# PLANT VARIETIES, INTELLECTUAL PROPERTY RIGHTS AND INNOVATION IN UK AGRICULTURE

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***Abstract***

*Starting with a brief overview of trends in plant variety protection (PVP) in the UK since inception of PVP legislation, this paper assesses the strength of incentives for innovation provided by the PVP regime. We modify and extend models from the patent literature that attempt to infer the private value of innovations from the behaviour of titleholders in relation to the annual renewal of protection. Our results suggest that the average private return to protection from new wheat varieties is fairly modest and that the distribution of these returns is highly skewed. This implies that a large proportion of PVP certificates have very little economic value. The move towards stronger forms of protection for plant variety innovations and the (successful) clamour from the industry for imposition of royalties on farm-saved seed of protected varieties can be understood as a response to the declining returns from variety innovations in agricultural crops brought about by increasing competition and accelerated turnover of varieties. Anecdotal evidence regarding the declining viability of conventional plant breeding for agricultural crops in the UK is also supported by our results.*

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## Introduction

The United Kingdom has been a pioneer in the establishment of intellectual property protection systems for plant variety innovations. Plant variety protection (PVP) has been implemented in the United Kingdom for almost four decades now with the avowed objective of stimulating innovation in plant breeding. Although variety innovations have been recognised as one of the key determinants of agricultural productivity growth (Evenson and Gollin: 2001), systematic studies on the impact of intellectual property rights (IPR) regimes on the generation of agricultural innovations have been limited. The incentive effects of IPR regimes and their impact on the generation of innovations have become a major concern for policy in the context of significant institutional change in the organisation of agricultural research in the UK, with greater emphasis being placed on the role of the private sector, particularly for "near-market" research.

From a policy perspective, a key question is whether the incentives for innovation provided by existing IPR regimes and institutional arrangements for agricultural research are adequate. Concerns regarding the adequacy of incentives have been heightened by a number of studies (DEFRA: 2003) showing a sharp slowdown in the growth of total factor productivity in UK agriculture since the mid-1980s, which coincides with period of institutional change in agricultural research. The withdrawal of some high-profile multinational seed firms from conventional plant breeding programmes in the UK appears to indicate declining enthusiasm of the private sector for conventional plant breeding on account on declining economic returns. Policies designed to encourage plant variety innovation also need to take into account the emergence of agricultural biotechnology. The application of biotechnology to agricultural innovations calls for investments of a much higher order of magnitude than that required for conventional plant breeding. With the private sector playing a dominant role in this area, stronger forms of protection appear to be required for stimulating innovations based on biotechnology.

This paper will focus on the incentive effects of PVP in the UK in the generation of new plant varieties. This paper will attempt a quantitative estimation of the returns appropriated by innovators in the UK from variety innovations. This will provide an empirical basis for assessing the incentives for innovation provided by IPR systems over the period of the study. The analysis will address the question of whether there is an economic case for stronger IPR regimes to stimulate crop variety innovations. The empirical application will be to wheat variety innovations in the UK protected through plant variety protection over the period 1965-2000.

**Data**

With legislation enacted in 1964, the UK has four decades of experience in the implementation of plant variety protection. Among EU countries, it has been one of the leading issuers of PVP certificates. Thus, the data for the UK are able to provide fairly large cohort sizes for agricultural and ornamental crops.

A key element of this study was assembling a comprehensive dataset on plant variety protection certificates issued in the UK since inception of PVP legislation to 2000. This dataset was put together from the information contained in various issues of the *Plant Varieties and Seeds Gazette* published by DEFRA[1] over this 36 year period. The dataset covers all species/genera of plants that have been protected in the UK and contains 13,365 records (including both grants and unsuccessful applications).

There are three important components of the total cost of obtaining a PVP certificate. These are (a) application fee (b) examination fee for DUS[2] testing and (3) annual renewal fee for keeping the certificate in force. While the application fee is a one-time fee, the examination fee has to be paid for each year or growing season over which the variety is tested and the renewal fee has to be paid each year. Data was provided by DEFRA on PVP application, testing and renewal fee schedules for the

[1] Department of Environment, Food and Rural Affairs in the UK and its predecessors.
[2] Distinctness, Uniformity and Stability.

period 1964-2000. Data on renewal fees is essential for the application of renewal models to PVP certificates. It must be noted that PVP fee schedules are periodically revised. When a schedule is revised, the revised fees apply to all PVP certificates renewed after the revision, irrespective of the cohort to which they belong. The fees applicable in nominal terms were converted into real terms (2005=100) using the retail price index for UK. The key features of renewal fees in the UK have been summarised in Srinivasan (2006).

For our empirical application to wheat varieties, we require not only the details of PVP certificates issued in the UK but information on the economic performance and other characteristics of varieties. The quantum of seed sold of protected wheat varieties in different years was estimated from seed certification data for the UK published by the National Institute of Agricultural Botany. Data on total usage of wheat seed in the UK, share of farm saved seed, price of wheat etc was obtained from DEFRA and FAO statistics.

**Overview of PVP in the UK**

The data used for the analysis is described in Table-1 and Table-2.

