Productivity Maintenance Research and Research Deterioration:

Concepts and Evidence

by

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Abstract

Productivity maintenance research (PMR) has received little attention in the literature. This paper defines PMR and incorporates PMR benefits in a economic surplus research evaluation framework. Research depreciation is illustrated through two examples for wheat in Mexico and Nepal. Estimated depreciation effects were found to be significant, implying that estimated agricultural research benefits and rates of return on agricultural research investments have likely been underestimated.

1. Introduction

At a time when research organizations are facing a scarcity of resources to invest in research, the need for prioritizing among types of research has become evident.[1] To better prioritize research, an understanding of where research benefits are distributed is critical. A basic feature of past research evaluation and prioritizing studies, particularly those which use economic surplus methods, is that with no investment in research, the supply curve of the commodity is assumed to remain static. Research investments, on the other hand, lead to an outward or downward supply shift. The former assumption is not necessarily true. If no research is undertaken, environmental changes can cause technologies to deteriorate or to be less productive. For example, decreases in pest resistance in crops leads to lower yields or higher production costs.

Productivity maintenance research, which seeks to sustain past productivity gains, has received little attention in the literature. Several authors have alluded to a potential backward or upward shift in the supply function (Swallow et al., and Adusei and Norton). However, past research evaluation studies have failed to incorporate benefits from productivity maintenance research aimed at avoiding declines in productivity levels. Also, scarce evidence exists on the magnitude of productivity maintenance research relative to total research expenditures and the relative intensity of productivity maintenance research among different crops. One of the few studies that does deal with this issue reported that, on average, 35% of the research effort in

[1] An invited papers session on research priority setting at the 1992 AAEA annual meetings is evidence of this trend.

public agricultural research institutions in the U.S. is devoted to maintenance work (Adusei and Norton).

The objectives of this paper are two-fold: (1) to define productivity maintenance research and incorporate it into a simple research evaluation framework, and (2) to obtain evidence of productivity deterioration from sets of experimental data for Mexico and Nepal.

2. Agricultural Productivity Maintenance Research: Definition and Evaluation

Maintenance research has been variously defined as the research needed to prevent yield declines, to replace deteriorating research information or gains from previous research, to maintain economic efficiency, and to prevent declines in productivity levels (Ruttan; Adusei and Norton; Pardey and Roseboom; Adusei; Swallow et al.; and Plucknett and Smith). The following definition will be used in this paper:

> Productivity maintenance research is any research required to sustain previous or current productivity levels in the face of changes in the environment.[2]

If there were no change in the environment, productivity maintenance research would not be necessary. Deterioration and obsolescence are the two reasons for depreciation in research output (Swallow et al.). Productivity maintenance research is aimied at avoiding deterioration, which occurs when research information embodied in technology becomes less productive because of changes in the environment.[3]

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[2] This definition follows very closely that of Blakeslee.

[3] "Obsolescence" refers to the replacement of current research information by improved information.

Environmental changes can be physical, economic, or biological, and productivity maintenance research can play a role in dealing with all of these (Blakeslee). Examples of these changes are soil degradation (physical changes), price changes (economic), and evolution of new virulent races of crop diseases (biological).

These changes can cause either decreases or increases in total factor productivity (TFP) levels. Productivity maintenance research is concerned with those changes which lead or may lead to decreases in TFP levels. We can examine the relationship between changes in the environment and TFP through the following expression:[4]

$$T = \hat{y} - \hat{x} = \hat{w} - \hat{p} \tag{1}$$

where T is the change in TFP, and $\hat{p}$, $\hat{y}$, $\hat{w}$, and $\hat{x}$ are rates of change of aggregated output prices, output quantities, input prices, and input quantities, respectively.

