPA stimulated any additional investment or gave rise to those varieties. Evidence of changes in wheat breeding effort might be more compelling as evidence of an investment response to the law, as the model predicts would happen if the law had, in fact, resulted in improved IPRs for wheat breeders. However, drawing on Frey, and Kalton, Richardson, and Frey, Venner documents that the number of private-sector wheat breeders, and the rate of private investment in wheat breeding have remained small and static, both in absolute terms and relative to hybrid corn. During 1982-94, the number of private-sector scientists who developed hybrid-corn varieties continued to increase while the number of private-sector scientists who developed varieties of wheat remained roughly constant.

On the other hand, during 1970-93, public expenditures on wheat breeding more than doubled in real terms, and State Agricultural Experiment Stations (SAESs), with a continued emphasis on the development and release of commercial varieties, accounted for over 90 percent of this increase (Pardey et al.). Since 1970, the numbers of scientists and investment in wheat breeding have increased substantially for the public sector, but not for the private sector. After reviewing this and other evidence of the same sort, Venner concluded that overall, the practice of obtaining PVPCs on public varieties of wheat appears to have contributed to greater public expenditures on varietal research.

Other evidence about the effects of the law may be found in royalty rates for wheat seed, which should have increased if the PVPA effectively made returns to wheat-breeding research more appropriable. Royalties and seed prices for individual varieties were not available, but annual average seed prices of corn and spring wheat were available from 1954 to 1994. Since the 1960s, the corn-seed price grew generally relative to the spring-wheat seed price. Since the mid-1970s, when the PVPA might have begun to take effect, the nominal price of wheat seed remained roughly constant, while the price of hybrid corn seed continued to rise. Further, as shown by Venner (p. 102), the premium of the wheat seed price over the wheat commodity price, an upper-bound estimate of the royalty rate, *fell* generally in real terms over the period 1954-1994. In sum, the data do not support the hypothesis that the PVPA has increased the price or royalty rate of wheat seed.

3. INDIRECT EVIDENCE OF RESPONSES TO THE PVPA: COMMERCIAL WHEAT YIELDS

If the PVPA were successful in promoting a faster rate of genetic improvement in wheat, and a faster rate of adoption of improved varieties, the effects might be seen as a faster rate of improvement in commercial wheat yields. (As noted earlier, other dimensions for varietal improvement have been relatively unimportant, while wheat yields have been growing significantly over recent decades.)

Ten-year average U.S wheat yields remained at 13 bu/ac from 1870 to 1930 and then increased to 15.5 for the ten years centered on 1940, 17.1 in the ten years centered on 1950, 24.2 in the ten years centered on 1960, 30.0 in the ten years centered on 1970, 34.3 in the ten years centered on 1980, and 36.4 bu/ac in the ten years centered on 1990. Yield gains beginning in the 1960s coincided with the widespread adoption of public as well as privately released short or so-called semidwarf varieties of wheat (Pardey et al.). Gains in ten-year average U.S. wheat yields were smaller in 1980 and 1990, the period when the PVPA might have increased yields.

Other factors were not held constant, however, so to test for an effect of the PVPA we model state-specific commercial wheat yields, by class. The analysis of commercial yields during 1950-94 is based on data for the following classes and states: hard-red spring (HRS) wheat (Minnesota, Montana, North Dakota, South Dakota), hard-red winter (HRW) wheat (Colorado, Kansas, Nebraska, Oklahoma, Texas), and soft-red winter (SRW) wheat (Illinois, Indiana, Ohio).

THE COMMERCIAL WHEAT YIELD MODEL

We propose a linear model of the form:

$$Y_{cst} = b_0 + b_1\ ACRE_{cst} + b_2\ SPVP_{cst} + b_3\ SSD_{cst} + b_4\ NF_{st} + b_5\ RPW_t\ + \\ + b_6\ YH_t + \Sigma_j\ w_j\ W_{jst} + e_{cst} \qquad (7)$$

Here, the average yield of wheat (of a given class, c) in state s in year t (Y_{cst}), depends on

(a) the total area planted to the class of wheat in state s in year t ($ACRE_{cst}$),

(b) the share of that acreage sown to varieties with PVPCs ($SPVP_{cst}$),

(c) the share of the class acreage in state *s* in year *t* sown to semidwarf varieties (SSD_{cst}),

(d) the rate of nitrogen fertilizer applied to wheat acreage in state s in year t (NF_{st}),

(e) the real U.S. price of wheat in year t (RPW_t),

(f) the year of harvest in year t (YH_t),

(g) a vector of indexes of precipitation (PREC) and temperature (TEMP) in selected months in state s in year t (W_{jst} – Venner provides complete details on these weather indexes), and

(h) a random error term, e_{cst}.

