An Analytical Model of Farmers' Demand for Replacement Seed

Paul W. Heisey and John P. Brennan

Seed replacement choices differ from decisions about other inputs, such as fertilizer, because the farmer can reproduce seed. Assumptions about rates of improvement in yield potential and depreciation of retained seed are combined with behavioral assumptions and price and technical information to develop a model predicting the number of years before a farmer will buy new seed. Parameter estimates for wheat in Pakistan are fed into the model and results compared with observed replacement times. Time horizon strongly conditions effects of model parameters. To speed varietal change, better information for farmers is likely to be preferred to seed subsidies.

Key words: Pakistan, seed replacement, time horizon, varietal change, wheat.

The purchase of new seed of a variety that a farmer is already growing, varietal replacement in general, and varietal choice during periods of rapid technological change are examples of seed replacement choices. A seed replacement choice differs from decisions about other inputs, such as fertilizer or labor, in that seeds can be reproduced for the next crop season. Benefits from the purchase of new seed can continue for several years, and purchased seed is a self-sustaining input, although it is subject to depreciation. Replacement seed is, therefore, in some ways analogous to a capital item rather than a variable input.

Agricultural economists, in general, have considered only the analysis of varietal choice with rapid technological change. Theoretical (Nowshirvani) and empirical (Herath, Hardaker, and Anderson; Gafsi and Roe) studies of varietal choice tend to model the farmer's decision as a single period portfolio allocation of land between modern and traditional varieties. Thus, the attributes of interest are yield, moments of the yield distribution, and occasionally other varietal characteristics. Other approaches to analyzing farmers' choice of seed technology emphasize how a related input (fertilizer, tubewells) affects the level and riskiness of return (Feder 1980, 1982). Prices, risk, the lumpiness of the associated inputs, and possible credit constraints determine the portfolio choice over time in these models. In none of these approaches is the more general case of demand for replacement seed explicitly recognized.

This paper proposes an analytical model of the demand for replacement seed. The model describes the factors that induce a farmer to replace seed and the optimal frequency of new seed purchase given myopic and infinite time horizons. The model is applied to wheat seed demand in Pakistan. Conclusions, limitations, and possible extensions of the model are also considered.

Model of Seed Replacement

The decision to replace seed without changing variety is caused by deterioration in production potential of the seed retained from the farmer's grain crop. Genetic deterioration is particularly evident for hybrids or for cross-pollinating crops like open-pollinated maize varieties, in which yield potential may diminish from one generation to the next. The seed of self-pollinating crops such as wheat can also deteriorate through intermixture with seed of other varieties or species or loss of germination potential during storage.

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Yield deterioration of the old variety may also affect the farmer's decision to replace seed for the purposes of varietal change. In addition to the reasons just specified, a breakdown in disease or pest resistance of the older variety may cause varietal replacement. In this case, the maximum yield potential of the older variety has not deteriorated; instead, mutation of the disease pathogen or pest overcomes the resistance formerly conferred by a gene or gene complex in the variety, causing a reduction in expected yield. Finally, varietal change will also be related to the superior yield of the new variety or improvement in other desirable characteristics, or both.

In the model, farmers' utility $u(\pi, t)$ is composed of two attributes; π is net benefits from planting a given variety at t, and t is the number of years since seed has been replaced. Further, $U(\pi, t)$ is assumed separable in π and t, $u(\pi, t) = v(\pi)\phi(t)$, where $v(\pi)$ is a value function and $\phi(t)$ is a discount function (Loewenstein and Prelec). Farmers understand the general pattern of yield deterioration in their own varieties. They are uncertain about the yield potential of replacement varieties, which they learn about over time. In the next section, we state the assumptions regarding the time dimension of the model, yield improvement of the crop, depreciation of farmers' seed, and farmers' uncertainty about potential yields.

Elements of the Basic Model

We assume for convenience that harvest in time t, the time at which benefits are received for that period, coincides with the time when the farmer decides to change varieties or plant retained seed for period $t + 1$. The relevant crop production period is one year, and the possibilities of fallow periods or rotation crops are ignored. The farmer's opportunity cost of using his or her own seed is the grain price p_g (per kilogram, kg). If the farmer buys seed, the price paid is p_s. Assuming equal seed rates of S kilograms per hectare, the per hectare cost of using seed retained from the previous grain harvest is p_gS, while the cost of using new seed is p_sS.

