Evaluating the genetic progress of wheat in NSW, 1992-2009

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Abstract

Intellectual Property Regimes (IPRs) have been justified on the basis that they promote innovation, but it is not always clear that they do so. Empirical studies of IPRs in an Australian context have been limited. Plant variety protection is one form of IPR. The passing of the Australian Plant Breeder's Rights Act of 1994 has been followed by significant commercialisation of the wheat breeding industry. The purpose of this paper is to consider whether this commercialisation has benefited wheat productivity through varietal improvement. We estimate a linear crop production function, using a random effects Hausman Taylor estimator to evaluate differences in genetic contributions to productivity between public and private wheat varieties commercially released in NSW over the period 1992-2009 using crop varietal data. Results from the Hausman Taylor estimator show that private varieties, on average, have outperformed public varieties over the period, suggesting that Plant Breeder's Rights has promoted productive innovation in wheat. However, when we consider the best performing genetics of the varieties, public varieties have, in some years, outperformed privately bred varieties.

Keywords: genetic change, technical change, innovation, wheat breeding, intellectual property

1. Introduction

There is a question as to whether Intellectual Property Rights regimes (IPRs) for plants have been of benefit to society or whether the benefit has been limited to certain groups. IPRs have been justified on the basis that they promote innovation. Kingwell and Watson (1998) have argued that increasing commercialisation of the Australian plant breeding industry has followed the implementation of the *Plant Variety Rights Act 1987* and its stronger revised version, the *Plant Breeder's Rights Act 1994* (Godden 1998). A result of this commercialisation has been the increased private sector engagement in Australian plant breeding. One measure of the success of plant variety protection (a form of IPR) in promoting innovation in this context would be the amount by which the contribution to yield of the genetics of privately bred wheat varieties differs from that of publicly bred varieties. In this study we attempt to quantify this difference.

To determine whether the introduction of plant breeders' rights has attained its stated objective, that is the promotion of innovation, a measure of technical change which is specific to plant breeding is required. This measurement can be achieved by isolating the effect on yield of varietal change, that is, the contribution of the genetic material of a variety to yield. It will then be possible to ascertain whether the varieties which offer the greatest contribution to yield through varietal change are bred by the public or the private sector.

We estimate a linear production function to determine which factors have had an effect on yield in the NSW wheat industry, and using a Hausman Taylor random effects estimator, we are able to quantify the changes in genetic contributions to yield of wheat varieties commercially available in NSW using varietal trial data from 1992 to 2009. The Hausman Taylor estimator has an advantage over a fixed effects model in that, as well as allowing us, to identify the contribution to yield of the genetics of the varieties, it enables us to identify the differences in contribution according to whether they were bred in the public or private sector. With a fixed effects model the public/private effect would be absorbed into the fixed effect for each variety.

The rest of the paper is divided into five sections. In section 2 we provide a background to the problem and some issues surrounding Plant Breeder's Rights in Australia. We present a brief literature review in section 3. The following section includes a description of the data and of the econometric methods employed. Our results are reported in section 5 and in section 6 we present some concluding comments.

2. Background

Wheat breeding in NSW has traditionally been carried out by the public sector, with institutions such as NSW Agriculture, CSIRO and the University of Sydney breeding new plant varieties (Kingwell and Watson 1998; Lindner 2004). The Grains and Research Development Corporation (GRDC) was founded in 1990 as a statutory corporation of the Commonwealth government. Its primary function is planning, investing and sustaining R&D in the Australian grains industry, and it acts as the arm of Commonwealth funding for Australian plant breeding (Grains Research and Development Corporation 2010). Commonwealth funding for plant breeding comes directly from the GRDC, which is in turn funded partly by growers' levy payments on grain production (Kingwell and Watson 1998).

The private sector has historically been a participant in breeding to some degree. Private firms began to develop new varieties, particularly wheat hybrids, in the 1980s (Godden and Brennan 2002; Brennan *et al.* 2004). The contribution of the private sector to wheat breeding was, however, quite small. Private sector engagement in wheat breeding has traditionally been low because wheat is a self-pollinating crop and farmers can use seed retained from a harvest, except for the F_1 hybrids, for future planting without any discernible effect on performance (Kingwell and Watson 1998). As such, the only revenue a breeder could expect to receive would be from the initial sale of seed and, since this revenue was unlikely to cover the fixed or sunk costs of breeding, the public sector has been the traditional breeder for open pollinated crops such as wheat (Godden 1998; Brennan *et al.* 2004). In 1985, a commercial company developed a high yielding open pollinated wheat variety which was simply released as a public variety, Vulcan, as the company was unable to capture the benefits from it in any meaningful way (Brennan *et al.* 2004).

