R&D Appropriability and Planned Obsolescence: Empirical Evidence from Wheat Breeding in the UK (1960-1995)

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Paper prepared for presentation at the X^th^ EAAE Congress
'Exploring Diversity in the European Agri-Food System',
Zaragoza (Spain), 28-31 August 2002

Xth Congress of the European Association of Agricultural Economists

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First draft: May 2000
Second revision: August 2000[1]
Third revision: December 2000[2]
This version: August 2001

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Plant breeders face a unique appropriation problem – plants are reproducible, genetic information is heritable and seeds can be multiplied. The paper uses indicators of varietal age as a proxy for durability to examine strategies of planned obsolescence. Using wheat breeding in the UK, evidence of strategies of planned obsolescence is confirmed. This is then corroborated with evidence of tendencies towards increased proliferation of varieties on the market and breeding strategies that focus on incremental productivity improvements (i.e. increased efficiency) and narrow and limited disease resistance (i.e. reduced durability).

Keywords: Planned Obsolescence, R&D appropriability, Innovation, Plant Breeding

JEL Codes: L13, O31, Q10

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[1] Published as Economics Discussion Paper 00/6. October 2000. School of Economics, Kingston University, UK.

[2] Submitted to *Industrial and Corporate Change* – January 2001. Revised and resubmitted in August 2001. Awaiting final acceptance.

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1. Introduction

Industrial sectors differ in their preferred appropriation strategies. Empirical studies of appropriation strategies indicate variations in preferred instruments and the sectoral differences in the effectiveness of specific instruments (see, Levin et al., 1989). Despite this rich literature, the evolutionary economics literature has not examined the special case of durable goods. However, models predict that oligopolists producing durable goods face incentives to reduce the durability of the good so as to induce regular replacement purchases by consumers, and thus ensure the appropriation of the returns to investments in R&D (Coase, 1972; Bulow, 1986; Waldman, 1993).

With these theoretical insights, the paper analyses the case of plant breeding, using wheat breeding in the UK for the years 1960-95 as a case study. Plant breeding provides a unique appropriation problem: plant varieties are easy to reproduce and multiply, and, for the most part, genetic characteristics are heritable, enabling a seed to replicate itself. Consequently, producers of genetic information face a problem in inducing farmers into regular replacement purchases. The problem in plant breeding, compared to other durable goods, is compounded by secondary competition from other breeders, seed merchants and farmers. A solution to this problem is to reduce the durability of varieties whilst simultaneously improving the efficiency of new vintages, i.e. planned obsolescence.

The use of strategies of planned obsolescence in plant breeding has been recognised in the literature (Berlan and Lewontin, 1986; Lim, 1993), though clear analytical treatment and, more importantly, empirical evidence has remained lacking. The novelty of the paper thus lies in providing a useful methodology to study the case of planned obsolescence in plant breeding by relating the dual technoeconomic focus on efficiency and durability respectively to breeding strategies that are directed towards either incremental productivity improvement or limited and narrow disease resistance profiles.

The paper is outlined as follows. It begins with a review of the literature concerning appropriation strategies in the context of durable goods, which suggests that monopolists face perverse incentives to undermine the durability of a good. The next section identifies the specific appropriation problem faced by breeding companies and briefly outlines possible options to appropriate the returns to investments in R&D. This is followed by an analysis of the case of planned obsolescence in wheat breeding in the UK, where empirically quantifiable indicators for varietal durability are developed and calculated. The section presents evidence of planned obsolescence in terms of (a) increasing proliferation of varieties, (b) diminishing varietal age, and (c) breeding strategies aimed at reducing varietal durability manifested in narrow disease resistance profiles.

2. Theoretical Review

Durable goods present a special situation concerning intertemporal links on the demand side. As the good exists across time periods, the supply of goods at different time periods are (imperfect) substitutes rather than complements (Tirole, 1988, pp. 72-73). Since future demand for the good is truncated by the durability of the product, the monopolist involuntarily engages in intertemporal price discrimination to capture residual demand[1]. In an extreme case where price revisions are all too frequent, it has been conjectured that trade would take place at a price close to marginal cost causing monopoly profits to be eliminated (Coase, 1972). It is possible to avoid the 'Coase Conjecture' and charge the monopoly price, if the monopolist is either able to make a

[1] Ideally, the firm would like not to price-discriminate and sell the product at the monopoly price.

credible commitment not to introduce additional units in the future, or offer a buy-back policy for additional units sold in the future, or lease the product rather than sell it.

It is argued that "reduced durability may prove to be a better way out of the difficulty" of intertemporal demand compared to the options of leasing, credible commitment, or buy-back policies (Coase, 1972, p. 148). In the sense, repeated model revisions could ensure frequent replacement sales in the future thus making planned obsolescence a necessary condition for technical progress (Fishman et al., 1993)[2]. The issue then is whether market structures impose any pressure concerning the choice of durability. Waldman (1996) demonstrates that monopolists producing durable goods have perverse incentives promoting investments in R&D which enable introduction of new vintages that make older units obsolete. For example, a textbook publisher would not only introduce a new edition but also seek to make the new edition different from earlier editions (Waldman, 1993). In doing so, the publisher succeeds to 'kill off' the market for old editions, which ensures that new students buy the latest edition. Empirically, it is also important to examine whether sectors and technologies reveal idiosyncratic properties that foster the adoption of strategies of planned obsolescence as a preferred mechanism to restore and protect monopoly profits.