The farmer harvests grain at year end. If he or she plants retained seed, the per hectare yield is Y_c and the associated gross per hectare revenue is p_gY_c. Alternatively, if he or she plants new seed, the per hectare yield is y_n and the associated gross per hectare revenue is p_gY_n.

Base yield (under farmers' management) obtained in the initial year the farmer buys seed of a new variety is denoted as Y_o. The expected yield under farmers' management of a potential replacement variety t years later, from the perspective of the plant breeders who develop it, is Y_{nt}. This can be expressed as

$$(1) \qquad Y_{nt} = (1 + i)^tY_0 = A^tY_0,$$

where $100i\%$ is the annual rate of gains in expected yield through breeding research and $A = 1 + i$. For exposition, i is assumed to be constant. If the farmer buys seed of a new higher yielding variety, then $A > 1$. If he buys new seed of his old variety, or of a new variety with no yield advantage, then $A = 1$.

Similarly, if the expected yield of the farmer's original variety deteriorates at an annual rate of $100j\%$, the projected yield, Y_{ct}, on farms in year t is

$$(2) \qquad Y_{ct} = (1 - j)^tY_0 = B^tY_0,$$

where $B = 1 - j$. If seed quality deterioration occurs, a fixed annual rate of farmer seed deterioration implies absolute losses become less from year to year.

We characterize farmers' uncertainty about the expected yield of potential replacement varieties by assuming farmers require a minimum acceptable marginal rate of return over the crop cycle, $100R\%$, higher than $100r\%$, the opportunity cost of working capital over the cycle (CIMMYT). The minimum acceptable rate of return is used to discount expected differences in profits from using a newer rather than an older variety. The farmer's level of uncertainty decreases the greater the number of years, t, that he or she retains seed. These assumptions are summarized as follows:

$$(3) \qquad R_t = R(t)$$

where

$$R' \leq 0, R'' \geq 0, \text{ and } \lim_{t\to\infty} R(t) = r.$$

Applying a discount rate defined in this way is analogous to applying an efficiency factor to yield. As the farmer accumulates knowledge about the expected yield of the replacement variety through experience, his or her expected yield approaches the actual yield. These assumptions are analogous to those of the passive learning model outlined by Kislev and Shchori-Bachrach. Learning curves of the type specified by Kislev and Shchori-Bachrach could result from Bayesian updating of expected values and variances if profits are distributed normally (Feder and O'Mara; Lindner, Fischer, and Pardey).

In this paper, R_t is defined implicitly as follows:

$$(4) \qquad (1 + R_t)^t = (1 + R_1)(1 + r)^{t-1}.$$

Thus, R_t satisfies the assumptions listed in (3). In the present construction, the value of $R_1 - r$ could be related to the farmer's general degree of confidence in new varietal development and R' to the speed of learning. The psychology literature sometimes uses specification (4) to characterize actual discounting behavior, and discount rates inferred both experimentally and from actual choices often approximate this pattern (Benzion, Rapoport, and Yagil; Loewenstein and Thaler).

In the development of the model, X_t, X_1, and W are defined as the discount factors associated with R_t, R_1, and r, respectively, for example by $X_t = 1/(1 + R_t)$, and thus from (4)

$$(5) \qquad (X_t)^t = X_1 W^{t-1}.$$

In the model, therefore, farmers maximize $u(\pi, t) = v(\pi)\phi(t)$ where $v(\pi) = \pi$ and $\phi(t) = X_1 W^{t-1}$, $t \geq 1$. Farmers can be viewed as "risk neutral" in the sense that $v(\pi)$ is linear. Decreasing uncertainty with greater experience of a variety is represented by the assumptions concerning the discount function $\phi(t)$.[1]

Myopic Horizon (Minimum Time of Profitable Varietal Replacement)

In the myopic version of the model, the farmer is concerned only with costs and benefits over the crop cycle in which he or she buys new seed.[2] This assumption, often made in "time to adoption" models (Lindner, Fischer, and Pardey), implies the farmer buys new seed in the first year in which he or she expects it is profitable to do so. In this version of the model, π is the difference in profits per hectare between planting new seed and planting seed retained from the previous year's grain crop, and the farmer's utility is

$$(6) \quad u(\pi,t) = p_g Y_0 (A^t - B^t)X_1 - (p_s S - p_g S).$$

From the year of initial purchase, the number of years until it is profitable for the farmer to buy new seed is T^*, where

$$(7) \qquad T^* = \min t \quad s.t.\ u(\pi,t) \geq 0,\ t \in Z^+$$

(i.e., t is a positive integer).