With the implementation of the *Plant Variety Rights Act 1987* (PVR) wheat breeders were able to apply royalties on initial sales of seed. This seed royalty did not provide sufficient incentive for commercialisation of the industry as it could only be applied on the original sale, and could not be recouped for future plantings of farmer saved seed (Brennan *et al.* 2004). PVR in itself therefore had minimal effects on wheat breeding and private incentives to breed because it provided for only limited opportunities to capture revenues sufficient to induce private sector investment in breeding activities (Godden 1998).

With the *Plant Breeder's Rights Act 1994* (PBR), and the introduction of the end-point royalty (EPR), a much greater incentive for private wheat breeding emerged. An EPR is a payment applied to the sales from using the patented product (in this case it is paid on the grain produced from the wheat variety when the gain is sold) and thereby provided a means for wheat breeders to gain sustained revenues from their wheat breeding programs. The market structure of wheat breeding changed as the private sector could now expect continued returns from investment (Brennan *et al.* 2004), and over the past two decades, wheat breeding has been conducted on a more commercial basis.

There has been some concern about the long term effects of EPRs on funding of plant breeding. Kingwell and Watson (1998) noted that public funding for breeding has been reduced since the 1990s. Anecdotal evidence of this includes the licensing of germplasm from the Wagga Agricultural Institute to private firms to use in their breeding efforts (Peter Martin, pers. comm. 2010). Effectively NSW Agriculture has moved out of wheat breeding, as have public institutions in other states, and the output of their long established breeding programmes has been made available to the private breeding sector. A particular concern is that availability of long term funding for wheat breeding may suffer under EPRs. EPR income is riskier than public funding, and Kingwell and Watson (1998) question whether there would be enough investment attracted by the private sector to offset the reductions in public funding.

One measure of the success of the introduction of PBR is the extent, if any, to which the productivity attributable to the genetics of private varieties exceeds that of publicly-bred varieties. In this study we estimate the genetic gains from the introduction of new varieties through breeding programs for new wheat varieties from 1992-2009. In particular we focus on the differing genetic contribution of privately and publicly-bred varieties, and quantify the relative productivity of the genetic characteristics of public compared to private varieties.

3. Literature Review

Traditional measures of technological change (or "innovation" or "progress") have included R&D expenditures, patent counts, rates of return on research and development (R&D) investments and crop production function approaches (Alston *et al.* 2009; Nolan and Santos 2010). R&D expenditures are inputs into the innovation process but may not be suitable measures of its output (Geroski 1994). The use of patent counts and counts of innovations also has limitations (Griliches *et al.* 1986; Lanjouw *et al.* 1998; Gallini 2002): in the context of the breeding of new plant varieties, for example, it is arguable whether the protection of breeders' rights, in the absence of merit standards, may have led to the patenting of trivial reformulations, labelled as "cosmetic breeding" (Kolady and Lesser 2009). The use of rates of return to wheat breeding as a measure of returns to R&D is widely used but these are generally aggregate measures. Brennan, Martin and Mullen (2004), for example, evaluated the Wagga Wagga research program carried out by NSW Agriculture, reporting a rate of return of 11 per cent. The rate of return method is limited by the aggregation of the progress being achieved, but has a compensating benefit is that it enables estimation of a tangible valuation of innovations to society in monetary terms.

Empirically the economic effects of technological change are typically measured through the estimation crop production functions, often including time trends, and using aggregate time series data, even if it is recognised that this can only be an approximation.

Problems especially arise when technical progress is discrete or cannot be approximated by a statistically manageable function of time (Peterson and Hayami 1977; Chambers 1988) Additionally, the use of a time trend does not allow for the separation of the effect of changes in varietal technology from improvements in management efficiency, increased use of other inputs, changes in input-output mix or changes in scale (Traxler *et al.* 1995; O'Donnell 2010).

The crop production function approach has been the most common approach in the agricultural economics literature. The methods have changed over time with earlier versions incorporating rates of return in a Marshallian supply and demand framework, such as the seminal paper of Griliches (1958). Other papers use an R&D variable for innovation, such as Griliches (1964) and Peterson (1967).

Past studies have been limited by econometric considerations. Studies such as Griliches (1963), use cross-sectional data. Other studies have used time-series data in a single region, for example Chavas *et al*. (2001). Only relatively recently has panel data been incorporated into the crop production function approach to estimating yields. More recent papers that have used the production function analysis with panel data include Nalley *et al*. (2008), Kolady and Lesser (2009). Some of those studies using the crop production function approach have incorporated new methods, such as Babcock and Foster (1991), Alston and Venner (2002), Nalley *et al.* (2008) and Kolady and Lesser (2009). The tendency in these recent studies has been towards using fixed effects regressions, including time trend variables to account for technological change or innovation. The major problem with this approach is the conflation of the time trend with other trends such as changes in management practices that make it difficult to separate the underlying changes in varieties (Traxler *et al.* 1995). A number of studies have considered the varietal and genetic improvement of a number of crops (see, for example, Babcock and Foster (1991); Chavas *et al.* (2001); Alston and Venner

(2002); Nalley *et al.* (2008); and Kolady and Lesser (2009)). Brennan (1989) provided a conceptual basis to evaluate a wheat breeding program.