Variations in market structure place differing pressure on incumbent firms with respect to quality and speed of innovations. In competitive markets, a firm that lags in introducing an innovation may see its market share dwindle and be forced to exit the industry. Competitive adoption of the existing vintage is a necessary prerequisite for the firm to remain in the market, thus making it difficult for a firm to suppress an invention. The question remains whether similar forces exist within a monopolistic market structure (Bulow, 1986; Waldman, 1993). More specifically, firms in a monopolistic market structure are often suspected of either suppressing inventions[3] and/or producing goods with uneconomically short lives[4]. Equally compelling is the rapid introduction of new models and quality changes in a product that not only reduce the value of earlier vintages, but force consumers into patterns of regular replacement purchases, such as in automobiles (Galbraith, 1958).

The relationship between durability and market structure is highly complicated and number of different model predictions are available (see Bulow, 1982, 1986 for details). For example, it is predicted that a monopolist selling the product, who is not threatened by entry, would opt for lower durability. By reducing the durability of the product, the monopolist reduces the quantity of the good available in subsequent periods, which increases residual demand and acts as a compelling commitment towards not lowering prices in the future.

The above models suggest that new product development could be a proxy for strategies of planned obsolescence. Characterising R&D expenditures as an indicator of a firm's desire "to make [an] existing version of a product obsolete" would allow an empirical test of the hypothesis that

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[2] Ironically, while Fishman et al. think that they challenge the theoretical contributions reviewed here, their characterisation of the problem reconfirms the predictions of the models. It may very well be the case that maintaining a steady rate of 'incremental product improvement', which delivers technological progress, is the firm's preferred strategy of appropriation.

[3] The manufacturers of the QWERTY, who "had considerable financial interest in retaining the traditional keyboard", successfully suppressed the adoption of the Dvorak keyboard (Frost and Egri, 1991). Dvorak's non-jamming keyboard not only meant faster and easier typing, but reduced the demand for replacing and repairing typewriters. Other examples of suppressing inventions and adopting the less durable alternative exist in electric lamps, phonograph needles, stainless steel razor blades and electronic vacuum tubes (see Avinger, 1981 for details).

[4] When AT&T was forced by the Federal Communication Commission in 1981 to revert to selling its handsets instead of leasing them, the durability of handsets certainly fell (Scherer and Ross, 1990, p. 609).

firms which sell, as opposed to rent, are more disposed towards planned obsolescence (Goering et al., 1993, p. 609). Using sales/rental and R&D data for IBM and Xerox, Goering et al. (1993) establish that as a firm increases its proportion of sales vis-à-vis rentals it invests more heavily in R&D. This is indicative of an incentive to speed up the development of new products, which is evidence of strategies of planned obsolescence. However, if the firm lacks the ability to make credible commitments on future R&D levels, does it lack the appropriate incentives to invest in R&D (Waldman, 1993, 1996)? Within a network externality setting, if a monopolist does not rent, the result will be suboptimal incentives in the second-period, leading to lower durability which is socially and privately suboptimal (Waldman, 1993). However, in other settings, pursuing a strategy of investing in R&D to make older products obsolete could lead to improved social welfare, even while the monopolist's profits may suffer (Waldman, 1996).

3. The Appropriation Problem in Plant Breeding

The basic objective of commercial plant breeding is to produce new genetically uniform pure line cultivars – varieties that are genetically similar but distinguishable from other groups of plants within the same species (Poehlman and Sleper, 1995, p. 163-65)[5]. While there is little agronomic virtue gained from the focus on uniformity (Simmonds, 1979, p. 60), it enables varietal identification for the grant of intellectual property protection (Fejer, 1966; Berlan and Lewontin, 1986). That apart, genetic uniformity also enables the effective exploitation of scale and scope economies associated with the wider technology system surrounding uniform varieties, which then proliferates because of path-dependency, technoeconomic irreversibility and lock-in effects (Swanson, 1995). The method of producing new cultivars, despite biological and reproductive differences, involves three core steps[6]. The first step is to generate variation by assembling germplasm with the desired characteristics that are sought to be recombined within the new variety. This is followed by identifying the desired recombination using appropriate methods of varietal selection, tacit skills embedded in the breeder, such as the 'eye of the breeder', and variety testing. Finally, once the preferred variety is selected, it is necessary to maintain the distinguishing characteristics of the variety through repeated cycles of propagation. Breeders work under two fundamental constraints (Allard, 1960, p. 50-51):

- Selection cannot create variability but *plays* with the assembled variation. Hence, the initial need to assemble diverse genetic material to generate variation. Naturally, the more diverse the genetic material assembled by breeders in the initial stages, the greater the range of variation from which the breeder makes selections.
- Selection can only act upon heritable characteristics and has little impact on complex characteristics that are substantially contingent on agricultural practices, other inputs and the environment. As a result, breeders tend to *focus* on characteristics that are more easily inherited and retained in progenies, which thus form the *core* objectives of breeding programmes[7].

Paradoxically, the very success of a breeding programme in producing a new cultivar heralds an appropriation problem, which is unique compared to other durable goods. Apart from the

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[5] The focus on genetic uniformity is historically situated in the institutional choice exercised by breeders in the early decades of the 20th century, coinciding with the rediscovery of Mendelian genetics, as a means of separating and distinguishing breeding from farming (Rangnekar, 2000a).

[6] The identification of these steps is based on a review of plant breeding texts like Allard (1960), Simmonds (1979) and Poehlman and Sleper (1995).