Optimal Rate of Replacement with Discounted Costs and Benefits

Alternatively, the model can be specified to represent the stream of net benefits from some initial point of varietal change, rather than the benefits received only in the year of the change as above.

In equilibrium, the farmer changes seed every T years. That is, a new variety is planted at times 0, T, $2T$, $3T$, and so on. Combined with the previous assumption that research increases the crop's yield potential over time, this implies that the farmer's yields follow the pattern shown in figure 1.

Net benefits π in this case consist of gross returns minus seed costs. Benefits from planting at time $\tau = nT + t$ occur at the end of the crop cycle, i.e., at time $nT + t + 1$. We can then show that the expected gross returns per hectare at any time $nT + t + 1$, discounted to $nT + t = 0$, are[3]

$$(8) \quad DGR_{nT+t+1} = p_g Y_0 A^{nT} B^t X_1^{n+1} W^{n(T-1)+t} \qquad n = 0,1,2, \ldots, t = 0,1,2, \ldots, T - 1.$$

By applying the rules for summation of series with multiplicative term less than one, we can demonstrate that the expected total gross returns per hectare at times from $nT + 1$ through $(n + 1)T$ are

$$(9) \quad p_g Y_0 A^{nT} X_1^{n+1} W^{n(T-1)} \left[\frac{1 - (BW)^T}{1 - BW}\right] \qquad n = 0,1,2, \ldots .$$

Similarly, the expected total discounted gross benefits per hectare over an infinite time hori-

[1] A more rigorous approach to observed patterns of time-dependent choices can be found in Loewenstein and Prelec and in Prelec and Loewenstein, who place restrictions on both $v(\pi)$ and $\phi(t)$. Among other characteristics, $-\phi'(t_1)/\phi(t_1) > -\phi'(t_2)/\phi(t_2)$ for all $t_2 > t_1$. In our model $-\phi'(t)/\phi(t)$ is constant for $t > 1$. The phenomenon of greater sensitivity to time delay if it occurs earlier rather than later is accounted for only by an implicit discontinuity in $-\phi'(t)/\phi(t)$ at $t = 1$.

[2] A major private U.S. soybean seed company plans using a myopic model assuming benefits only in the year of seed change, coupled with a very high minimum acceptable marginal rate of return (McMullen).

[3] Details of these and other derivations are available from the authors upon request.

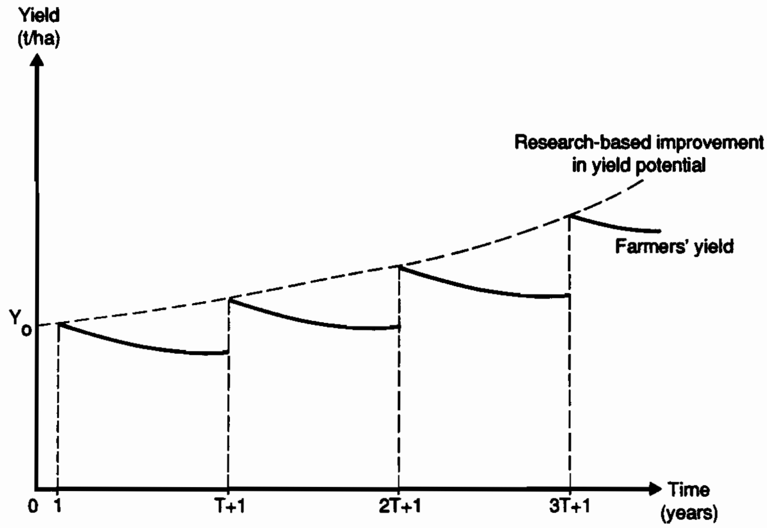

Figure 1. Farmers' yields over time with varietal change every *T* years.

zon (*TDGB*) can be expressed as

$$(10)\quad TDGB = p_g Y_0 X_1 \left[\frac{1-(BW)^T}{1-BW}\right]\left[\frac{1}{1-Z}\right]$$

when $Z = A^T X_1 W^{T-1}$ is less than one.[4]