Brennan (1984) argued that experimental yield data are the only reliable source of information about relative variety yields. Because of simultaneity problems, the tendency in the literature has been to use more experimental data (Griliches and Mairesse 1995). A particular benefit for us is that by using this type of data we can assume that capital and labour structures are usually uniform, meaning that those inputs do not need to be included in our model.

Our analysis builds on previous work but, using experimental data, we are able to identify the changes in varietal technology and separate them from effects of other drivers of increased yield or increased efficiency. We have not found data used in previous Australian studies to be as detailed as that used in our empirical model, and as far as we are aware, no previous studies have directly estimated the contribution of genetic characteristics of specific varieties to productivity changes in Australia. We contribute to the discussion by quantifying the contribution to yield of the genetics of individual varieties which are trialled each year. We are also able to identify the difference between the contributions of public and privately bred varieties. Using privately bred varieties as a proxy we arrive at a value for PBR in terms of wheat yields by quantifying the contribution of the private varieties to wheat genetic improvements in productivity.

4. Methods

4.1 Data

We use experimental trial data collated from two separate sources: data for trials that were run by NSW Agriculture as part of the Crop Variety Trial system (compiled by Dr. Peter Martin of the Wagga Wagga Agricultural Institute) and data for trials from 2005 from the website NVT Online (National Variety Trials 2010). Figures 2 and 3 (in the Appendix) show the NSW location of the trials in the two systems. Experimental data is ideal for the purpose of identifying and measuring the causes of changes in productivity, and hence for assessing the economic value of wheat breeding programs (Babcock and Foster 1991).

The dataset contains 24,050 observations, reporting on results for 139 unique varieties in 1439 unique trials. The dataset is treated as panel data. The cross-sectional element is the wheat variety. As the cross section, that is the varieties, changes over time, we treat the data as an unbalanced panel. All commercially released varieties over the trial period 1992-2009 are included in our data. In our analysis we have only considered bread wheats, and have excluded feed wheats and durum wheats. The variables are defined and summarised in Table 3 (in the Appendix). Because the estimation of fixed effects is not very meaningful unless there are a number of observations for each cross sectional element, we have excluded varieties for which we have less than five observations. Twenty one observations were thus eliminated from our dataset.

The dependent variable is yield in tonnes per hectare, and site mean yields are used. The quantitative independent variables include organic carbon, soil nitrogen, soil zinc and soil phosphorous, fertiliser applications of sulphur, phosphorous and nitrogen. The climate variables include rainfall, and average monthly maximum and minimum temperatures. Site rainfall data have been recorded for most of the trials conducted under the NVT. For the Crop Variety Trial system and where the rainfall was not recorded for the NVT trials, missing data, as well as all temperature data, have been obtained from the Bureau of Meteorology website (Bureau Of Meteorology 2010). Dummy variables are used to indicate soil type, variety, whether irrigation was applied, whether the trial was full season or short season, whether the trial was held under DPI management or under the new NVT scheme (although the trials under the new system are conducted by the same people as under the old), the year and the region of the trial. The dummy variables for year and region of trial are included to control for all the factors affecting yield in that year and that location which are not accounted for by the other variables. There is some data that is unavailable and for such data we include a dummy variable to control for its absence.

A dummy variable is also used to indicate that a variety is privately bred in a commercially focused breeding programme and we have followed Lindner (2004) in defining private breeding as being breeding with private benefit as its objective. A 'public' variety is a variety bred in the public sector and is the output of a programme which is not commercially focused but which has social objectives, or some objectives other than private benefit.

As our data are experimental we are able to avoid the problems commonly encountered in dealing with capital and labour in production analysis. The use of on-farm data usually leads to simultaneity problems because the changes in inputs are determined within the system, in a behavioural fashion by the producer and not by the econometrician. Those input variables are therefore endogenous to the system, violate regression assumptions of exogeneity, and the coefficients cannot be reliably used for interpretation (Griliches and Mairesse 1995; Woolridge 2002). Using experimental data means underlying behaviour of the agents involved are unimportant.

4.2 Econometric procedures

We estimate a linear production function using using the random effects Hausman Taylor estimator. Our methodology allows us to quantify the contribution to yield of the genetic characteristics bred into the wheat varieties.

We begin by considering the fixed effects specification of a linear production function:

$$(1) \qquad y_{it} = x'_{it}\beta + \alpha_i + \mu_{it}$$

where y_{it} is the yield of variety i in year t, and x'_{it} is the set of covariates presented in table 3, together with a set of region and year fixed effects that account, respectively, for any regional specific practices for the trials that we use in the estimation of this function, and year specific occurrences that were not accounted for elsewhere in the data. Note, however, that we do not include a complete set of controls for the locations of trials.