**[Tables 1 and 2 here]**

As in most other countries with PVP legislation, PVP grants are dominated by ornamental crops. Grants for ornamentals account for 50% of all grants, while agricultural crops (which include cereals) account for only 32%. The remaining 18% is accounted for by grants for horticultural crops (mainly fruit species). The proportions are similar when we consider the currently valid grants. It is somewhat surprising that an IPR instrument which is primarily intended to encourage innovation in agricultural crops (food crops and industrial crops) has its greatest impact on the generation of ornamental varieties. As discussed later, this may be partially explained by the differences in the appropriability regime for agricultural and ornamental crops. There are statistically significant differences in the survival patterns of varieties in different crop groups (Table-2). Ornamental and horticultural varieties survive for significantly longer durations than agricultural varieties. The Kaplan-Meier survival functions for PVP certificates of the three crop groups for all cohorts from 1965-2000 is plotted in

Figure-1. The survival function for ornamentals completely dominates the survival function for agricultural varieties – that is, at any age the proportion of ornamentals surviving is greater than agricultural varieties. For all crop groups, the mean/median survival duration of PVP certificates is considerably less than the maximum duration of protection allowed under the legislation of 20-25 years. Only 40 to 60% of PVP certificates for agricultural crops survive for more than five years and less than 30% survive for more than ten years. Less than 3% of the certificates survive for the full term. The average agricultural variety survives remains protected for only for 6 years. The fact that on average IPR royalties are collected by breeders over a relatively short time span has important implications for the appropriability of returns from variety innovations.

**[Figure-1 here]**

There are significant differences in the survival pattern of varieties within crop groups across decades. For the purpose of analysis we have divided the entire period into three time periods- 1965-1980, 1980-1990 and 1990-2000. The data for these three time periods is summarised in Tables 3 and 4 and the Kaplan-Meier survival functions is plotted separately for each time period in Figure-2. The mean and median period of survival of varieties within crop groups has steadily fallen from the 1960s to the 1990s. This shows that the turnover of varieties quickened over the three decades. The declining mean period of survival in the context of an increase in the number of PVP grants indicates that new varieties have been faced with increasing competition over time. The relative patterns of survival have remained the same, with the survival function for ornamental varieties dominating that of agricultural varieties in all the three time periods.

**[Tables 3 and 4 here]**

**[Figure 2 here]**

**Appropriability models**

The incentive effects of the PVP regime cannot be assessed by the number of varieties protected in different crop categories over a period of time. The difficulty lies in attributing causality to the PVP regime in the development of new varieties. Even prior to the enactment of PVP legislation, new varieties were being developed – and it is quite possible that new varieties that would have been developed anyway are merely taking advantage of protection once PVP law is enacted. The research effort of public sector institutions[3] in the development of new varieties could also be quite unrelated to the incentive effects of PVP. Therefore, in order to assess the stimulus for innovation provided by PVP, we need to look at the economic returns[4] that can be appropriated by innovators as a result of protection. Large economic returns would imply that the IPR regime provides stronger incentives for innovation.

While estimating the returns to protection, it must be noted that innovators and plant breeders can and do use various methods to protect their innovations including IPRs (patents or PVP certificates), trade secrets, different forms of first mover advantage etc (Levin et al.: 1987; Cohen, Nelson and Walsh: 1996). The decision to seek IPR protection for an invention or a new plant variety depends on the costs and benefits of these alternative benefits. For example, in the case of hybrids, trade secrets based protection of parental lines may provide adequate protection for a new variety. The private value of IPRs, which represents only the *incremental* returns that could be generated by holding IPRs, must be distinguished from what could be earned using alternative measures (Schankerman: 1998). It is important to note that the private value of PVP certificates does not constitute the entire value of returns to innovation in plant breeding.

Plant variety protection certificates are seldom marketed or traded and hence their private value is usually not observed. In the patent literature a number of models have been developed (e.g., Schankerman and Pakes (1986), Pakes (1986)), that attempt to infer the value of plant variety rights from the economic responses of PVP certificate holders. These models rely on the fact that in almost all countries with PVP legislation, certificate holders must pay an annual renewal fee in order to keep the certificate in force. If it is assumed that certificate holders make their renewal decisions based on the value of returns they obtain from the renewal, then the data on renewal of PVP certificates and

[3] The research effort of public sector institutions may be determined by the mandates and budgetary allocations given to them.
[4] Note that the reference here is to private returns which can be appropriated by innovators and not to social returns.

renewal fee schedules contains information on the *private* value of PVP rights[5]. Such a renewal model implies that protected plant varieties for which protection is more valuable (e.g. because it commands a larger market share) will be protected by payment of renewal fees for longer periods of time. A breeder will not renew protection for a variety for which he sees no commercial potential. The estimates of the private value of PVP certificates derived from renewal models can be used to supplement the data on the *number* of PVP certificates as a measure of inventive output. It is also possible to estimate how the average value of PVP certificates differs across crop groups or over time. If the distribution of the value of PVP certificates is highly skewed and dispersed, then the number of certificates granted alone may not be a good indicator of the value of breeders' innovations.

Schankerman and Pakes (1986) assume that each cohort of PVP certificates is endowed with a distribution of initial returns, which decay deterministically thereafter. The model allows both the distribution of initial returns and the decay rate to vary over time. It is assumed that certificate holders choose the lifespan of the certificates so as to maximise the discounted value of net returns (i.e. current returns minus renewal fees). Schankerman and Pakes show that for a given schedule of renewal fees, these assumptions imply a sequence of renewal proportions over age for each cohort. The proportion of PVP certificates renewed in each year depends on parameters, which determine the distribution of initial returns and the decay rates. Their model estimates a vector of parameters, which makes the renewal proportion predicted by the model as close as possible to the ones actually observed.