One test of the effect of the PVPA on commercial wheat yields involves the coefficient on SPVP. Under the null hypothesis of no effect of the PVPA, $b_2 = 0$, and the average commercial wheat yield does not depend on the share of acreage planted to varieties having PVPCs. A second test of the effect of the PVPA on commercial wheat yields is a test for structural change in the yield model after the passage of the PVPA in 1970. Varietal development time is generally 5-7 years for spring wheat and 10-12 years for winter wheat. Therefore, the PVPA is hypothesized to have contributed to the development of higher-yielding varieties starting in 1976 for spring wheat and in 1981 for winter wheat. These hypotheses were tested using an intercept dummy variable equal to one after 1976 for spring wheat (D76) and after 1981 for winter wheat (D81). We also tried slope dummies (i.e., an interaction term between D76 or D81 and the year-of-harvest, YH), to test whether the PVPA increased the general rate of yield gain.

Models of the form of (7) were estimated as seemingly unrelated regressions, across states, within a given class of wheat. A variety of specifications were tried. The results reported in Tables 1 through 3 for the different wheat classes are from preferred specifications, but it should be noted that the essential results did not change materially across specifications. (Note that, to save space, the parameter estimates for weather variables are not reported here. Those estimates are reported in Venner.)

ESTIMATION RESULTS

In Table 1, for HRS wheat, the coefficient on the PVP-share variable is not statistically significant at the 5 percent level of significance for any of the states. In a separate set of regressions, the estimated coefficient on the D76 variable is not statistically significant at the 5 percent level of significance in any of the states. The results indicate that commercial yields of HRS wheat did not increase after 1975 in response to the PVPA nor in response to the adoption of PVP varieties.

Table 1 Coefficient estimates for commercial yields of hard red spring wheat

	Minnesota	Montana	North Dakota	South Dakota
		- - coefficient estimate[a] - -		
Regression 1				
YH	0.62**	0.17**	0.58**	0.46**
	(4.94)	(2.98)	(9.72)	(6.63)
SPVP	-2.54	-12.80	1.46	-4.29
	(-0.90)	(-1.60)	(0.36)	(-0.71)
SSD*PREC(June-July)	-0.11	1.22**	-0.36	0.11
	(-0.25)	(3.56)	(-1.02)	(0.42)
ACRE	1.06	-1.13**	-1.36**	-1.97*
	(0.79)	(-2.56)	(-5.76)	(-2.51)
Constant	334.27**	143.82**	217.53**	202.47**
	(5.38)	(5.44)	(11.11)	(7.05)
Mean yield	30.8	21.9	24.0	19.6
R^2	0.75	0.86	0.92	0.87
Durbin Watson	1.51	2.20	1.79	2.10
N	45	45	45	45
Regression 2				
YH	0.60**	0.13	0.60**	0.50**
	(4.96)	(1.70)	(9.54)	(6.13)
D76	-1.80	0.68	-1.88	-2.66
	(-0.58)	(0.43)	(-1.39)	(-1.34)
SSD*PREC(June-July)	-0.088	1.13**	-0.072	0.21
	(-0.20)	(3.21)	(-0.20)	(0.77)
ACRE	1.43	-1.35**	-1.28**	-1.52
	(1.05)	(-2.73)	(-5.23)	(-1.75)
Constant	331.87**	142.95**	213.54**	205.54**
	(5.36)	(5.23)	(10.82)	(7.47)
Mean yield	30.8	21.9	24.0	19.6
R^2	0.75	0.85	0.92	0.87
Durbin Watson	1.54	2.09	1.86	2.07
N	45	45	45	45

[a] * = 5 percent significance level; ** = 1 percent significance level.
The t-statistics are in parentheses.