An important part of the fixed effects transformation is that it eliminates the time-invariant variables altogether as they are absorbed into the fixed effect. As we are interested in determining the effect on yield of a time invariant variable, that is whether the variety is "public" or "private", the fixed effects results are limited. A random effects model would allow us to estimate the coefficients of time invariant variables, but requires that there be no correlation between the error term and the independent variables. For the purposes of our study it is reasonable to assume that the unobserved effect for a variety is endogenous with the region in which the variety is trialled. This is because varieties are regionally targeted for commercial purposes and they also have set production targets against which they perform best. This means the choice of region will be affected by the attributes of the variety; there exists correlation.

The random effects estimator proposed by Hausman and Taylor (1981) uses instrumental variables to deal with the endogeneity problem and allows us to identify the effects of the time invariant variables. In this case using the Hausman and Taylor approach allows us to compare the difference between average output of public and private varieties as we are able to identify the private component of the fixed effect, and obtain a coefficient value in terms of productivity.

The Hausman Taylor estimator fits a panel data random effects model in which some of the covariates are correlated with the unobserved individual level random effect but none of the explanatory variables are correlated with the idiosyncratic error, μ_{it}. Following Greene (2003) we use three sets of observed variables to express this estimator:

(2) $$y_{it} = \beta_0 + x'_{1it}\beta_1 + x'_{2it}\beta_2 + z'_{1i}\gamma_1 + \alpha_i + \mu_{it}$$

where x_{1it} is K_1 variables that are time varying and uncorrelated with α_i, (for example those trial characteristics not under the control of the seed breeder, such as rainfall, and temperatures), x_{2it} is K_2 variables that are time varying and are correlated with α_i, (for example those trial characteristics known in advance by the breeder, such as regional characteristics,) and z_{1i} is L_1 variables that are time invariant and uncorrelated with α_i, (in this study, private breeding)[2] .

Additionally the following assumptions about the random terms in the model are:

$E[\alpha_i] = E[\alpha_i \mid \mathbf{x}_{1it}] = 0$ but $E[\alpha_i \mid \mathbf{x}_{2it}] \neq 0$,

$\mathrm{Var}[\alpha_i \mid \mathbf{x}_{1it}, \mathbf{z}_{1i}, \mathbf{x}_{2it}] = \sigma_\mu^2$,

$\mathrm{Cov}[\mu_{it}, \alpha_i \mid \mathbf{x}_{1it}, \mathbf{z}_{1i}, \mathbf{x}_{2it}] = 0$,

$\mathrm{Var}[\mu_{it} + \alpha_i \mid \mathbf{x}_{1it}, \mathbf{z}_{1i}, \mathbf{x}_{2it}] = \sigma^2 = \sigma_\varepsilon^2 + \sigma_\mu^2$, and

$\mathrm{Corr}[\mu_{it} + \alpha_i, \mu_{it} + \alpha_i \mid \mathbf{x}_{1it}, \mathbf{z}_{1i}, \mathbf{x}_{2it}] = \rho = \sigma_\mu^2 / \sigma^2$.

Therefore the Hausman Taylor estimator assumes that the variables with index 1 are uncorrelated with both α_i and μ_{it} whereas the variables x_{2it} and z_{2i} are correlated with α_i but not with any μ_{it}. Under these assumptions, and following Hausman and Taylor (1981), one can use x_{1it}, z_{1i} and $x_{2it} - \bar{x}_{2i}$, $\bar{x}_{1i}$ as instrumental variables in the estimation of equations such as that in equation (2). The columns of x_{it} which are uncorrelated with α_i can serve two functions because of their variation across both individuals and time. Using deviations from individual means they produce unbiased estimates of the βs and, although this is not a problem for this study, using the individual means they provide valid instruments for the columns of z' that are correlated with α_i. In our estimation, the exogenous variables serve as their own instruments,

[2] Greene (2003, p. 303) also mentions a fourth set of variables, $\mathbf{z}_{2i}$, that are time invariant and correlated with α_i but we omit the reference to it, as there are none in our study.

and x_{2it} is instrumented by its deviation from individual means as in the fixed effects approach. The Hausman Taylor approach allows identification and efficient estimation of both β and α, performs better than traditional instrumental variables methods, which rely on excluded exogenous variables for instruments (Hausman and Taylor 1981) and has a strong advantage in that there is no need to use external instruments (Verbeek 2008).