Pakes (1986) has extended the renewal model by allowing patent holders to be uncertain about the returns in each time period and using a dynamic programming approach to model the patent holders'

[5] Renewal models by their very nature can estimate only the private value of PVP certificates, which *can* be appropriated by the IPR holder. As Schankerman and Pakes (1986: p. 1069) observe: 'It should be emphasised that these estimates refer only to the *private* value of patent rights. We cannot address the broader question of social benefits of patent protection with the present model of renewal behaviour. The social benefits must encompass both the private value and gains in consumer surplus created by the additional R&D effort which is stimulated by patent protection (these latter gains, of course, continue after the patent has expired).' The self-reproducing nature of seed implies that breeders have considerable difficulty in appropriating returns from their innovations. The renewal model used in this paper also estimates only the private returns that can be appropriated by the plant breeder or the certificate holder.

renewal behaviour. In Pakes' model, patent holders renew the patent if the discounted value of expected future returns plus the current returns exceeds the renewal costs. One advantage of this model is that it does away with the rigid and somewhat unrealistic assumption of a deterministic decay rate of economic returns from patents and allows for the possibility of future returns being greater than current returns. The expected future returns are explicitly taken into account in the patent holder's renewal decision.

The patent renewal models described above have generally been estimated using large aggregated patent datasets in which the information available is restricted to the proportion of patents in each cohort that failed to be renewed at any given age. While these patent data sets are large (containing several thousand patents in different countries) they do not have any associated patent specific information such as the economic performance of a patent during its protected life, ownership characteristics or the degree of competition faced from newer innovations[6].

The dataset on PVP certificates, which we will be using in our analysis, is a much richer data set containing information on characteristics and performance of individual protected varieties. For instance, our dataset contains information on the quantity of certified seed sold of a protected variety in each year of protection. The data also suggest that the assumption of a deterministic decay rate, as in the Schankerman and Pakes (1986) model may be inappropriate for PVP certificates. In the case of protected plant varieties, the returns to breeders accrue by way of royalties on the sale of seed of protected varieties. These royalties (which are generally fixed per unit volume of seed sold) are related to the total volume of seed sold of protected varieties. Most new plant varieties generally experience an adoption lag in which seed sales for a variety increase before they reach their adoption peak. After reaching their peak, seed sales tend to decline as the variety is replaced by newer varieties. Figure-3 shows that for varieties in our sample, the average amount of certified seed (which we use as a proxy for seed sold) indeed follows the characteristic pattern of adoption and replacement.

[6] For example, information on royalties generated by licensing of the patent in different years, whether owned by public or private institutions, number of new competing innovations etc.

**[Figure-3 here]**

Our theoretical model is an adaptation of the model used by Schankerman and Pakes (1986) to study the private value of patents in post-1950 Europe. We slightly modify this model to make it suitable for the estimation of private returns to plant variety protection. Our decision-making agent is the owner of a plant-variety protection certificate. In order to keep the certificate in force, the owner has to pay an annual renewal fee denoted by $C_{it}$, where the subscript I denoted the protected variety and the subscript t denotes the present lifespan of the PVP-certificate. If the renewal fee is paid, the certificate is renewed and the owner receives the implicit returns to protection $R_{it}$ during the following year. We assume (following Schankerman and Pakes 1986) that the PVP-owner has complete knowledge of the all the $R_{it}$ over the life of the variety and chooses the optimal length of protection T to maximize her net returns[7]:

$$\max_{T \in \{1,2,\dots,\bar{T}\}} V(T) = \sum_{t=1}^{T} (R_{it} - C_{it})(1+i)^{-t}$$

where i is the discount rate and $T^{-}$ is the maximum length of plant variety protection.

Though the level of seed sales is certainly not the only factor influencing the value of a PVP-certificate, it seems reasonable to assume that it plays a large role in determining it. Thus, we assume that, like the average pattern of seed-sales, the returns to plant variety protection follow an inverted U-shaped curve, which is non-decreasing until it reaches the adoption peak at time $T^{peak}$, and non-increasing afterwards.

Under this assumption the PVP-owner will renew protection until the first year in which the renewal-fee exceeds the returns ($R_{it} < C_{it}$) to protection and the variety is past its adoption peak ($T \geq T^{peak}$). There are two possibilities for corner solutions. Either there exists no T such that the discounted sum

[7] Like Schankerman and Pakes we do however allow for uncertainty in our empirical model.

of net returns V (T) is positive, in which case the optimal length of protection is 0 (i.e. the owner of the variety will not seek to protect it), or there exists not T such that $R_{it} < C_{it}$ and $T \geq T^{peak}$, in which case the optimal length is the maximum possible length of protection T.

**Empirical model**

In order to exploit the information on the survival duration of individual varieties and their characteristics available in the dataset, we use a discrete time survival model (Singer and Willet). In this model the survival of a variety in each time period is influenced a number of determinants (e.g., quantity of certified seed sold) affecting current returns and expected future returns. This allows us to assess the relative importance of different factors influencing the longevity of a variety. In addition, by calibrating the model we are also able to retrieve the estimates of private returns appropriated from PVP certificates.