Table 2 Coefficient estimates for commercial yields of hard red winter wheat

	Colorado	Kansas	Nebraska	Oklahoma	Texas
			- - coefficient estimate[a] - -		
Regression 1					
YH	0.28**	0.70**	0.46**	0.60**	0.49**
	(3.06)	(5.54)	(1.91)	(4.42)	(6.40)
SPVP	4.55	-5.42	-11.70	-6.80	-2.54
	(0.93)	(-1.94)	(-1.95)	(-1.30)	(-0.59)
NF*PREC(Sep-May)	0.0047	-0.67	0.0073	-0.51	-0.0022
	(0.40)	(-1.40)	(0.77)	(-1.49)	(-1.03)
ACRE	-0.43	-0.30	-1.66	0.35	-0.23
	(-0.39)	(-0.97)	(-0.69)	(0.50)	(-0.66)
Constant	-10.80	-12.43	14.40	-2.58	29.35
	(-0.61)	(-0.76)	(0.52)	(-0.13)	(1.84)
Mean yield	24.6	28.3	30.9	24.6	22.3
R^2	0.85	0.85	0.72	0.72	0.89
Durbin Watson	1.25	1.80	1.57	1.56	1.31
N	44	44	44	44	44
Regression 2					
YH	0.31**	0.65**	0.15	0.55**	0.46**
	(4.39)	(5.48)	(0.91)	(4.25)	(6.56)
D81	4.06	-2.18	-1.79	-1.68	-0.12
	(1.90)	(-1.21)	(-0.80)	(-0.82)	(-0.083)
NF*PREC(Sep-May)	-0.0017	-0.0069	0.0074	-0.0051	-0.0019
	(-0.15)	(-1.44)	(0.77)	(-1.50)	(-0.90)
ACRE	-0.52	-0.30	-3.82	0.45	-0.27
	(-0.52)	(-0.94)	(-1.87)	(0.64)	(-0.73)
Constant	-12.84	-6.57	44.26	-1.29	31.75*
	(-0.82)	(-0.41)	(1.94)	(-0.064)	(2.03)
Mean yield	24.6	28.3	30.9	24.6	22.3
R^2	0.87	0.84	0.69	0.72	0.89
Durbin Watson	1.54	1.68	1.48	1.44	1.25
N	44	44	44	44	44

[a] * = 5 percent significance level; ** = 1 percent significance level.
The t-statistics are in parentheses.

Table 3 Coefficient estimates for commercial yields of soft red winter wheat

	Illinois	Indiana	Ohio
		- - coefficient estimate[a] - -	
Regression 1			
YH	0.96**	0.74**	0.58**
	(4.32)	(3.71)	(3.18)
SPVP	-8.20*	-6.08	-3.92
	(-2.28)	(-1.91)	(-0.65)
SSD	0.94	1.90	5.59
	(0.33)	(0.71)	(1.19)
NF	-0.031	0.046	0.084
	(-0.34)	(0.59)	(0.94)
Constant	-3.46	0.36	7.49
	(-0.31)	(0.032)	(0.72)
Mean yield	39.4	40.2	40.1
R^2	0.85	0.82	0.90
Durbin Watson	1.40	2.16	2.56
N	44	44	44
Regression 2			
YH	0.63**	0.54**	0.56**
	(3.47)	(3.08)	(3.28)
D81	5.40	-2.91	-6.37*
	(1.56)	(-0.86)	(-2.05)
SSD	-7.15	3.22	10.59*
	(-1.58)	(0.82)	(2.44)
NF	0.027	0.081	0.079
	(0.31)	(1.01)	(0.95)
Constant	13.56	10.86	9.17
	(1.51)	(1.12)	(0.97)
Mean yield	39.4	40.2	40.1
R^2	0.84	0.81	0.91
Durbin Watson	1.48	2.04	2.55
N	44	44	44

[a] * = 5 percent significance level; ** = 1 percent significance level.
The t-statistics are in parentheses.

In Table 2, for HRW wheat, the variable SSD (the semidwarf share) is omitted from the model because of its extreme positive correlation with SPVP (the share of acreage sown to PVP varieties). Nonetheless, for HRW wheat, none of the estimated coefficients on SPVP are both positive and statistically significant, which indicates that commercial HRW wheat yields did not increase in response to the adoption of PVP varieties. In the test for structural change, since SSD is omitted, the D81 variable also reflects yield effects from the adoption of semidwarfs. The coefficient estimate on the D81 dummy variable is nevertheless not statistically significant at the 5 percent level for any of the five states.