Total costs consist of new seed costs at time 0, *T*, 2*T*, . . ., and the opportunity costs of retaining some of the harvest as seed in all other years. New seed costs are $p_s S$ per hectare. The total discounted costs per hectare of new seed, *TDCNS*, are

$$(11)\quad TDCNS = p_s S\left[\frac{1}{1-X_1 W^{T-1}}\right].$$

Opportunity costs of retaining grain for seed are $p_g S$ per hectare at times $nT + 1, \ldots, (n + 1)T - 1$ for $n = 0, 1, 2, \ldots$. Total discounted costs per hectare of retained seed, *TDCRS*, are

$$(12)\quad TDCRS = p_g S X_1\left[\frac{1-W^{T-1}}{1-W}\right]\left[\frac{1}{1-X_1 W^{T-1}}\right].$$

Expected discounted profits per hectare, $ED\pi = \sum_{\tau=0}^{\infty} u(\pi, \tau)$, are thus equivalent to

$$(13)\quad ED\pi = TDGB - TDCNS - TDCRS.$$

The optimal rate of varietal replacement, T^{**}, given an infinite time horizon, is the value of *T* that maximizes (13). First-order conditions for maximizing (13) can be derived, but they are untidy, and numerical methods are required to solve them. Calculating $ED\pi$ for feasible integer values of *T* and determining T^{**} by inspection, after inserting empirically determined values of the parameters, is simpler.[5]

Discounted net benefits can be plotted against *T* for various assumptions about parameter values. Figure 2 displays one example based on Pakistan data for wheat. The notable feature of figure 2 is that the discounted expected profit curve increases quickly initially and then flattens. This relative insensitivity of the level of discounted net benefits around the optimum, T^{**}, is shared by a similar problem from elementary capital theory, optimum replacement of an infinite chain of machines. Attempts to determine precise optima may be unwarranted, a feature these time-dependent problems may share with many single-period optimization procedures (Anderson). Given the parameters used to derive figure 2, any varietal replacement period of three years or more will result in discounted expected profits 90% or more of the maximum level. In situations in which it is appropriate to assume rather stable parameters and farmers who consider discounted costs and returns over a long

[4] This is likely to be the case, given reasonable assumptions about the minimum acceptable marginal rate of return over period 1, the discount rate, and the rate of growth in yield potential. Both $1 + R_1 = 1/X_1$ and $1 + r = 1/W$ are likely to be larger than *A*, from which $Z = A^T X_1 W^{T-1} < 1$.

[5] Copies of the spreadsheet used in calculating the optimal replacement times reported below are available from the authors on request.

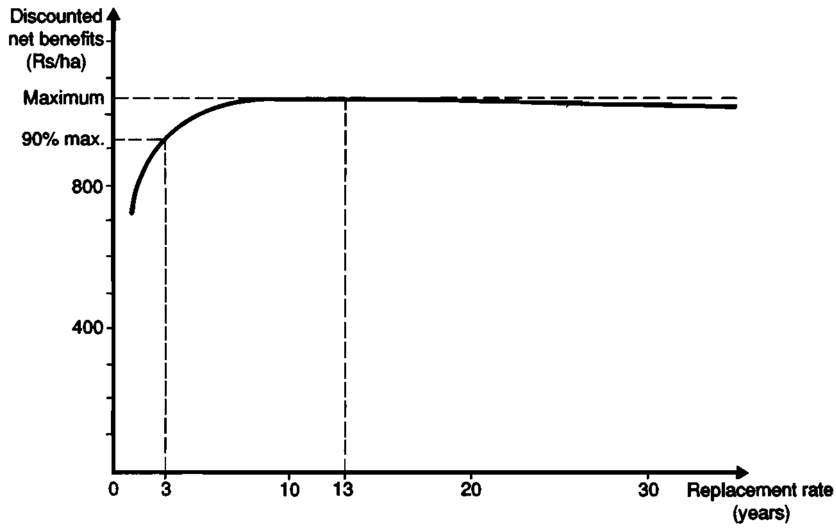

Figure 2. Discounted net benefits with different periods of varietal replacement

time horizon, a wide range of varietal replacement times will be consistent with near-optimal behavior.