Since it follows from our theoretical model that (provided that protection of the variety is profitable at all) any T before the adoption peak cannot be an optimum length of protection, we consider only those observations in which varieties are past their adoption peak (i.e. those for which $t \geq T^{peak}$).

We assume that R is a function of a vector of explanatory variables X. In this we include characteristics of the variety as well as other possibly important variables such as the price of wheat that may affect appropriability. The explanatory variables are discussed separately below. We also include an error term ε that is distributed normally with mean 0 and variance $\sigma^2$, to capture measurement errors as well as uncertainty about future returns to the protection of a variety. It follows from our theoretical model that a PVP-certificate for variety i is renewed in year t if

$$R(X_{it}) - C_{it} + \varepsilon_{it} \geq 0$$

and surrendered otherwise. Thus, the probability of renewal is

$$\Pr\left(R\left(X_{it}\right) - C_{it} + \varepsilon_{it} \geq 0\right) = \Phi\left(-R\left(X_{it}\right) + C_{it}\right)$$

The likelihood-function of the observed data for variety i is therefore:

$$L\left(X_i, C_i\right) = \prod_{t=1}^{T-1}\left[\Phi\left(-R\left(X_{it}\right) + C_{it}\right)\right]\Phi\left(R\left(X_{iT}\right) - C_{iT}\right)$$

The total likelihood-function is the product of the likelihood functions of the individual varieties.

Choosing a linear functional form for R(X) yields the Probit-model, in which a PVP-certificate is renewed when

$$R\left(X_{it}\right) - C_{it} = \alpha + X_i\beta - \gamma C_{it} + \varepsilon_{it} \geq 0$$

where α is a constant and β and γ parameters to be estimated. A well known limitation of the Probit-model is that not all of the parameters of the model are simultaneously identified. This is usually dealt with by normalizing the variance to 1 and estimating the other parameters conditional on this normalization. For our present purpose this is not satisfactory since we are interested in the economic value of the PVP-certificates in money-terms. Fortunately, since our theoretical model suggests that the coefficient associated with the renewal fee C is equal to -1, we are able to circumvent this problem by imposing the restriction of $\gamma$=-1, which then allows us to estimate the other parameters in the model. This normalization also ensures that the parameters can be directly interpreted as the effect of the variables on the value of the PVP-certificate denoted in Pound Sterling.

## Results

The empirical model was estimated for protected UK wheat varieties as a stacked probit model, in which the dependent variable is the status of the protected variety (renewed or not renewed), in each time period (which is generally a year or a fraction thereof). The covariates are allowed to vary in each time period, thus for a variety which survives for 10 years, there will be ten rows of observations. Two econometric models were estimated; an extended one which includes a wide variety of explanatory variables and a parsimonious one in which only variables whose coefficients were statistically significant at least at the 10% were included. A brief description of the variables and their expected impact on survival is given below:

Variety Specific Variables:

*Quantity of seed certified (tonnes):* This is used as a proxy for the quantity of seed sold in the UK. The larger the quantity of certified seed sold of a protected variety, larger the royalties and greater the probability that protection for the variety will be renewed.

*Protected under CPVO (dummy):* A variety which is protected in other EU countries in addition to the UK is likely to have seed sales in those countries that will generate royalties for the breeder and, hence, will have a higher probability of renewal of protection.

*Age of PVP certificate (years):* We are considering only those observations beyond the peak adoption period. Consequently, in the declining phase of sales of a protected variety the probability of renewal is likely to decrease with the age of the variety (protected duration).

*Quantity of seed certified at peak adoption (tonnes):* This is an indicator of the quality and market share potential of the variety. Larger quantity of seed certified at peak adoption is likely to increase the probability of survival.

*Any seed certified during the period of protection (dummy):* There are a number of protected varieties which never have any sales of certified seed during the entire tenure of protection. For such a variety, the probability of non-renewal during any time period is likely to greater than that for a variety which has achieved some certified sales previously.

*Grant year 1998 or later (dummy):* 1998 was the year in which plant breeders were allowed to collect royalties on farm saved seed (on varieties granted protection after a cut-off date), following EU legislation and the amendments to the UK PVP legislation. We do not have data on the use of farm-saved seed of protected varieties in the post-1998 years. However, it is to be expected that varieties on which the collection of royalties on farm saved seed was allowed (albeit at a lower rate than on certified seed) would have a higher probability of survival in any given time period than varieties on which royalties could be collected only on certified seed sales.

General variables:

*Current year 1991 or later (dummy):* The clamour from the industry for stronger protection and for royalties on the use of farm-saved seed (which hitherto had not been in existence) emerged in the 1990s possibly as a response to the declining returns realised by breeders from new varieties. This dummy is used to assess whether returns from PVP certificates did in fact decline in the post 1990 period.

*Fraction of wheat seed saved on farm:* An increase in the proportion of farm saved seed used for the crop is likely to exert a downward pressure on royalty rates for certified seed. Breeders may have to lower royalty rates in order to promote the sale of certified seed. Thus, an increase in the proportion of farm saved seed may imply lower total royalties for protected varieties and would increase the probability of non-renewal.

*Price of wheat (pounds/tonne):* A higher price of wheat may be associated with farmers being willing to pay higher royalty rates and thus may increase the probability of survival of a variety.