We are especially interested in estimating the contribution of genetic innovation, and the effect of the move to private breeding, to change in yield. Our first step in addressing these questions is the estimation of the variety unobserved effects, and we interpret these unobserved effects as the contribution of genetics to yield, including and net of, respectively, the private sector effect. We assume that we do not forget previous innovation: when the maximum fixed effect in one year is less than that in the previous year, we assume that the better performing hybrid is still available commercially, even though it has not been submitted for trial. The change in the maximum unobserved effect gives an estimate of technical change that is free of the difficulties of interpretation associated with a time trend (Eisgruber and Schuman 1963; Peterson and Hayami 1977; Traxler *et al.* 1995; Nalley *et al.* 2008). This provides one measure of innovation in the wheat breeding industry.

5. Results

Overall, the signs and magnitudes of each coefficient are consistent with *a priori* expectations. The South-east region of NSW appears to be the most highly productive, early season trials appear to perform better than main season trials. The coefficients for the year variables are mostly negative compared with the base year 1992. These variables are included to control for events in each year which are not accounted for by the other included variables. While the negative coefficients may appear to be unexpected, a plot of the sample mean yield per hectare against year (shown in Figure 2 in the Appendix) does show that yield in 1992 was relatively high.

Table 1 Regressions results for Hausman Taylor estimator

Random Effects Hausman Taylor estimator			
	Coeff	z-stat	P>|z|
Time varying exogenous			
Soil information			
Nitrogen (mg/kg)	0.00	-1.65	0.10
Phosphorus (mg/kg)	0.01	10.44	0.00
pH (CaCl2)	0.05	9.96	0.00
Nitrogen unknown	0.02	0.34	0.73
Phosphorus unknown	-0.02	-0.49	0.63
pH unknown	0.01	0.41	0.68
Organic carbon unknown	-0.02	-0.73	0.47
Organic carbon (%)	0.07	3.38	0.00
Soil texture			
Alluvial	-0.23	-2.31	0.02
Loam	-0.98	-16.82	0.00
Loamy clay	-0.14	-4.59	0.00
Sandy	-0.94	-2.83	0.01
Sandy Clay loam	-0.50	-11.53	0.00
Sandy Loam	-0.29	-6.90	0.00
Unknown	-0.09	-2.65	0.01
Fertiliser inputs			
Nitrogen (kg/ha)	0.01	28.00	0.00
Phosphorous (kg/ha)	0.00	-2.93	0.00
Sulphur (kg/ha)	0.00	-1.44	0.15
Fertiliser unknown	0.31	7.97	0.00
Rainfall			
January	0.00	8.90	0.00
February	0.00	1.72	0.09
March	0.00	4.98	0.00
April	0.01	17.69	0.00
May	0.00	2.00	0.05
June	0.01	14.80	0.00
July	0.00	7.39	0.00
August	0.01	14.70	0.00
September	0.01	12.70	0.00
October	0.00	3.36	0.00
November	0.00	-2.04	0.04
December	0.00	6.28	0.00
Average maximum temperature			
January	-0.03	-4.09	0.00
February	0.06	4.11	0.00
March	-0.15	-9.63	0.00
April	0.18	10.03	0.00
May	-0.21	-10.37	0.00
June	-0.08	-3.51	0.00
July	0.00	-0.14	0.89
August	0.48	24.91	0.00
September	-0.12	-7.10	0.00
October	-0.19	-11.86	0.00
November	-0.12	-8.15	0.00
December	0.12	8.25	0.00

Average minimum temperature			
January	0.21	16.04	0.00
February	-0.12	-7.21	0.00
March	0.03	1.54	0.13
April	-0.13	-7.44	0.00
May	-0.05	-3.23	0.00
June	-0.08	-4.57	0.00
July	0.15	10.01	0.00
August	-0.09	-5.80	0.00
September	-0.02	-1.08	0.28
October	0.05	2.71	0.01
November	0.02	1.21	0.23
December	-0.01	-0.55	0.58
Years (with 1992 as base)			
1993	-1.81	-15.07	0.00
1994	-1.97	-16.30	0.00
1995	-2.11	-12.78	0.00
1996	-0.76	-5.47	0.00
1997	-1.08	-8.79	0.00
1998	-2.79	-19.54	0.00
1999	-1.63	-13.17	0.00
2000	-0.59	-4.29	0.00
2001	-1.09	-8.18	0.00
2002	-1.55	-12.85	0.00
2003	-1.93	-16.45	0.00
2004	-1.49	-14.07	0.00
2005	-2.19	-14.72	0.00
2006	-2.08	-13.43	0.00
2007	-1.30	-9.18	0.00
2008	0.02	0.14	0.89
2009	-2.02	-13.81	0.00
NVT	-0.01	-0.18	0.86
Early	0.15	5.85	0.00
Irrigated	2.66	72.88	0.00
Time varying endogenous			
North-East	-0.24	-5.96	0.00
South-West	-0.44	-15.95	0.00
North-West	-0.39	-10.98	0.00
Time invariant endogenous			
Private	0.22	2.39	0.02
Constant	4.93	17.47	0.00
Number of observations	24050		
Number of groups	139		
Wald chi^2 (79)	22818.42		
Prob>chi^2	0.00		