Change in Parameters and Rate of Varietal Replacement

The impacts of changes in other parameters on T^* and T^{**} are summarized in table 1. Most of these effects (e.g., those for i, j, and p_s/p_g) accord with intuition, but several merit further explanation.

The higher the base yield, Y_0, the faster the rate of varietal replacement with either myopic or infinite time horizons. This result is driven by the model's assumptions that varietal improvement and farmer seed deterioration can be represented by an annual percentage increase or decrease. If the base yield is higher, a given percentage difference between an old and a new variety translates into a greater absolute yield gain, greater benefits, and a faster rate of varietal replacement.

Given the myopic, or single-period time horizon, increases in R_1 slow the rate of varietal turnover T^*. In the infinite time horizon case, a larger R_1 will lead to a greater T^{**}, as expected, but the larger the discount rate r, the lower will be T^{**}. The reason for the opposite effects of changes in R_1 and r given an infinite time horizon is that the difference $R_1 - r$ is related to the farmer's initial uncertainty about the yield of new varieties. If $R_1 - r$ is large, the desired seed replacement period is long. Keeping R_1 constant and raising r (or keeping r constant and lowering R_1) speeds varietal replacement by making farmers' perceptions of yield gains more nearly similar to actual yield gains. Furthermore, in the infinite time horizon case, a higher base discount rate, r, speeds varietal replacement by contributing to heavier discounting of future net benefits, so that waiting to change variety is less advantageous.

Uses of Seed Replacement Models

The model presented above can be used in several ways. First, if values can be assigned to all the other parameters, the predicted rates of varietal replacement can be found. Alternatively, values can be specified for several parameters and the required values of the other parameters

Table 1. Effects of Model Parameters on Rates of Varietal Replacement

Infinite Horizon Case (Optimal Replacement) T^{**}		Myopic Case (Minimum Profitable Replacement) T^*
$\partial T^{**}/\partial i < 0$		$\partial T^*/\partial i < 0$
$\partial T^{**}/\partial j < 0$		$\partial T^*/\partial j < 0$
$\partial T^{**}/\partial (p_s/p_g) > 0$		$\partial T^*/\partial (p_s/p_g) > 0$
$\partial T^{**}/\partial Y_0 < 0$		$\partial T^*/\partial Y_0 < 0$
$\partial T^{**}/\partial R_1 > 0$	$R_1 > r$	$\partial T^*/\partial R_1 > 0$
$\partial T^{**}/\partial r < 0$		

that will lead to a fixed level of T^* or T^{**} can be determined. We now postulate certain parameter values and apply the model to some hypothetical examples drawn from wheat research in post-green revolution Pakistan.

Demand for Wheat Seed in Pakistan

In the following analysis, i, the rate of genetic improvement for wheat varieties in Pakistan, is set at 0.75%, a relatively conservative figure slightly below Byerlee's estimate of 1.00% per annum for Pakistan's Punjab in the period since the introduction of semi-dwarf varieties. Byerlee also estimated that losses attributable to declining rust resistance in wheat in Pakistan were approximately 0.25% per year, but estimates for j comparable to the estimate for i are not available because j includes losses to seed intermixture or loss of germination potential as well as the losses to disease. Available estimates from other countries of annual yield losses for wheat grown from farmers' seed range from nil in one dryland area of Australia (Plater, personal communication) to 1.6% in Nepal (S. Biggs, personal communication). Selvaraj and Subramanian also found a 1.6% annual decline in the yield potential of rice, another self-pollinated crop, in India. The differences in results between these studies probably reflect differences in farmers' seed management practices as well as differences in disease and pest pressure. For the analysis of replacement wheat seed in Pakistan below, j is set initially at 0.75%.

The average wheat seed-to-grain price ratio in Pakistan is approximately 1.5 (Chaudhry and Heisey). A base yield Y_0 of 2,000 kilograms per hectare represents current yields for irrigated wheat in Pakistan, and the seed rate for wheat is assumed to be 100 kilograms per hectare, in line with farmers' current practice (Byerlee et al.).