[7] The terms 'focus' and 'core' are used in a manner consistent with the evolutionary economics tradition (Dosi, 1982, 1988; Sahal, 1990; Rosenberg, 1994).

obvious recycling option available to other consumers of durable goods, seeds can be multiplied. Thus, after purchasing a bag of seeds from the market, a farmer[8] can potentially enter the market as a supplier of 'similar' seeds[9]. Hence, the conundrum: why should farmers either return to the market for a fresh stock of seeds or pay a royalty on something they already possess (Berlan and Lewontin, 1986), particularly as most economically relevant characteristics are heritable (Buttel and Belsky, 1987)? Part of the answer lies in recognising the dual properties of varietal characteristics (i.e. genetic software) and physical attributes of the seed (i.e. diskette) (Lewontin and Berlan, 1990). As such, the durability of a variety is contingent on maintaining the software (i.e. purity of varietal characteristics) over repeated propagation and ensuring the reliability of the diskette mechanism (i.e. viability of seeds) as carriers of genetic information (Rangnekar, 2000b, chapter 6). Additionally, heritability of genetic characteristics differ across species, with natural out-crossing in cross-pollinated species causing loss of genetic purity[10]. To a considerable extent, these diskette-software factors mitigate against costless and easy market entry by 'copies'. Further, breeders adopt a number of different strategies to enable appropriation, which span regulatory, organisational, technological and market-based approaches:

- Intellectual property rights and seed market regulation: Intellectual property rights in plant varieties, i.e. plant breeders' rights (PBRs), tend to be the most widely noted and analysed solution to the appropriation problem (Godden, 1981, 1982; Dworkin, 1982; Lesser, 1987; Evenson, 1990). PBRs define the subject matter of protection as the plant variety, the latter being defined by varietal characteristics, and establish the scope of protection in terms of transactions involving the propagating material of the variety. Other regulations, such as seed certification, variety testing and national listing, are of crucial importance, though rarely studied in the literature. Yet some contributors draw attention to the importance of high standards of purity and quality under seed certification schemes in the European Union since the 1950s, which reinforced the differentiation between dedicated seed producers and grain farmers (Rangnekar, 2000b).

- Organisational solutions: Difficulties in appropriating the returns to R&D investments draws attention to information spillovers, or "untraded interdependencies", generated by the innovation process (Dosi, 1988, p. 1146). These spillovers can be controlled through a number of organisational strategies. For example, a firm or group of firms can maintain exclusive control over specialised assets that are specific to the innovation (Teece, 1990). Alternatively, firms might seek to horizontally and/or vertically integrate into allied activities producing goods and/or services that are closely linked to the innovation. In the case of seeds, many commentators have noted the merger and acquisition activity between seed companies and chemical companies (e.g. Mooney, 1983; Juma, 1989; Hobbelink, 1991). In addition, horizontal integration between breeders, seed merchants and down-stream processors has also been noted (Lim, 1993). Unilever's purchase of the public sector Plant Breeding Institute, Cambridge (UK) in 1987 is a reflection of this strategy (see table 1). Further, contracts that delimit the farmer's

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[8] While the discussion centres on farmers, it is obvious that other breeders and seed merchants can use an existing variety and compete with the original breeder in subsequent periods.

[9] In reality, the production of 'grain' and the production of 'seed' are not identical activities and require different skills and incur varying costs. 'Seed' production requires more care and monitoring to safeguard against genetic contamination of the crop – a requirement reinforced by regulation. It is for this reason that an industrial division of labour exists at the farm level separating grain farming from seed production.

[10] Wheat, the subject of the paper, is self-pollinated. Hence, with little out-crossing, the wheat plant tends to maintain its genetic constitution over a number of generations, which gives farmers the opportunity to retain a portion of harvested *grain* to use as *seed* in the next cycle of cultivation.

right in using genetic information (Marsden and Whatmore, 1994) are efforts at 'controlled diffusion' of the innovation.

- Discontinuous heritability[11]: This *technological* solution specifically tackles the problem of secondary competition by attacking the viability of the diskette mechanism (i.e. the seed) as carrier of genetic information. Discontinuous heritability may occur by making specific traits in the variety deteriorate over successive generations (Lim, 1993, pp. 52-53), as in F1-hybrids[12]. The economic sterility of saved seeds, as progenies do not retain the yield vigour of their parents, ensures that farmers return to the market for fresh seeds after each harvest (Rangnekar, 2000b). More recently, biological sterility, i.e. zero heritability, has been achieved with the development of 'terminator technology'[13], where the diskette breaks down completely upon single use, i.e. seeds saved from harvested grain do not germinate (Berlan and Lewontin, 1998).
- Planned obsolescence: The literature recognises that "a private breeder has a vested interest in reducing as far as possible the lifetime of his varieties towards the ideal that farmers should adopt new varieties every year" (Berlan and Lewontin, 1986, pp. 786-87). To achieve regular replacement purchases breeders could seek to modify the genetic software. For example, by introducing qualitative and quantitative changes in the latest vintage of varieties farmers could be induced to purchase the latest vintage (Lim, 1993, p. 52). Further, as will be demonstrated below, it is also possible to undermine durability by developing narrow disease resistance.

Clearly, "claims that infer [that] breeders cannot appropriate utility from plant breeding without PVR [i.e. plant variety rights] are exaggerated" (Godden, 1981, p. 29). Breeding companies may adopt any of the above options singularly or, as is more the case, in combination. The rest of the paper is an empirical analysis of the option of planned obsolescence as an appropriation strategy.

4. Appropriation through Planned Obsolescence

Seed market shares can be examined either at the varietal or the corporate level, where varietal market shares refer to the share of a single variety[14]. As companies invariably have a portfolio of varieties, corporate market shares are the summation of the relevant varietal market shares. Figure 1 brings together data on UK wheat varietal market shares for 1960-95[15], where the following tendencies are clearly marked. Firstly, the very high concentration ratios of the 1960s, where two varieties accounted for more than 80% of the total market, have diminished significantly. From the mid-1970s, the share of the market accounted by the top two and top five varieties has

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[11] Discontinuous heritability is a type of planned obsolescence. Yet, we differentiate between the two on the grounds that the former results from bio-technological solutions in the *method* of breeding plants that affect the diskette mechanism. In contrast, strategies of planned obsolescence are results of *normal* breeding of plants working through the genetic software of the variety.