Environmental changes will affect T through changes in $\hat{y}$, $\hat{x}$, $\hat{w}$, or $\hat{p}$. Environmental changes relevant to productivity maintenance research are those which result in a decrease in total factor productivity, or $T<0$. Physical and biological changes can result in $\hat{y}<0$ with $\hat{x}=0$, or $\hat{x}>0$ with $\hat{y}=0$; in other words, a decrease in aggregate output holding input quantities constant or an increase in input quantities holding output constant. Both of these conditions will lead to $T<0$ due to efficiency losses. A negative T can also occur if both aggregate output and input quantities change ($\hat{y}\neq 0$ and $\hat{x}\neq 0$), but ($\hat{y}$ - $\hat{x}$) is negative.

Economic changes lead to changes in $\hat{w}$ and $\hat{p}$.[5] There are three possible cases in which

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[4] This expression was derived by Evenson et al. It assumes an economic sector in long run equilibrium and that firms are not making profits, or at least not abnormal profits.

[5] Economic changes will initially be reflected in price changes, so at first $T = (\hat{w} - \hat{p}) \neq 0$. Eventually changes in input and output prices lead to changes in physical quantities, so ($\hat{y}$ -

$T<0$. These are $\hat{p}>0$ with $\hat{w}=0$ (increase in output prices as a result of efficiency losses); $\hat{w}<0$ with $\hat{p}=0$ (decrease in factor rewards due to efficiency losses); and, $\hat{w}\neq 0$, $\hat{p}\neq 0$ and $(\hat{w} - \hat{p})<0$. Equation (1) is a theoretical relationship. In reality, physical and biological changes may cause changes in input or output quantities with prices remaining constant.

Suppose T_i is the level of TFP in period i. Then environmental changes causing $T<0$ lead to $T_i > T_{i+1}$. Productivity maintenance research may be necessary to ensure that $T_{i+1} = T_i$. Research benefits include not only increases in productivity ($T_{i+1} > T_i$) but the gains from avoiding a decrease in productivity ($T_i > T_{i+1}$).

In measuring research benefits we are concerned with comparing economic benefits in a situation without research and one with research. In a static framework, previous studies have assumed that research induces a rightward or downward shift in the commodity's supply function. The former is measured as the percent yield increase of the new technology over the old one, holding inputs constant, while the latter measures the cost reductions of the new technology, holding yields constant. Traditionally, without investment in research, the supply function is assumed to remain static. In reality this is not necessarily the case. As emphasized above, changes in the production environment can cause deterioration in technologies. The effect of deteriorating technology is a reduction in output while keeping input levels constant or an increase in input use (higher cost) while keeping output constant. This means that in the absence of research, the supply curve would shift backward (loss in yield) or upward (higher cost of production).

$\hat{x}) \neq 0$ since $T = (\hat{y} - \hat{x})$.