*Total wheat seed used in UK (tonnes):* This is an indicator of the overall size of the market. The impact of an increase in market size on the survival of individual varieties is not unambiguous. In general we would expect an increase in the demand for wheat seed to be associated with higher royalty rates. However, if the increased demand is as a result of extension of cultivation to marginal areas associated with increased use of non-protected or zero-rated varieties, then the impact of increased seed use on royalty rates is not clear.

*Average yield (hg/hectare):* A higher yield per hectare may also be associated with greater willingness to pay higher royalties and may contribute to higher probability of survival for a variety.

*Concentration index of seed certified by variety:* The concentration index of seed varieties is the Herfindahl index based on the market share of protected varieties and is used as an indicator of market power. A higher degree of concentration may indicate a higher level of market power that enables higher rates of royalties to be charged, thus increasing the probability of survival.

*Number of new varieties in the current year:* This is an indicator of the additional competition faced by a given variety in the current period. Increased competition is likely to lower the probability of survival.

*Renewal fee 2004:* Higher the renewal fee, lower the net return for titleholders which is likely to decrease the probability of survival.

Table -5 reports the results of the regressions.

**[Table-5 here]**

As would be expected the value of a PVP-certificate increases with the amount of seed certified in a given year and the amount of seed certified at the peak of adoption. The value of certified seed seems to be not quite linear, since even small non-zero amounts of seed add significant value to the certificate. Also, protection under CPVO increases the value of the certificate significantly. The likely reason for this is that seed of varieties that are protected under CPVO is sold in other EU countries. This is not included in our seed data, which is therefore likely to be an under-estimate of actual seed-sales of CPVO-protected varieties. A look at the general variables shows that the value of PVP-certificates has significantly decreased after the year 1990. Their value also decreases with an increase in the amount of wheat seed sown in the UK. The increase in average yield leads to an increase in the value of PVP-certificates as does increased concentration of seed sales at the varietal level. This is quite intuitive since as wheat yields increase, protected varieties are worth more to farmers who are therefore willing to pay a higher premium. The concentration index probably reflects the effect of market power that allows companies to charge a higher premium for protected varieties. It is worth noting that PVP-certificates that were granted in 1998 or later are not significantly more valuable than those granted before. These certificates fall under the provisions of the Plant Varieties Act of 1997 which requires farmers to pay royalties on farm saved seed. The purpose of this new legislation, which was strongly backed by the British plant breeding industry, was to increase the private return to investments in plant breeding. Our results suggest that the Plant Varieties Act has not achieved this objective.

Also reported are the coefficients that are obtained by normalizing the coefficient of the renewal fees to equal -1. In accordance with our theoretical model these coefficients can be directly interpreted as money values denoted in Pound Sterling (deflated with base year 2005). To get an idea of the value of PVP-certificates the values of the certificates in our sample were calculated using the estimated coefficients (Table-6).

**[Table-6 here]**

As can be seen in Table 6, the values of the PVP-certificates in our sample are surprisingly low. These results should however not be over-interpreted. The crucial parameter for the estimation of the money-values is the coefficient associated with the renewal-fees. Unfortunately the standard error of this coefficient is very high, probably because there is too little variation in the renewal fees over time. Thus there is a great deal of uncertainty associated with our point estimates. What can however be said with certainty is that, as in the case of patents, the distribution of values is highly skewed. As shown in Figures 4 and 5, there are a large number of PVP-certificates that have values close to 0 and only a few with very high values.

The figures also show that even though the predicted point-values differ significantly between the models, the shapes of the distributions are very similar.

**[Figures 4 and 5 here]**

**Discussion**

The enactment of PVP legislation in the UK has been followed by large flows of new varieties of agricultural, horticultural and ornamental crop species. However, competition between newly emerging varieties has led to accelerated turnover of agricultural crop varieties with a significant decline in the average longevity of new varieties over the last three decades. Our empirical analysis of protected wheat varieties shows how a decline in the average survival duration of protected varieties, a substantial increase in the proportion of farm-saved seed and a shrinking seed market have sharply reduced the appropriability of private returns from the protection of new varieties – particularly since the early 1990s. This diminished appropriability of returns from protection appears to be mainly responsible for the clamour from the seed industry for stronger protection. The changes to the EU/UK legislation in the mid-1990s circumscribing the use of farm-saved seed and allowing the collection of royalties on farm-saved seed can be seen as a response these trends. Our analysis suggests that arrangements for collection of royalties on farm-saved seed, although helpful to breeders, are yet improve the appropriability of returns from varieties significantly. It is perhaps somewhat early for the full impact of these changes to be reflected in the data. The response of the industry to the declining appropriability of returns is likely to be three-fold. Firstly, demands for stronger IPRs for plant varieties will continue to be made. Secondly, the industry is likely to move towards innovations for which stronger forms of protection are available. Biotechnology based innovations (e.g., genetically modified varieties) are likely to receive greater attention from the seed industry than conventional plant breeding. Thirdly, the use of alternative forms of protection like trade secrets or so-called terminator technologies (which do not rely on PVP law) is likely to increase. The stimulus for the development of new varieties that may have been provided by PVP also appears to have contributed to the decline in the viability of conventional plant breeding.