The discount rates r, and R_1, which reflects farmers' initial uncertainty about the expected yield associated with replacement seed, are difficult to value appropriately. Interest rates varying from 12% to 150% per year have been reported in different studies of rural areas of developing countries (Ghatak, Sarap, Ahmed), with rates depending on the status of the borrower, the purpose of the loan, and the nature of the lending agency. For this analysis, r is initially set at 30% per annum to indicate a subjective, but unproven, belief in a certain degree of imperfection in rural capital markets. Following CIMMYT, we use 50% as the minimum acceptable rate of return over the initial crop cycle, R_1. CIMMYT proposed this figure for technologies that represent only simple adjustments to farmers' practice, such as seed of a new wheat variety for a farmer who has already adopted semi-dwarf wheat technology.

Substituting these parameters into expression (6) produces a value of three years for T^*, the myopic solution; using expressions (10) through (13) generates a value of thirteen years for T^{**}, the optimal replacement rate associated with an infinite time horizon. Ninety percent of the maximum discounted net benefits in the infinite time horizon case could be obtained if variety were replaced every three years.

If farmers face identical parameters and differ only with respect to year of initial varietal change (i.e., the calendar year in which $nT + t = 0$), the average length of time farmers have been using a given variety can be approximated by $(T + 1)/2$, where T is actual replacement time. In a sample from two major irrigated wheat-growing areas of the Punjab in 1985–86, farmers had been growing wheat varieties for an average of two and one-half to three years, which implies a replacement time of four to five years. The same study found farmers in an irrigated area of northwest Pakistan growing varieties for an average of over five years, suggesting a replacement time of over nine years (Heisey). These values lie between the times predicted by the myopic and infinite time horizon assumptions. This study, however, was made four years after the actual release of several good new varieties and may underestimate long-run varietal replacement times.

Aggregate average age of wheat varieties, weighted by the proportion of area sown to each variety, can be used as another estimate of T, or replacement time. This measure, however, depends in rather complicated ways not only on demand for replacement seed but also on the lag between varietal release and widespread seed availability, on the length of time it takes for farmers to become aware of potential replacement varieties, and on the degree to which farmers replace seed with seed from seed dealers or from other farmers; therefore, the average age measure may tend to overestimate T.

In any case, the mean weighted age of wheat varieties averaged 11.1 years for Pakistan's Punjab between 1978 and 1986 (Brennan and Byerlee), which is closer to the T^{**} predicted using the assumption of an infinite time horizon. It is still likely that farmers' wheat seed replacement times lie somewhere between the extremes predicted by the two assumptions regarding time horizon.

Sensitivity of Results to Changing Parameters

The effects of varying assumptions about the wheat parameters on T^{**}, on the value of T for which 90% of the optimal benefits are obtained in the infinite horizon case, and on T^* are shown in table 2. All parameters are varied to a level one-third below and one-third above their base level. In addition i and j are reduced by 100%, to 0.

The seed-to-grain price ratio, seed rate, and base yield have almost no impact on the optimal rate of seed change T^{**}. Increasing the rate of varietal improvement or increasing the rate of seed deterioration both speed varietal replacement noticeably, although these effects become less pronounced as i and j move farther from zero. (Effects of increasing i or j also become less pronounced at higher levels of the other parameter). Both r and R_1 have a major effect on T^{**}, in opposite directions. Many different combinations of r and R_1 can be inserted into the model given the assumption of an infinite horizon. If this is done, equal differences $R_1 - r$ lead to approximately equal values of T^{**}, although given a fixed $R_1 - r$, T^{**} is lower for higher values of r. This implies that if an infinite horizon is assumed, farmers' uncertainty concerning yield of potential replacement varieties plays a much greater role than does the opportunity cost of working capital in determining optimal replacement time. Higher opportunity cost of capital in and of itself, with no changes in the uncertainty measure $R_1 - r$, does speed varietal replacement to a minimal extent.

Only the parameters R_1 and r have any noticeable effect on the initial slope of the net benefit curve for alternate replacement periods T in the infinite horizon model. This is indicated in table 2 in the column showing the replacement times at which 90% of the net benefits are obtained. In other words, only the uncertainty measure $R_1 - r$ substantially changes the range

Table 2. Sensitivity of Wheat Results to Different Parameter Values

Parameter	Value	T^{**} (Years)	90% of Optimum (Infinite Horizon Model) (Years)	T^* (Years)
p_s/p_g	1.00	13	3	1
	1.50	13	3	3
	2.00	14	3	5
Y_0	1333	13	3	4
	2000	13	3	3
	2667	13	3	2
i (%)	0.00	23	3	6
	0.50	15	3	4
	0.75	13	3	3
	1.00	12	3	3
j (%)	0.00	23	3	5
	0.50	15	3	3
	0.75	13	3	3
	1.00	12	3	3
S	67	13	3	2
	100	13	3	3
	133	13	3	4
r (%)	20	20	5	
	30	13	3	
	40	8	2	
R_1 (%)	33	5	1	3
	50	13	3	3
	67	20	4	3

Note: In each case, values of the other parameters are held at the initial levels specified in the text.

of replacement times for which net benefits are near optimal.