Our results show that, on average, for the whole period 1992-2009, private varieties are more productive than public varieties, as the dummy variable for private has a positive coefficient of 0.21 with a p value of 0.02. On average, and with all else held constant, private varieties produced 0.21 tonnes per hectare more than public varieties, indicating that varieties originating from commercial breeding programmes appear to be more productive over the 1992-2009 period. Since most of the private varieties were released after the public programs stopped it would be expected that they would be higher yielding. It should be noted that we are considering only the effects on yield, and that ultimate on-farm effects, and whether this potential translates to greater yields on the farm level is something we have not considered.

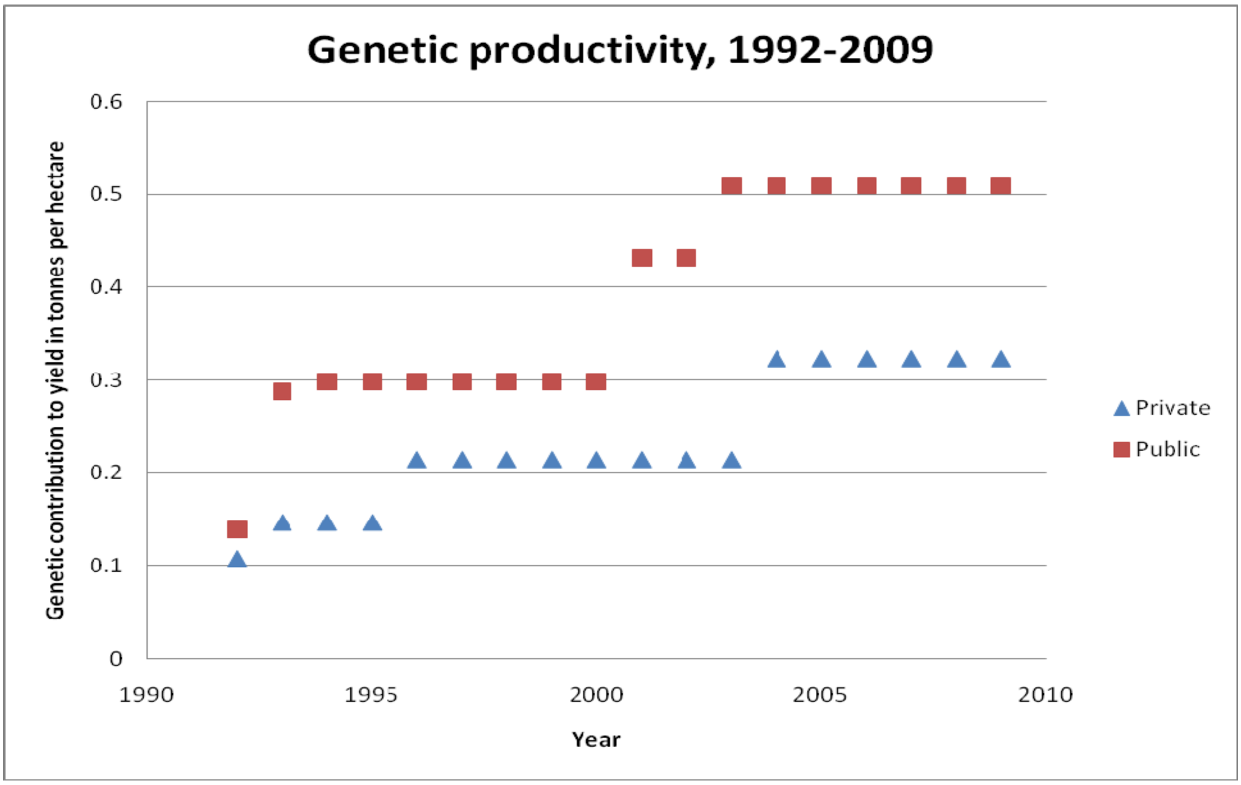

Figure 1 Genetic contribution to yield at the frontier

However, this advantage is based on an average value, that is, on average yield performance. If we take the maximum unobserved effects from year to year we are able to derive a kind of frontier for the change in productivity which can be directly attributed to the genetics of a particular variety, and we are able to estimate the unobserved effect for that variety exclusive of the effect of private breeding.