Finally, the results in Table 3 show no evidence to support the hypothesis that the PVPA increased commercial yields for SRW wheat. After allowing for the effects of other factors, commercial SRW wheat yields in Illinois are estimated to have declined in response to the adoption of PVP varieties, and the estimated coefficient on the D81 dummy variable was negative and statistically significant for Ohio, indicating a downward shift in SRW wheat yields in Ohio after 1980.

4. INDIRECT EVIDENCE OF RESPONSES TO THE PVPA: EXPERIMENTAL WHEAT YIELDS

Experimental data by individual variety can enable a comparison of performance by type of variety, such as between varieties with and without PVPCs. In experimental trials, the quality and quantity of production inputs change across years and sites, but are the same for all varieties tested at the same year and site. The experimental yield data were provided by Pardey et al. for the following classes and states: HRS wheat (Minnesota, Montana, North Dakota, South Dakota), and HRW wheat (Colorado, Kansas, Nebraska, Oklahoma, Texas). The experimental yield data set is large, extending from 1950 to 1993, and includes 7,505 observations for HRS wheat and 12,780 observations for HRW wheat, where a particular variety tested in a particular year and site represented one observation.

THE EXPERIMENTAL WHEAT YIELD MODEL

The data for the experimental yields are by sites and by particular variety, and the model is of the general form shown below, although not all of the variables are always included:

$$Y_{irt} = b_0 + b_1\ YH_t + b_2\ DYR_{it} + b_3\ YR_i + b_4\ PRIV_i + b_5\ PVP_i + b_6\ SD_i + b_7\ DI_{rt} + b_8\ DF_{rt} + b_9\ DS_{rt} + b_{10}\ SITE_r + b_{11}\ RPW_t + \Sigma_j\ w_j\ W_{js(r)t} + \Sigma_k\ v_k\ V_{ks(r)t} + e_{irt} \qquad (8)$$

The average yield of wheat of variety i in experimental site r in year t (Y_{irt}), might depend on

(a) the year of harvest in year t (YH_t),

(b) a year-of-release dummy variable, DYR_{it} = 1 if variety i was released in year t,

(c) a continuous variable, YR_i = year-of-release of variety i,

(d) a dummy variable, $PRIV_i$ = 1 if variety i was developed by a private breeding program,

(e) a dummy variable, PVP_i = 1 if a PVPC was obtained for variety i,

(f) a dummy variable, SD_i = 1 if variety i is a semidwarf,

(g) a dummy variable, DI_{rt} = 1 if site r was irrigated in year t,

(h) a dummy variable, DF_{rt} = 1 if site r was fallow in the year prior to t,

(i) a dummy variable for source, DS_{rt} = 1 if site r was on a farmer's field rather than a public experiment station in year t,

(j) a site dummy, $SITE_r = 1$ if the experiment was conducted at site r,

(k) the real U.S. price of wheat in year t, RPW_t,

(l) a vector of indexes of precipitation and temperature in selected months in state s in year t, which are assumed to apply to site r when site i is in state s, $W_{js(r)t}$ (Venner provides complete details on these weather indexes),

(m) a vector of interaction terms between nitrogen fertilizer and precipitation and between rainfall and temperature in the same month, $V_{ks(r)t}$ (Venner provides complete details on these), and

(n) a random error term, e_{irt}.

As with the commercial yield model, a variety of specifications and tests were tried. Here we report several variants for each of two wheat classes, and again we can see that the key findings are not affected materially by these specification choices. In one version of the experimental yield model, yield differences among varieties are represented with a dummy variable for each year of varietal release, DYR. In an alternative version, the dummy variable for year-of-release is replaced with a single continuous variable equal to the year of release of each variety, YR. The coefficient of the continuous year-of-release variable can be used to test for structural change after the passage of the PVPA. A potential disadvantage of a continuous year-of-release variable is the imposition of a constant relationship between yield and year of release, such as linear or quadratic, when the true relationship may be more complex and may have changed over time.

Another test of the effect of the PVPA on experimental yields is a test of whether PVP varieties are higher yielding. A finding that PVP varieties are higher yielding may indicate that additional revenues to be generated by a PVPC led to greater investment and to the development of higher-yielding varieties, but the use of intellectual property rights need not imply that IPRs contributed to innovation.

The variable YH, the year of harvest, is intended to capture the effects of annual changes in the quantities and qualities of production inputs, and the effects of any changes in environmental conditions. For HRW wheat, we were also able to include the variable, N, the rate of nitrogen fertilizer, in the model. The environment is represented with dummy variables for irrigation, for fallowing, for whether the experimental trial was conducted on private land, and for each trial site. In order to allow for nonlinearities and interaction effects, a quadratic functional form was selected. The experimental yield models contain interaction terms between nitrogen fertilizer and precipitation and between rainfall and temperature in the same month.