In the single period case, in contrast to the infinite horizon case, the uncertainty parameter R_1 has no perceptible effect on T^*. Only by moving R_1 considerably higher than reported in table 2 will T^* increase noticeably. The effects of i and j in the myopic case are similar to those in the infinite horizon case. Again in contrast to the infinite horizon case, T^* is noticeably affected by changes in p_s/p_g, Y_0, and S.

Conclusions

This paper has presented a framework for comparing the costs and benefits of seed replacement, which is then related to varietal replacement by assuming that the yield differences leading to varietal change result from yield improvements in available varieties and deterioration in the potential performance of seed retained by farmers. Parameters indicating the rates of yield improvement and farmers' seed deterioration are unlikely to be constant over time but may be affected by both partially predictable factors (e.g., investment in breeding research) and random events (e.g., changes in environmental conditions leading to changes in disease spectrums). In reality, even predictable factors such as investment in research will lead to small jumps in yield potential after varying periods of time rather than smooth year-to-year increases. Because breeders and seed supply agencies presumably use expected values in their planning, the assumptions that rates of increase in yield potential and decline in farmers' seed are constant are sufficient to draw conclusions on the likely impact on farmers' demand for seed. Changes in these parameters lead to the expected results: increasing the rate of yield improvement speeds varietal replacement; decreasing the rate of farmer seed deterioration slows varietal replacement.

The effects of other factors influencing seed change are strongly conditioned by the assumptions made about time horizon. Assumptions made about uncertainty associated with new seed have a marked influence on the rate of varietal replacement if farmers' time horizons are taken to be infinite. Assumptions made about seed price, in particular, affect the rate of varietal replacement in a single period horizon version of the model.

If there is reason to believe that the private and social costs and benefits of the rate of seed change diverge, the specification of demand for replacement seed has policy implications. For example, in the case of a varietal breakdown in disease resistance, there are many instances in which society would place greater value on avoiding a major disease epidemic than an individual farmer would, especially given the probability that such an epidemic would affect an individual farmer. Thus, it can be in society's interest to promote more rapid varietal replacement.

The analysis above indicates that, except for investment in research to promote faster yield improvement, the policy instruments available to influence seed demand will depend on farmers' time horizons. Desired varietal replacement times are already relatively small in short time horizon situations in which seed prices are likely to affect demand, and experience shows that farmers are willing to pay prices that guarantee returns to seed distributors and growers if they are convinced of the benefits of the new seed (Kelly, Asian Productivity Organization). This suggests that increasing the flow of information concerning the yield potential of new varieties is likely to be preferred to seed subsidies as a policy instrument.

Further research might explore several avenues. The model might be applied to data for different crops and different countries, certain parameters could be made endogenous, or related inputs and non-yield varietal characteristics could be considered. The behavioral specification could be improved to include risk preference through different assumptions on $v(\pi)$. Theoretical models that combine both time and risk preference over more than two periods, however, tend to be either conceptually intractable or theoretically unappealing (Anderson, Dillon, and Hardaker), even though decision making over time and under uncertainty have many common elements (Prelec and Loewenstein).[6] In addition, in any period, the farmers' choice might be framed as one among three alternatives: planting seed from the grain harvest, planting new seed of the same variety, and planting new seed of a new variety, which involves the greatest uncertainty. Such a specification would necessitate a rigorous specification of the time horizon relevant to varietal replacement and recognition that a plan viewed as optimal at one time might not appear optimal at another (Strotz). Different assumptions con-

[6] The effects of risk aversion on the rate of seed change are likely to be ambiguous (Lindner and Fischer).

cerning time horizon might not change comparative statics, but they do alter predictions considerably, a finding that likely applies to many models of decision making over time.

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