[12] The history concerning the development of the technology of F1-hybrids is covered in Lewontin and Berlan (1990).

[13] The relevant patent was granted in March 1998 to the US Department of Agriculture and Delta and Pine Land Company, a private cottonseed company that was acquired by Monsanto in May 1998.

[14] All commercially transacted seeds in the European Union must be certified for its purity and authenticity (Ministry of Agriculture Fisheries and Food, 1993 for details). This certification process provides the data for generating market shares at the variety and/or company level. Market shares are based on the weight of seeds entering the certification process, which is the accepted practice in estimating market shares (e.g. Silvey, 1979, 1981). PBRs data collected from the Plant Variety Rights Office allows the identification of ownership in varieties across space and time to generate corporate market shares.

[15] Varieties that recorded market shares of $\geq 1\%$ are included in the figure.

fluctuated within a range of 30-50% and 70-80% respectively. Yet, these levels of concentration ratios are substantial given that wheat is self-pollinating and easy to replicate, and that breeders and farmers are legally permitted to either use or save the variety. The second marked feature is the increased proliferation of varieties, which is captured in the graphs labelled 'Next 5' and 'Balance' in figure 1. The market shares of these categories are significantly lower, varying between 10-23% and 5-13% respectively between 1975-95. However, the marked increase in the number of varieties is important to note. As figure 2[16] demonstrates, the number of marketed varieties in 1975 was 50% more than in 1965, while the number of protected varieties had doubled in the same period and tripled to 30 by 1980. Consequently, while an increasing number of varieties have successfully secured proprietary protection, only a small, but growing, subset are able to overcome the barriers to entry and establish market presence. To put this in perspective, of the total protected varieties, 46% never registered any market share.

In contrast to the dual tendencies of increasing proliferation of varieties and diminishing varietal concentration ratios from the mid-1970s onwards, market concentration at the company level continues to remain high (figure 3). The market share of the dominant company has consistently been above 35-40% throughout the period of study. In addition, there have been periods where the market leader has accounted for between 60-80%, such as the 1960s by Desprez and 1977-94 by Plant Breeding International (PBI).

Clearly the composition of the market leaders has changed during the period of study: in the 1960s and 1970s continental breeding companies like Desprez and Cambier were the market leaders; however, from the late 1970s domestic breeding companies, such as PBI, Nickersons and Zeneca have occupied this position. Interestingly, the latter companies have all been acquired by, and merged within, large multinational companies (cf. table 1). It is in this context of substantially high corporate market shares that the evidence of dual trends of increasing proliferation of varieties and diminishing varietal concentration ratios requires closer scrutiny and appropriate explanation.

[16] In this figure, the graph for marketed varieties includes those that recorded market shares of $\geq 0.5\%$.