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**Table-1: Data for survival analysis by Crop Group (Cohort range 1965-2000)**

| Crop Group | Total number of PVP certificates | Number of expired/surrendered/ terminated certificates | Number of valid certificates as at 31/12/2000 (censored cases) | Percent censored |
|---|---|---|---|---|
| Agricultural | 2313 | 1794 | 519 | 22.44 |
| Horticultural | 1262 | 983 | 279 | 22.11 |
| Ornamental | 3556 | 2584 | 972 | 27.33 |
| Overall | 7131 | 5361 | 1770 | 24.82 |

**Table-2: Mean and median survival durations**

| Crop group | Mean survival duration (years) | Median survival duration (years) |
|---|---|---|
| Agricultural crops | 6 | 4 |
| Horticultural crops | 9 | 5 |
| Ornamental crops | 8 | 5 |

**Test Statistics for Equality of Survival Distributions of Different Crop Groups**

| Test | Statistic | df | Significance |
|---|---|---|---|
| Log Rank | 154.42 | 2 | .0000 |
| Breslow | 112.22 | 2 | .0000 |
| Tarone-Ware | 128.02 | 2 | .0000 |

**Table-3: Data for survival analysis by crop group and time periods**

| Crop Group | Total number of PVP certificates | Number of expired/surrendered/ terminated certificates | Number of valid certificates as at 31/12/2000 (censored cases) | Percent censored |
|---|---|---|---|---|
| **Cohort time period 1965-80** | **1683** | **1648** | **35** | **2.08** |
| Agricultural | 439 | 433 | 6 | 1.37 |
| Horticultural | 416 | 396 | 20 | 4.81 |
| Ornamental | 828 | 819 | 9 | 1.09 |
| | | | | |
| **Cohort time period 1980-90** | **2399** | **1944** | **455** | **18.97** |
| Agricultural | 782 | 710 | 72 | 9.21 |
| Horticultural | 468 | 359 | 109 | 23.29 |
| Ornamental | 1149 | 875 | 274 | 23.85 |
| | | | | |
| **Cohort time period 1990-2000** | **3049** | **1769** | **1280** | **41.98** |
| Agricultural | 1092 | 651 | 441 | 40.38 |
| Horticultural | 378 | 228 | 150 | 39.68 |
| Ornamental | 1579 | 890 | 689 | 43.64 |
| | | | | |
| **Total for all crop groups and cohort time periods** | **7131** | **5361** | **1770** | **24.82** |

**Table-4: Mean and median survival durations**

| **Crop group** | **Mean survival duration (years)** | | | **Median survival duration (years)** | | |
|---|---|---|---|---|---|---|
| Cohort time period | **1965-80** | **1980-90** | **1990-2000** | **1965-80** | **1980-90** | **1990-2000** |
| Agricultural crops | 7 | 6 | 4 | 7 | 4 | 3 |
| Horticultural crops | 8 | 9 | 6 | 6 | 6 | 4 |
| Ornamental crops | 8 | 9 | 6 | 5 | 6 | 6 |

**Test Statistics for Equality of Survival Distributions of Different Crop Groups**

| Test | Statistic | df | Significance |
|---|---|---|---|
| Log Rank | 154.42 | 2 | .0000 |
| Breslow | 112.22 | 2 | .0000 |
| Tarone-Ware | 128.02 | 2 | .0000 |

**Table -5: Regression results for discrete time survival models**

| | Model 1 (extended) | | Model 2 (parsimonious) | |
|---|---|---|---|---|
| Variable | Coefficient (Standard Error) | Normalized coefficient | Coefficient (Standard Error) | Normalized coefficient |
| Constant | 0.922 (0.746) | 2013.4 | 0.369 (0.630) | 435.8 |
| *Variety-specific variables* | | | | |
| Quantity of seed certified (tonnes) | 0.000291 (7.43e-005)*** | 0.635 | 0.000292 (7.40e-005)*** | 0.345 |
| Protected under CPVO (dummy) | 0.928 (0.208)*** | 2026.1 | 0.902 (0.203)*** | 1065.4 |
| Age of PVP-certificate (years) | -0.113 (0.0151)*** | -246.9 | -0.112 (0.0137)*** | -132.3 |
| Quantity of seed certified at adoption peak (tonnes) | 2.13e-005 (4.38e-006)*** | 0.0465 | 2.16e-005 (4.34e-006)*** | 0.0255 |
| Any seed certified during life of variety (dummy) | 1.10 (0.106)*** | 2398.6 | 1.11 (0.105)*** | 1315.2 |
| Grant year 1998 or later (dummy) | -0.0379 (0.167) | -82.83 | | |
| | | | | |
| *General variables* | | | | |
| Current year 1991 or later (dummy) | -0.664 (0.224)*** | -1450.0 | -0.660 (0.168)*** | -779.6 |
| Fraction of wheat seed saved on-farm | -0.843 (1.22) | -1841.6 | | |
| Price of wheat (pounds/tonne) | 0.00152 (0.00653) | 3.310 | | |
| Total wheat seed used in UK (tonnes) | -8.04e-006 (4.17e-006)* | -0.0176 | -4.39e-006 (1.37e-006)*** | -0.00519 |
| Area planted with wheat (hectares) | -5.20e-007 (3.50e-007) | -0.00114 | | |
| Average yield (hg/hectare) | 4.13e-005 (1.44e-005)*** | 0.0903 | 1.82e-005 (7.818e-006)** | 0.0215 |
| Concentration index of seed certified by wheat varieties | 5.62 (2.63)** | 12262.8 | 6.58 (2.01)*** | 7777.8 |
| Number of varieties protected in current year | -0.00385 (0.00637) | -8.405 | | |
| Renewal fees (2004 pounds) | -0.000458 (0.000422) | -1 | -0.000847 (0.000354)** | -1 |