Figure 1 shows the contribution to yield in tonnes per hectare of the varieties whose genetics had the greatest contribution to yield in each year. We have charted these contributions over the period 1992-2009. There are instances where varieties which are still commercially available drop out of the trials and the maximum effect falls from one year to the next. We have made the assumption in this graph that this variety is still commercially available, and only consider improvements in the maximum effects from year to year. The graph of unobserved effects from the Hausman Taylor estimator shows the "underlying varietal effect" which is net of the private effect on yield of varieties. We have in our graph differentiated the top genetically producing varieties according to each year. It is interesting to note that although private varieties have performed better on average over the period, all of

Table 2 Varieties with best performing underlying genetics in each sector

	Privately bred varieties			Publicly bred varieties		
Year	Variety	Breeder	Genetic contribution	Variety	Breeder	Genetic contribution
1992	HYBRID APOLLO	HYB Wheat Aust	0.108	DIAMONDBIRD	NSW DPI	0.139
1993	HYBRID MERCURY	HYB Wheat Aust	0.147	SILVERSTAR	VIC DPI	0.288
1994	HYBRID MERCURY	HYB Wheat Aust	0.147	TRIDENT	Uni Adelaide RAC	0.298
1995	HYBRID MERCURY	HYB Wheat Aust	0.147	TRIDENT	Uni Adelaide RAC	0.298
1996	H45	HYB Wheat Aust	0.215	TRIDENT	Uni Adelaide RAC	0.298
1997	H45	HYB Wheat Aust	0.215	TRIDENT	Uni Adelaide RAC	0.298
1998	H45	HYB Wheat Aust	0.215	TRIDENT	Uni Adelaide RAC	0.298
1999	H45	HYB Wheat Aust	0.215	TRIDENT	Uni Adelaide RAC	0.298
2000	H45	HYB Wheat Aust	0.215	KRICHAUFF	Uni Adelaide Waite	0.298
2001	H45	HYB Wheat Aust	0.215	EGA GREGORY	QLD DPI&F	0.432
2002	H45	HYB Wheat Aust	0.215	EGA GREGORY	QLD DPI&F	0.432
2003	H45	HYB Wheat Aust	0.215	WAAGAN	NSW DPI	0.509
2004	SENTINEL	Longreach	0.324	WAAGAN	NSW DPI	0.509
2005	SENTINEL	Longreach	0.324	WAAGAN	NSW DPI	0.509
2006	SENTINEL	Longreach	0.324	WAAGAN	NSW DPI	0.509
2007	SENTINEL	Longreach	0.324	WAAGAN	NSW DPI	0.509
2008	SENTINEL	Longreach	0.324	WAAGAN	NSW DPI	0.509
2009	SENTINEL	Longreach	0.324	WAAGAN	NSW DPI	0.509

the varieties whose genetic characteristics make the greatest contribution to yield have been developed and released under public breeding programmes. A list of the varieties with the best performing genetics, in both the publicly and privately bred categories, is provided in Table 2.

6. Conclusion

Our results show that breeders' efforts to improve varieties by selection of favourable genetic traits have led to productivity increases. Whether the introduction of various types of IPRs, and the subsequent privatisation of the industry) has had a positive effect on this process is still open to debate. What our results show is that varieties from commercial wheat breeding programmes (which have developed since the introduction of IPRs in the Australian plant breeding industry) have on average outperformed publicly bred varieties. However, it should be noted that this privatisation is recent, and that there is now very little public breeding. If it is accepted that continued breeding over time should continue to improve genetic contribution it would be expected that on average the yield contribution of varieties would be greater in the private era. However it should also be recalled that much of the current breeding program is based on germplasm which has been the result of over a century of public plant breeding. We have not been able to quantify the value of that contribution.

We can say that on average private breeding programmes have resulted in more productive varieties over the period. This can suggest that Plant Breeder's Rights, which has played a role in promoting commercialisation of wheat breeding, has had a positive effect on productivity working through improved varieties. This could be considered as evidence in favour of IPRs for plant varieties and a vindication of the monopoly profit incentive thesis about intellectual property for plant protection (Godden 1982,1998).

However, when considering the varieties with the most productive genetics it is mostly public varieties that dominate. The varieties which have had the highest genetic contributions to yield since 2001 tend to be publicly bred varieties, as can be seen from table 2. It therefore appears that if we are concerned specifically with the maximum contribution to yield of the genetic characteristics of wheat varieties, then we need to be aware that some publicly bred varieties perform better.

In this study we limit ourselves to estimating the effect of a number of variables on yield per hectare, and do not take into account changes in costs, changes in input/output mix, or changes in risk, among other things. These aspects could provide a basis for future research. It would be interesting to investigate the effects of varietal change on factors other than yield, for example on quality, disease resistance and other factors which farmers consider when adopting varieties (Barkley and Porter 1996; Godden and Brennan 2002). Studies of on-farm effects which consider varietal adoption rates can better show the effect that changes in the breeding industry have produced.