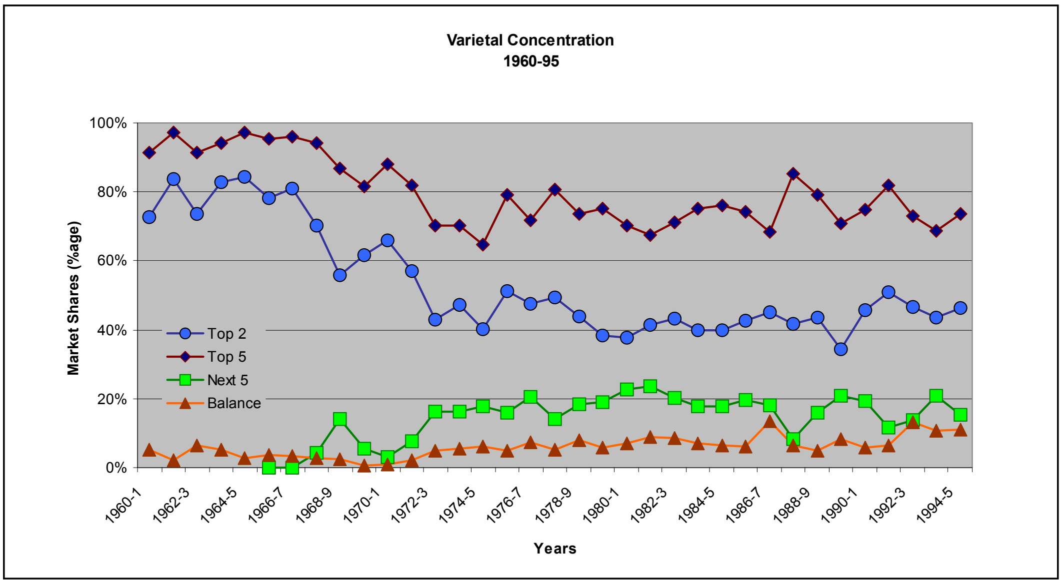


Figure 1

Figure 2

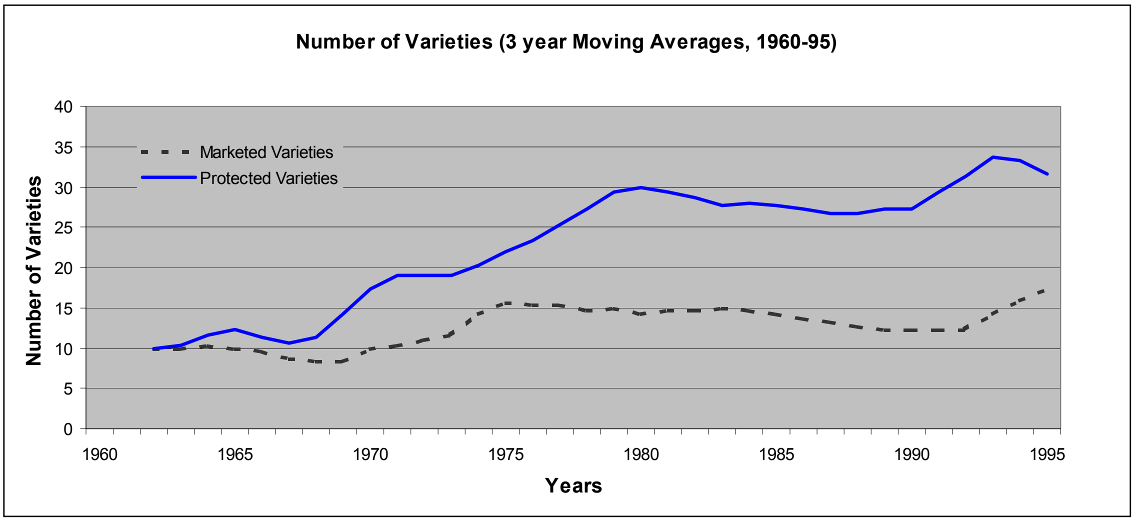
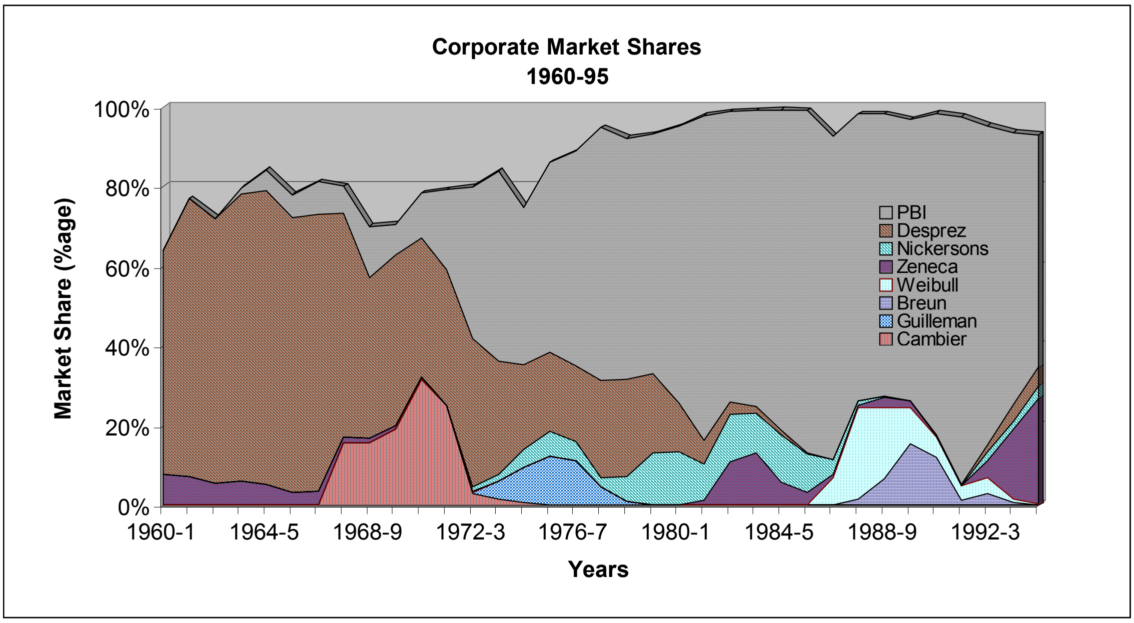


Figure 3



Of interest here is whether breeding companies have adopted strategies of planned obsolescence involving reduced durability and increased efficiency as a means to appropriate the returns to investment in R&D. Following the economic models reviewed earlier, could the direction of technical change be focussed towards improving *efficiency* whilst simultaneously reducing *durability*? The enhanced efficiency of newer vintages supported by the reduced durability of earlier vintages would together ensure regular replacement purchases. As such, empirical evidence of such strategies exists in the case of light bulbs, vacuum tubes for radios, and phonographic styluses (Avinger, 1981). For example, with respect to light bulbs, appropriation strategies and the direction of technical change focussed on (a) improving lamp efficiency but not in extending lamp life, (b) suppressing more durable alternatives, such as the introduction of fluorescent lamps and cold cathode fluorescent tubes. In the case of plant breeding the interlinking between increased efficiency and reduced durability could take any one of the following forms:

- The breeding effort: Breeders could focus on improving yield components (e.g. grain weight, number of ears, etc.) whilst compromising the disease resistance profile of the variety. Here, incremental productivity improvements act as an incentive for farmers to adopt the current vintage, while the limited disease resistance profile of earlier vintages militates against reusing saved seeds.
- Changing technology mix[17]: Changes in components within the seed-input package can render existing varieties obsolete and promote the adoption of newly introduced vintages. For example, in the case of genetically-modified organisms, where varieties are bred to be resistant/responsive to brand name chemical inputs, changes in the composition of the tightly interlinked seed-input package would induce the farmer to adopt the entire package. As such, piecemeal adoption of the package limits the extent of possible economic gain.

Independent of the specific strategy, an empirical referent for durability of varieties is the number of years a variety remains protected. As with other instruments of intellectual property protection, such as patents[18], we can safely assume that the decisions concerning renewing protection involve a cost-benefit matrix. These costs include the annual renewal fee and costs associated with maintaining the distinguishing characteristics of the variety[19]. On the other side of the matrix are considerations involving the market share of the variety and the available competition. Consequently, the number of years a variety remains protected is an economic decision taken by the company. Reductions in the age of varieties are indicative of reduced durability of plant varieties.

Table 1

Industrial History of Main British Wheat Breeding Companies

Breeding Company	**Parent Owner**	**Historical Developments**

[17] This also involves modifications in the breeding strategies; however, separate focus is essential to draw attention to the relationship between 'seeds' and 'inputs' in a component compatibility sense.