***,** and * denote statistical significance at the 1%, 5% and 10% levels

**Table -6: Estimated values of PVP-certificates (summary statistics)**

| | Model 1 | Model 2 |
|---|---|---|
| Average value | 26,828 | 15,849 |
| Median value | 11,581 | 6,992 |
| Maximum value | 531,330 | 293,530 |
| Minimum value | 615 | 659.9 |
| Number of varieties | 374 | 374 |

All values in 2005 Pound Sterling

**Figure-1: Kaplan-Meier Product Limit Estimates of Survival Function of PVP Certificates of Different Crop Groups**

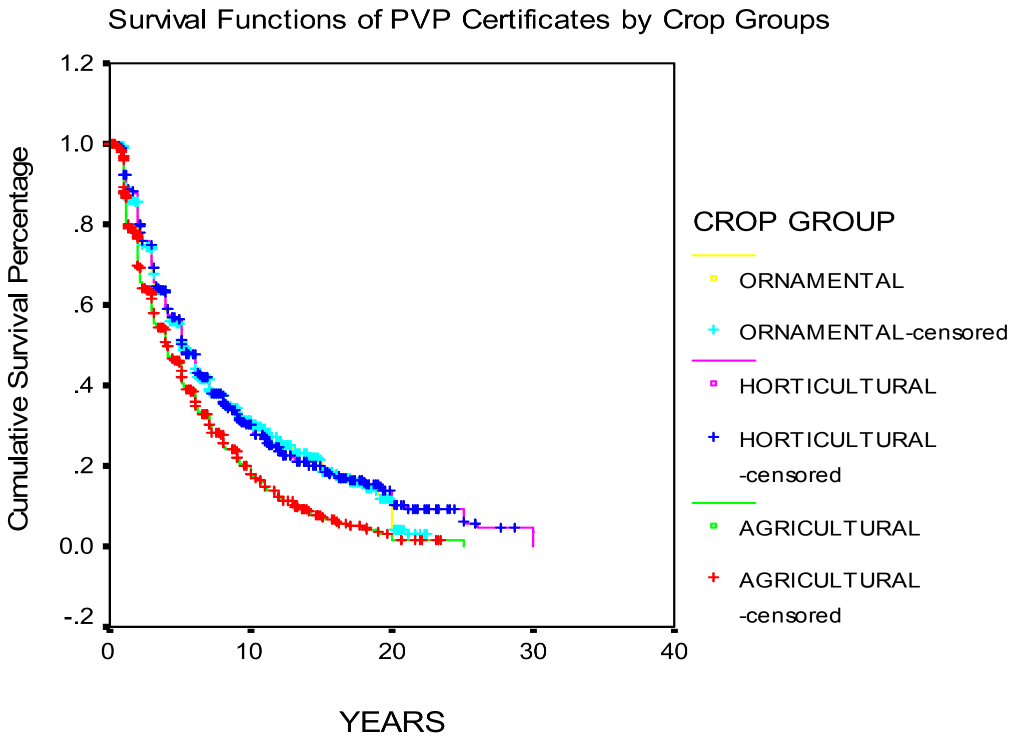

**Figure-2: Kaplan-Meier Product Limit Estimates of Survival Function of PVP Certificates of Different Crop Groups by Time Periods**