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Appendix

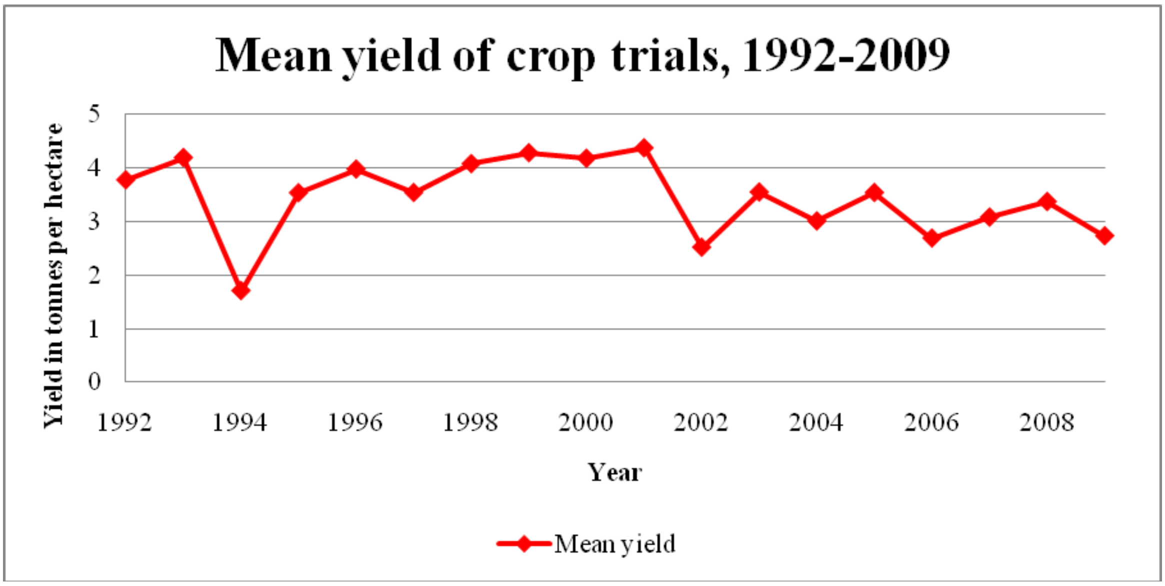

Figure 2 Mean yield in each year of the crop trial

Table 3 Definition of variables

Variable	Definition
Yield (t/ha)	The dependent variable is grain yield in tonnes per hectare. Site mean yields are used.
Nitrogen (mg/kg)	This is nitrogen levels in the soil in milligrams per kilogram measured at a depth of 10cm
Phosphorus (mg/kg)	This is phosphorous levels in the soil in milligrams per kilogram measured at a depth of 10cm
pH ($CaCl_2$)	This is a measure of pH levels in the soil
Nitrogen unknown	A variable to account for Nitrogen (mg/kg) being unknown
Phosphorus unknown	A variable to account for Phosphorous (mg/kg) being unknown. The Colwell soil test is used.
pH unknown	A variable to account for pH ($Cac1_2$) being unknown
Organic carbon unknown	A variable to account for Organic carbon (%) being unknown
Organic carbon (%)	The percentage of naturally occurring carbon in the soil at the trial site
Alluvial	A binary variable for an alluvial soil texture at a site
Loam	A binary variable for a loam soil texture at a site
Loamy clay	A binary variable for a loamy clay soil texture at a site
Sandy	A binary variable for a sandy soil texture at a site
Sandy Clay loam	A binary variable for sandy clay loam soil texture at a site
Sandy Loam	A binary variable for sandy loam soil texture at a site
Unknown	A binary variable for an unknown soil texture at a site at a site
Nitrogen (kg/ha)	A variable that measures nitrogen fertiliser application to a trial in kilograms per hectare
Phosphorous (kg/ha)	A variable that measures phosphorous fertiliser application to a trial in kilograms per hectare
Sodium (kg/ha)	A variable that measures sodium fertiliser application to a trial in kilograms per hectare
Fertiliser unknown	A binary variable that indicates that fertiliser application for a trial is not reported. It only indicates those for which none of the fertiliser applications (in nitrogen, potassium and sodium) is reported.
Monthly rainfall	Monthly rainfall in millimetres
Average monthly maximum temperature	Average monthly maximum temperature in degrees celsius
Average monthly minimum temperature	Average minimum temperature in degrees celsius
NVT	A binary variable to account for a change in trial management from the Department of Primary Industries run Heron Crop Trials to the National Variety Trial (NVT) system
Early	A binary variable that indicates whether a trial is early season or main season
Irrigated	A binary variable that indicates whether a trial is irrigated or not
North-East	A binary variable that indicates whether a trial is conducted in north-east NSW or south-east
South-West	A binary variable that indicates whether a trial is conducted in south-west NSW or south-east
North-West	A binary variable that indicates whether a trial is conducted in north-west NSW or south-east
Private	A binary variable that indicates whether a variety is produced by a private breeding program or a public breeding program