[18] See Griliches (1990) for supporting argument in the case of patents.

[19] To enable legal protection, plant varieties require some unambiguous method of identification that would allow consistent identification throughout the period of grant (Lange, 1985). Thus, article 10(2) of the Convention of the International Union for the Protection of New Varieties of Plants states the grounds for revocation of a grant as follows:

> The breeder or his successor in title shall forfeit his right when he is no longer in a position to provide the competent authority with reproductive or propagating material capable of producing the new variety with its morphological and physiological characteristics as defined when the right was granted.

Table 1

Industrial History of Main British Wheat Breeding Companies

Breeding Company	**Parent Owner**	**Historical Developments**
Plant Breeding International, Cambridge	Unilever (1987) Monsanto (1998)	Formerly a public institution of the UK government (Plant Breeding Institute, Cambridge), sold to Unilever in 1987, along with the National Seed Development Organisation. Later, purchased by Monsanto for US$525Mn.
Nickersons Seeds	Shell (1981) Limagrain (1991)	Initially an independent breeding company, purchased by Shell in 1981. Sold by Shell in 1991 to Limagrain, a French seed company.
Zeneca Seeds	Imperial Chemical Industries (1987) Advanta (c. 1996)	Formerly Miln Masters Group formed by combination of independent breeding companies in the UK. Purchased by ICI in 1987. Divested by ICI in 1993 and renamed Zeneca Seeds. Merged with van der Have (Nl) to form Advanta (c. 1996).
Source: Rangnekar (2000b).		

Using PBRs data it is possible to calculate the age of a variety, A_{it}, as the number of years at time t from the date of introduction/release of variety i[20]. Bringing together the data for all varieties, we can calculate <u>average age</u>, A_t, in year t as,

$$A_t = \sum_i A_{it} / \sum i \quad (1)$$

The above indicator of varietal age suffers from a number of problems, similar to those confronted in using patent statistics as indicators of inventive activity (Griliches, 1990; Cohen and Levin, 1988, for relevant details), such as the intersectoral differences in the propensity to patent, which in the case of plants could relate to inter-species differences, and overlapping patents or dormant patents. It is necessary to develop a more accurate indicator for varietal age to capture the dynamics of changing product life cycles associated with the appropriation strategies of breeding companies. Using market shares as weights is considered a useful correction (Brennan and Byerlee, 1991). The adjusted indicator is calculated as follows[21]:

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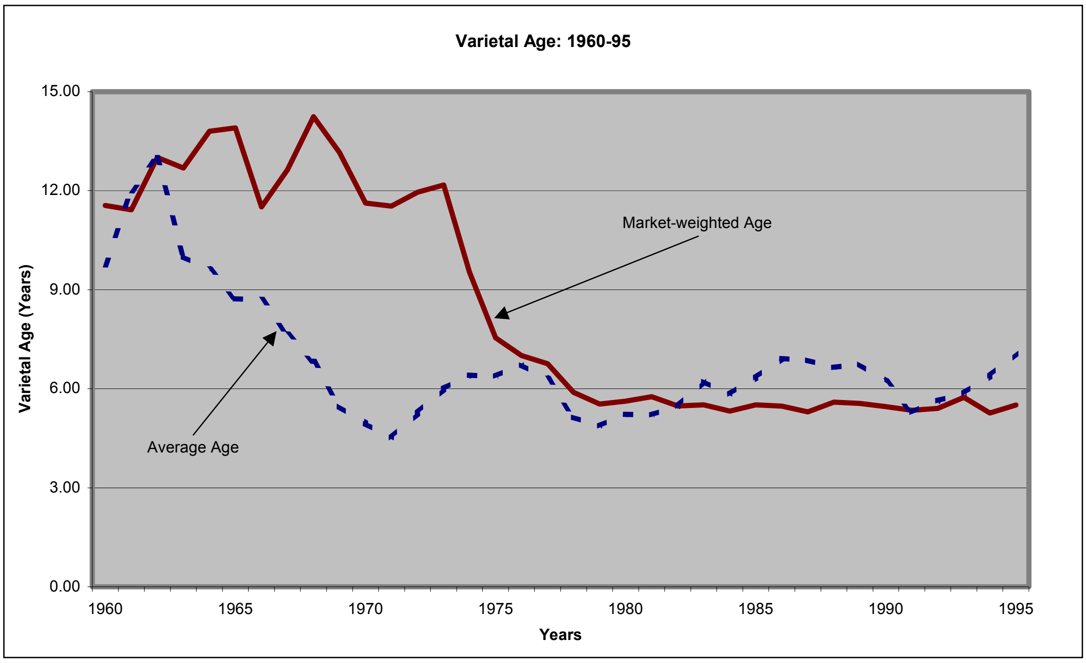
[20] The introduction/release date a variety is taken as the date protection was granted. Given the regulations controlling marketing of seeds and the availability of legal protection from 1964 it is unlikely that firms would introduce varieties without securing proprietary protection, a fact validated by scrutinising the data.

[21] The practice here follows Brennan and Byerlee (1991) who however term the indicator 'varietal turnover' to capture the *rate of varietal replacement on the field*. It has been pointed out that the construction of this 'rate' is misdirected and it is not a 'time-denominated' equation (Daly, personal communication, November, 1997).



$$\tilde{A}_t = \sum_i \Omega_{it} A_{it} \quad \text{..........} \quad (2)$$

where, $\tilde{A}_t$ is the market-weighted age of varieties in year t, and Ω_{it} is the market share of variety i in year t. Naturally, equation 2 only includes extant varieties with a corresponding market presence, whereas equation 1 gives the average age for all extant varieties.

Figure 4 brings together graphs for both indicators of varietal age for the period 1960-95. Three periods are distinguishable from the figure: an initial period, 1960-73, marked by relatively long-living varieties, a period of transition, 1974-78, marked by wide variation in varietal age, and finally, 1979-95, a period marked by short-lived varieties (table 2 for summary statistics).