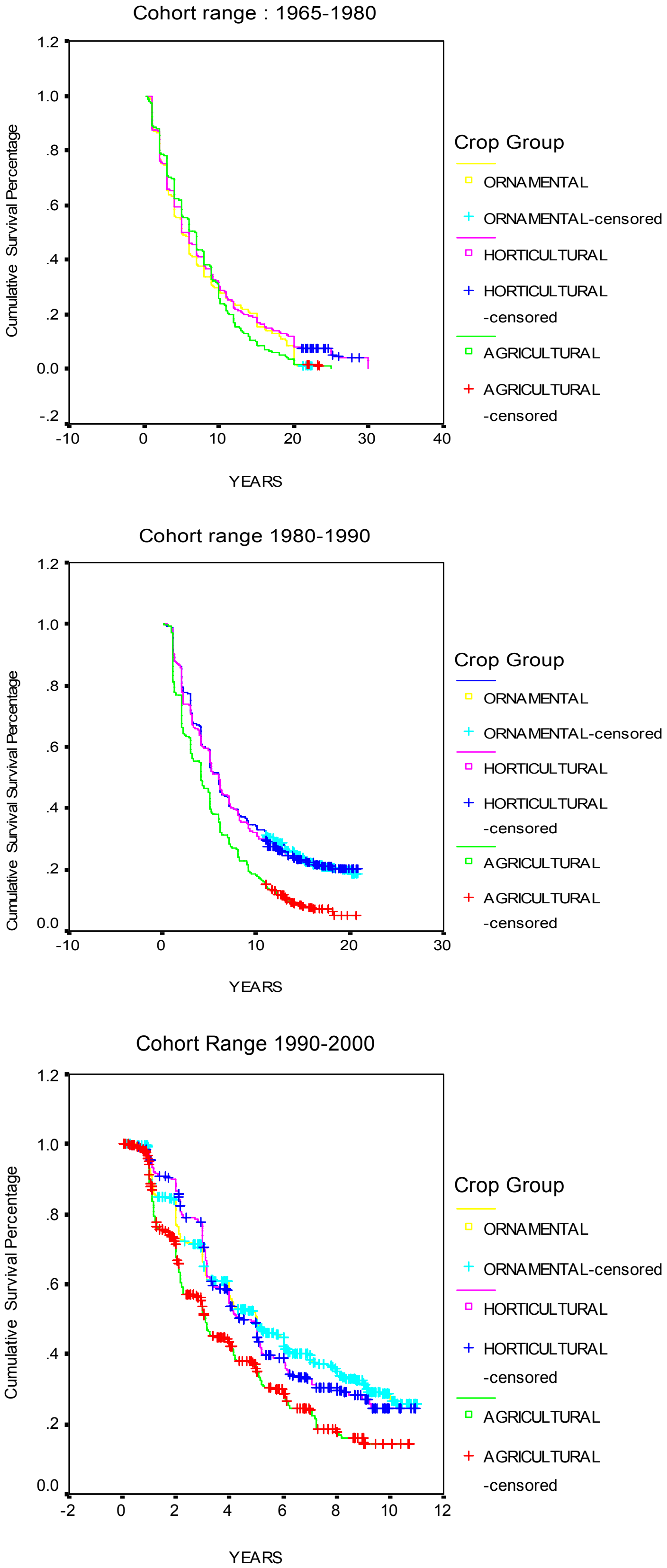

**Figure-3: Average time path of adoption of protected wheat varieties in the UK**

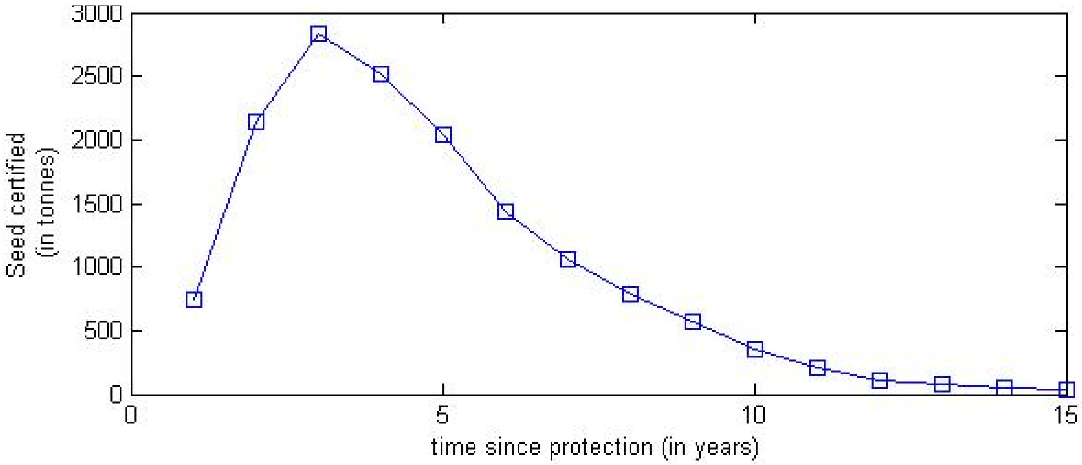

**Figure-4: Histogram of estimated values of PVP certificates (Model 1)**

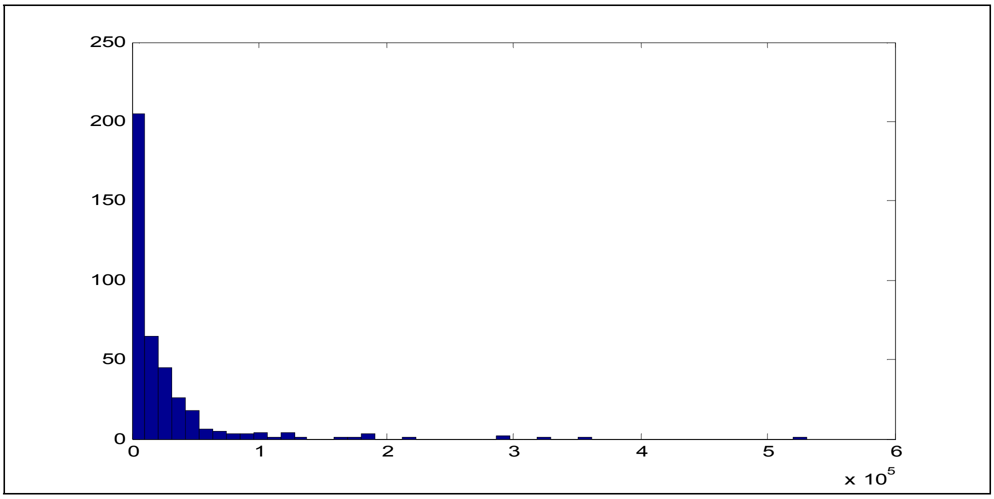


**Figure-5: Histogram of estimated values of PVP certificates (Model 2)**