Results

The results for experimental yields are shown in Table 4 for HRS wheat and table 5 for HRW wheat.[7] Table 4, regression 1 indicates that experimental yields of HRS wheat increased by 0.35 bu/ac per year increase in year-of-harvest and by 0.12 bu/ac per year increase in year-of-release. For HRS wheat, after accounting for the effects of the other variables in the model, private varieties were 1.16 bu/ac higher-yielding than public varieties, and semidwarf varieties were 2.44 bu/ac higher-yielding than non-semidwarfs, with both effects statistically significant. Fallowing increased experimental yields by 2.57

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[7] Venner reports a more complete set of regression results and discusses the results on the effects of nitrogen fertilizer, rainfall, temperature, and the presence of semidwarf

bu/ac and irrigation by 23.10 bu/ac. After accounting for the effects of the other model variables, experimental HRS wheat yields of varieties with PVPCs were, on average, 0.63 bu/ac lower than yields of varieties without PVPCs, but this result was not statistically significant. Similar findings can be seen across the other models in Table 4. In regression 2, the estimated coefficient on the quadratic year-of-release variable is not statistically significant, which suggests that annual gains in experimental yields of HRS wheat have not diminished. The PVPA was expected to have contributed to higher experimental yields of HRS wheat after 1975. Instead, as shown in regression 3, the coefficient on the D76 dummy variable (equal to one after 1975) is negative and statistically significant, indicating a downward shift in experimental yields of HRS wheat after 1975.

In Table 5 regression 1, experimental yields of HRW wheat increased by 0.28 bu/ac per year-of-harvest and by 0.23 bu/ac per year-of-release. After accounting for the effects of the other variables in the model, private HRW wheat varieties were 1.10 bu/ac lower-yielding than public varieties, and semidwarf varieties were 0.80 bu/ac higher-yielding than nonsemidwarfs; with both effects statistically significant. As with HRS wheat, the difference in yields between varieties with and without PVPCs was not statistically significant. In Table 5 regression 2, the negative and statistically significant estimated coefficient on the quadratic year-of-release variable indicates that annual gains in experimental HRW wheat yields declined over time. In regression 3, the test for structural change indicates a downward shift in experimental yields of HRW wheat after 1980.

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genes. The estimates are generally plausible, lending support to the view that the hypothesis tests were conducted within a well-specified model.

Table 4 Coefficient estimates for experimental yields of hard red spring wheat

	Regression number				
Variable	1	2	3	4	5
	- - coefficient estimate[a] - -				
YH	0.35**	0.35**	0.35**	0.30**	0.33**
	(16.73)	(16.16)	(16.85)	(11.53)	(12.49)
YR	0.12**	0.12	0.14**		0.12**
	(7.18)	(1.67)	(7.79)		(6.82)
YR^2		0.000046			
		(0.075)			
D76			-1.05*		
			(-2.32)		
∑DYR				b	
PRIV	1.16*	1.16*			1.20*
	(2.41)	(2.40)			(2.50)
PVP	-0.63	-0.65			-0.54
	(-0.81)	(-0.80)			(-0.69)
SD	2.44**	2.43**	3.03**	7.92**	2.13**
	(5.41)	(5.13)	(6.26)	(5.96)	(4.69)
DF	2.57*	2.57*	2.57*	2.63*	2.16
	(2.23)	(2.23)	(2.22)	(2.29)	(1.87)
DI	23.10**	23.10**	23.13**	23.23**	19.84**
	(18.85)	(18.85)	(18.87)	(19.01)	(14.08)
DI*SD					4.76**
					(4.61)
DS	-10.67**	-10.67**	-10.64**	-10.80**	-10.58**
	(-3.55)	(-3.55)	(-3.54)	(-3.61)	(-3.52)
RPW					-0.18
					(-1.13)
Constant	259.2**	259.4**	258.8**	269.6**	249.4**
	(29.40)	(28.29)	(29.4)	(30.12)	(30.64)
Mean yield	38.0	38.0	38.0	38.0	38.0
R^2 adj.	0.56	0.55	0.55	0.56	0.56
No. var.	113	114	114	134	116
N	7,505	7,505	7,505	7,505	7,505

[a] * = 5 percent significance level; ** = 1 percent significance level. The t-statistics are in parentheses.
[b] Set of coefficients, one per year of release of each variety in the data set.