Period 1 is distinguished by high values for both indicators of varietal age. In particular, market-weighted age, which tends to rise during this period, has a mean value of 12.51 years. In contrast, average age has a much lower mean value at 8.03 years and tends to decrease during this period. The reason for the difference between the two indicators is the persistent popularity of older varieties, such as Cappelle Desprez, Hybrid 46 and Koga, which were introduced in the 1940s-50s, and account for over 70% of the market through the 1960s. Hence, the relatively high value of mean market-weighed age. In comparison, average age falls dramatically throughout period 1. Importantly, the large variance and standard deviation indicate that many protected varieties are short-lived. In this respect, the introduction of legal protection under the Plant Variety and Seeds

Table 1: Varietal Age: Summary Statistics

Market-weighted Age	1960-73			1974-78			1979-95		
	Mean	Std. Deviation	Variance	Mean	Std. Deviation	Variance	Mean	Std. Deviation	Variance
Age	12.51	0.98	0.97	7.35	1.36	1.85	5.49	0.14	0.02
Max. Age	8.63	1.98	3.93	2.86	1.34	1.78	1.71	0.41	0.17
Average Age									
Age	8.03	2.67	7.12	6.19	0.61	0.37	6.05	0.67	0.47
Max. Age	25.07	2.76	7.61	27.6	6.58	43.3	15.52	2.28	5.19

Act (1964) provided stimulus for the release of new varieties that must have congested the borders of the market with potential entrants. Period 2, 1974-78, is a period of transition that is marked by a significant decrease in mean market-weighted age, the mean value having fallen by 41% in comparison to period 1. It is in this period that the number of plant varieties, both marketed and protected, increase: the average number of protected varieties per year in period 2 almost doubled compared to period 1 (cf. figure 2).

The increased proliferation of varieties is accompanied by greater varietal turnover rates. In the sense, while older long-lived varieties continued to remain on the market, there is increased market penetration by new varieties that exhibit higher rates of turnover. The latter dynamics, i.e. more rapid turnover rates, are reflected in the decreased variance around the mean average age of 6 years. The enhanced proliferation of varieties is an important component of the tendency towards reduced varietal lifespan.

In period 3, 1979-95, these tendencies of increased proliferation of varieties and shortening lifespan stabilise at lower mean values: 5.49 years for market-weighted age and 6.05 years for average age. Not only is market-weighted age now below average age, but also the variance is lower than before. Indicative of the tendency towards rapid varietal turnover is the 38% decrease in mean average age from its period 1 level. Compared to period 2, the numbers of marketed and protected varieties have only marginally changed[22]. This suggests that changes in varietal age are on account of increases in the rate of turnover. As such, the large number of protected varieties congests the borders of the market making market entry difficult. However, they also act as a pool of regularly changing varieties from which a select few enter the market for shortened durations.

Clearly, the period from the mid-1970s onwards marked a new phase of wheat breeding in the UK that involved a dual strategy of maintaining a broad portfolio of constantly changing (protected) varieties, each for a shortened duration. In this respect, the market leader PBI performance is telling. During the 1975-85 period it had a portfolio of 14 varieties per annum, while in comparison, competitors like Nickerson and Zeneca managed only 5 and 2 varieties per annum respectively. As such, the increasing proliferation of varieties from the mid-1970s accompanies diminishing life spans. Yet, to complete the exposition of strategies of planned obsolescence it is necessary to examine breeding strategies, as that would reveal the technoeconomic focus with respect to reduced durability and/or enhanced efficiency.

The focus on enhanced efficiency is evident in efforts aimed at achieving incremental productivity improvements in new vintages. One indicator of this effort would be yield. The adoption of dwarf wheats in the UK in the mid-1970s supported by widespread use of a range of chemical inputs (e.g. fertilisers, fungicides, herbicides, growth regulators, etc.) established a new technology mix that formed the basis for the yield increases. Breeders succeeded in exploiting the latent productivity by making the varieties amenable to the new mode of farming (e.g. closer cropping, intensive use of machinery, and chemical inputs). Average wheat yields increased from 4.05 t/ha in period 1 to 4.50 t/ha in period 2 and reached 6.44 t/ha in period 3. The 1994 wheat yield of 7.35 t/ha was just over double the 1960 yield.

Changes in varietal disease resistance profiles can be used as a proxy for breeding strategies aimed at durability. Developing genetic resistance to agronomic stresses and diseases is accepted as superior to the dependence on chemical inputs like fungicides, pesticides and herbicides (Bingham et al., 1991). Research conducted at the National Institute of Agricultural Botany, UK explores the relationship between varietal resistance and the changing significance of diseases in part motivated by evidence of increased importance of the disease *Septoria tritici* amongst UK wheats in the 1980s (Bayles, 1991). Field tests were conducted to examine the level of varietal resistance, which were

[22] The respective averages for 1993-95 is markedly higher at 17 and 32.

than mapped to the year of release of the variety, to enable a temporal examination of disease resistance profiles. The following evidence is indicated:

- The majority of varieties with superior resistance were introduced prior to 1976 (e.g. Cappelle Desprez, Bouquet, Maris Huntsman, Flinor, Atou, Mega).
- The most susceptible varieties were introduced between 1977-83 (e.g. Bounty, Hobbit, Longbow, Brigand, Norman, Avalon, Kinsman).
- Mean susceptibility of UK wheat increased sharply through the late 1970s and early 1980s, reaching its maximum value in 1982-84[23].

Clearly, varieties of more recent vintages tended to have higher susceptibility. The effort to seek and develop improved genetic sources of disease resistance relaxed as fungicide use, introduced in 1970, and other growth regulators became widespread. Breeders themselves tended to focus more on securing incremental yield increases while tackling the disease resistance problem through the *continuous* development and introduction of new varieties with narrow and specific resistance (Rangnekar, 2000b)[24]. Further, the proliferation of varieties with lower disease resistance profiles had a knock-on effect on mean susceptibility across wheat farms. The period identified by Bayles corresponds to the widespread adoption of dwarf wheats and the phenomenal increase in chemical inputs into agriculture. During this period, yield gains proved to be the dominant development goal (Interview, breeder: January, 1997). By adopting the chemical fix approach toward disease resistance, the industry proceeded along a "treadmill" cycle: a particular genetic software-chemical package being promoted until disease susceptibility leads to its abandonment, after which another package is introduced to resolve the specific disease susceptibility[25]. Importantly, this strategy requires the continuous production and adoption of new varieties, not only to replace the susceptible varieties, but also as an insurance against unforeseen changes in the disease profile. In this manner, limited disease resistance profile leads to reduced durability of the variety which, combined with regular incremental productivity improvements, ensures the regular adoption of new vintages. Hence, the conclusion that wheat breeding companies in the UK adopted strategies of planned obsolescence.

Conclusion

The paper provides empirical insights into R&D appropriability in plant breeding through a focus on strategies of planned obsolescence. Breeders face a unique appropriation problem: not only are varieties a durable good, in that genetic characteristics are heritable, but easy reproducibility of seeds allows farmers, competing breeders and seed merchants to enter the market, thus aggravating the problem of secondary competition normally faced by a durable good producer[26]. Hence, the specific interest of the paper in examining how corporate breeders have been able to appropriate the returns to investments in R&D, particularly since corporate market shares have remained remarkably high (cf. figure 3).

[23]Bayles used national acreage of each variety to weigh the recorded susceptibility for each year to arrive at this result.

[24]The development of new varieties to replace susceptible older varieties indicates a degree of interdependence between the limited disease resistance profile of earlier vintages and the piecemeal nature of reworking the profile of resistance in contemporary varieties.

[25]Simmonds (1979) draws attention to this boom-bust cycle of varietal popularity and susceptibility.

[26] Yet, as noted earlier (cf. fn10), the mode of propagation of the species and attendant costs in maintaining the software purity (i.e. varietal characteristics) and diskette reliability (i.e. viability of the seed), mitigate against easy and costless misappropriation.

Adoption of strategies of planned obsolescence has been recognised in the literature (Berlan and Lewontin, 1986; Lim, 1993). However, an empirical identification of the same has not yet been conducted. Evidence reported here establishes that market-weighted age has fallen from a high of 13 years (1960s) to 5.5 years (1990s). This decrease in the life span of varieties has been accompanied by a proliferation of varieties. In terms of the breeding effort, the strategy of planned obsolescence is apparent in the dual focus of improving the efficiency (i.e. yield increases) whilst simultaneously ensuring reduced durability (i.e. narrow and limited disease resistance), inducing farmers to regularly purchase fresh seeds.

Importantly, the evidence reported here suggests that strategies of planned obsolescence might have a lower bound, in that the average life-span of varieties appears to have stabilised around a value of 5.5 years (cf. figure 4)[27]. To an extent breeding companies face a 'credible commitment problem': how often to introduce new varieties and how substantive should the qualitative change be in the new vintage? This is similar to the problem faced by textbook publishers (cf. Waldman, 1993). A substantial delay in introducing a new edition (i.e. new varieties) allows older editions (i.e. earlier vintages) to enjoy some value, while a more dramatic change in the new edition forces 'students' (i.e. farmers) to adopt it. Yet, if these dramatic changes are all too regular, students might prefer to 'lease' the book rather than buy a personal copy.

In the case of the seed market, companies tend to introduce new varieties on an annual basis so as to maintain a broad portfolio of regularly changing varieties. However, 'textbook revisions' tend to be nominal, with annual yield increases in the 1-2% range. It is the susceptibility of varieties, i.e. reduced durability that acts as a stronger factor in motivating adoption of the new variety. It is difficult to speculate on the future level of average varietal lifespan, in part because models predict that firms may prefer to collude on the rate of obsolescence as means to increase industry-wide profits (cf. Bulow, 1986). Empirical evidence validates this insight (cf. Avinger, 1981).

Two important questions remain in terms of the evidence of planned obsolescence in plant breeding. First, how does the evidence reported here relate to other strategies of maintaining monopoly control, in particular the use PBRs? A number of aspects of the PBRs system aid and abet the dual breeding strategies underlying planned obsolescence. To state briefly, the absence of a merit test for the grant of protection allows the introduction of varieties that register nominal productivity improvements whilst also might possess limited and narrow disease resistance. Remarkably, in the 1950s-60s breeders in Europe worked hard to establish a PBRs system that, in contrast to patents, did not have a merit test (cf. Rangnekar, 2000b for details). Second, is the methodology and evidence presented here an idiosyncratic feature of wheat breeding or generalisable to other crops? We suspect that planned obsolescence is an appropriation strategy that might be adopted by breeding companies across a range of crops. For example, much of genetic engineering innovation has resulted in the development of herbicide-tolerant crops, which provides a closer interaction between software (i.e. variety) and components (i.e. inputs). Consequently, not only is there a greater premium on adopting the complete variety-input technology package, but changes in either the variety or the inputs requires the adoption of the new technology package. Yet, we suspect there will be idiosyncratic characteristics in the innovation-appropriation dynamics at the species level. Additional research into breeding programmes across a variety of crops would shed useful insights. Equally, an analysis of farmer adoption issues, which have been totally neglected here, would be insightful.

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[27] I am grateful to one of the anonymous referees for raising this point and suggesting further clarification.

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