Table 5 Coefficient estimates for experimental yields of hard red winter wheat

	Regression number					
Variable	1	2	3	4	5	6
	- - coefficient estimate [a] - -					
YH	0.28**	0.30**	0.29**	0.28**	0.26**	0.23**
	(15.00)	(15.49)	(15.28)	(13.60)	(11.04)	(4.92)
YR	0.23**	0.48**	0.25**	2.63**	0.23**	0.23**
	(15.45)	(7.61)	(16.55)	(4.39)	(15.80)	(9.01)
YR^2		-0.0023**				
		(-4.10)				
∑DYR				b		
D81			-3.69**			
			(-8.38)			
PRIV	-1.10*	-0.72	-1.26**		-1.01*	-1.99*
	(-2.47)	(-1.58)	(-2.83)		(-2.28)	(-2.20)
PVP	-0.33	0.0099	0.18		-0.16	1.17
	(-0.85)	(0.025)	(0.46)		(-0.43)	(1.81)
SD	0.80*	1.56**	1.80**		-0.54	1.16
	(2.07)	(3.63)	(4.45)		(-1.32)	(0.83)
DF	3.59**	3.61**	3.61**	3.88**	3.44**	5.27**
	(8.38)	(8.43)	(8.44)	(9.07)	(8.06)	(6.10)
DI	25.40**	25.42**	25.42**	25.59**	22.22**	18.11**
	(45.80)	(45.87)	(45.97)	(46.35)	(35.80)	(14.62)
DI*SD					8.48**	5.07**
					(11.20)	(3.23)
N						0.062**
						(4.86)
N*SD						-0.015
						(-0.85)
DF*SD						-0.66
						(-0.61)
DS	5.22	3.15	5.27	9.46*	5.23	
	(1.25)	(0.75)	(1.27)	(2.29)	(1.26)	
RPW					-0.06	
					(-0.47)	
Constant	63.71**	56.17**	59.43**	71.49**	66.54**	57.24**
	(13.00)	(9.27)	(10.28)	(12.28)	(10.52)	(5.21)

Table 5 (cont'd.) Coefficient estimates for experimental yields of hard red winter wheat

	Regression number					
Variable	1	2	3	4	5	6
			- - coefficient estimate[a] - -			
Mean yield	42.2	42.2	42.2	42.2	42.2	45.9
R^2 adj.	0.45	0.45	0.45	0.46	0.46	0.47
No. var.	189	190	190	217	191	122
N	12,780	12,780	12,780	12,780	12,780	3,466

[a] * = 5 percent significance level; ** = 1 percent significance level. The t-statistics are in parentheses.
[b] Set of coefficients, one per year of release of each variety in the data set.

In sum, the results of the experimental yield regressions consistently show no discernible effect of the PVPA on the rate of genetic improvement in wheat. Varieties with PVPCs are not higher yielding than varieties without PVPCs and, if anything, the annual rate of improvement in experimental yields of hard red winter wheat and hard red spring wheat declined after the PVPA was introduced. Of course, the growth rate of wheat yields might have fallen even faster in the absence of the PVPA. However, when we consider the yield evidence in conjunction with the other evidence on rates of investment and royalties, it seems reasonable to conclude that the PVPA did not hasten the rate of genetic improvement in wheat.

5. CONCLUSION

The primary hypothesis derived from the economic model is that an improvement in intellectual property rights would enhance innovation. This would be seen as an increase in research investments, an increased rate of technological improvement, and, depending on the trade off between more invention and less adoption, perhaps, a faster rate of technological change. In the case of the PVPA, there are reasons to suspect that the intellectual property protection has not been strong, and our empirical results support that view. There is no evidence of an increase in private investments in wheat breeding, and no evidence of an increase in the average price of wheat seed as evidence of an increase in inventor royalties to wheat breeders. Our regression models consistently indicate that the PVPA has not contributed to increases in commercial or experimental yields of wheat. The increase in the share of wheat acreage sown to private varieties—from 3 percent in 1970 to 30 percent in the early 1990s—combined with the still-minimal private-sector investment in wheat breeding, and the lack of gain in wheat yields as a result of the PVPA, indicate that the PVPA has served primarily as a marketing tool.

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