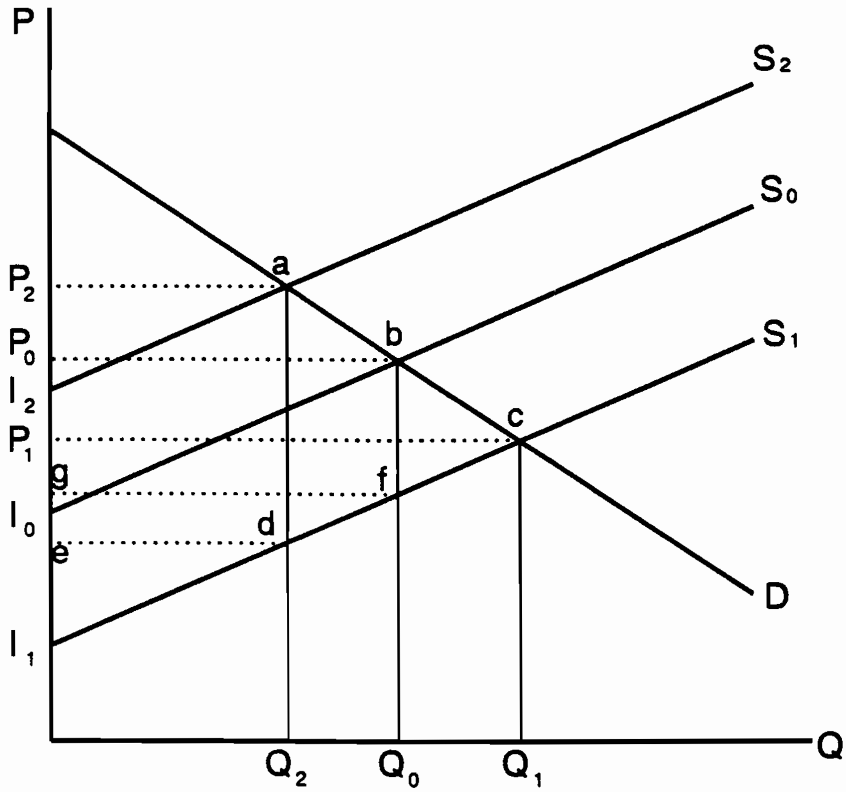

Figure 1. A simple model of research benefits

A simple economic surplus model of research benefit evaluation for a closed economy is shown in Figure 1. This model, in contrast to traditional models, includes a backward (loss in yield) or upward (higher cost of production) shift of the supply curve. S_0 and D are the initial supply and demand for the crop using old technologies in, say, period t.[6] S_1 represents the supply of the crop when new technologies are used in (t+1). S_2 represents the (potential) shift in supply that would have occurred had new technologies not been used in (t+1). P_0 and Q_0 are equilibrium prices and quantities when old technologies are used; with new technologies these are P_1 and Q_1. P_2 and Q_2 are the equilibrium price and quantity that would have prevailed had new technologies not been developed and adopted.

Research benefits are measured as the sum of changes in producer and consumer surplus resulting from investments in research. The change in producer surplus is (P_1cI_1) - (P_2aI_2), or, assuming a parallel shift in the supply curves, P_1cde. The change in consumer surplus is P_2acP_1. The benefits obtained when productivity maintenance research effects are considered are greater than those which would have traditionally been computed:

for consumer surplus, P_2acP_1 greater than P_0bcP_1; and,

for producer surplus, (P_1cI_1)-(P_2bI_2) or P_1cde greater than (P_1cI_1)-(P_0bI_0) or P_1cfg.

3. Evidence of Technology Deterioration

A critical parameter needed to estimate research benefits, particularly those from productivity maintenance research, is the magnitude of technology deterioration. The focus of

[6] Old technologies can either be traditional technologies or improved technologies. New technologies are those which replace the old technologies.

this section is to estimate deterioration in wheat yields through time. Two sources of data are used for this purpose. The first source consists of data from a one-year trial conducted by CIMMYT of 15 wheat cultivars. All but one of the cultivars have been or are widely grown in the irrigated wheat production area of northwestern Mexico. The second source of data, from Nepal, consists of 15 years of experimental data on one widely grown cultivar.

3.1. Mexico

In northwestern Mexico, an assessment of yield loss was carried out by CIMMYT to characterize the expression of leaf rust resistance in 15 wheat cultivars.[7,8] Two separate plots were planted; one plot was protected against leaf rust with a fungicide (tebuconazole), while the other was left unprotected. "Spreader rows" were used to encourage disease infection.

Of the 15 cultivars tested, six are no longer grown in Mexico because of their unacceptable leaf rust resistance levels, although all of the cultivars had acceptable levels of resistance when they were released. Another six continue to have acceptable levels of leaf rust resistance but have been replaced by new, higher yielding cultivars. Two are still widely grown in northwestern Mexico, and one, Sonalika, is an Indian variety selected from CIMMYT germplasm in the mid-1960s but still widely grown in India, Pakistan, Nepal, and Bangladesh.

Figure 2 shows the trial results for two planting dates and for protected and unprotected plots. A regression line is fitted to the four sets of data to show the trend in yield gains. Yield

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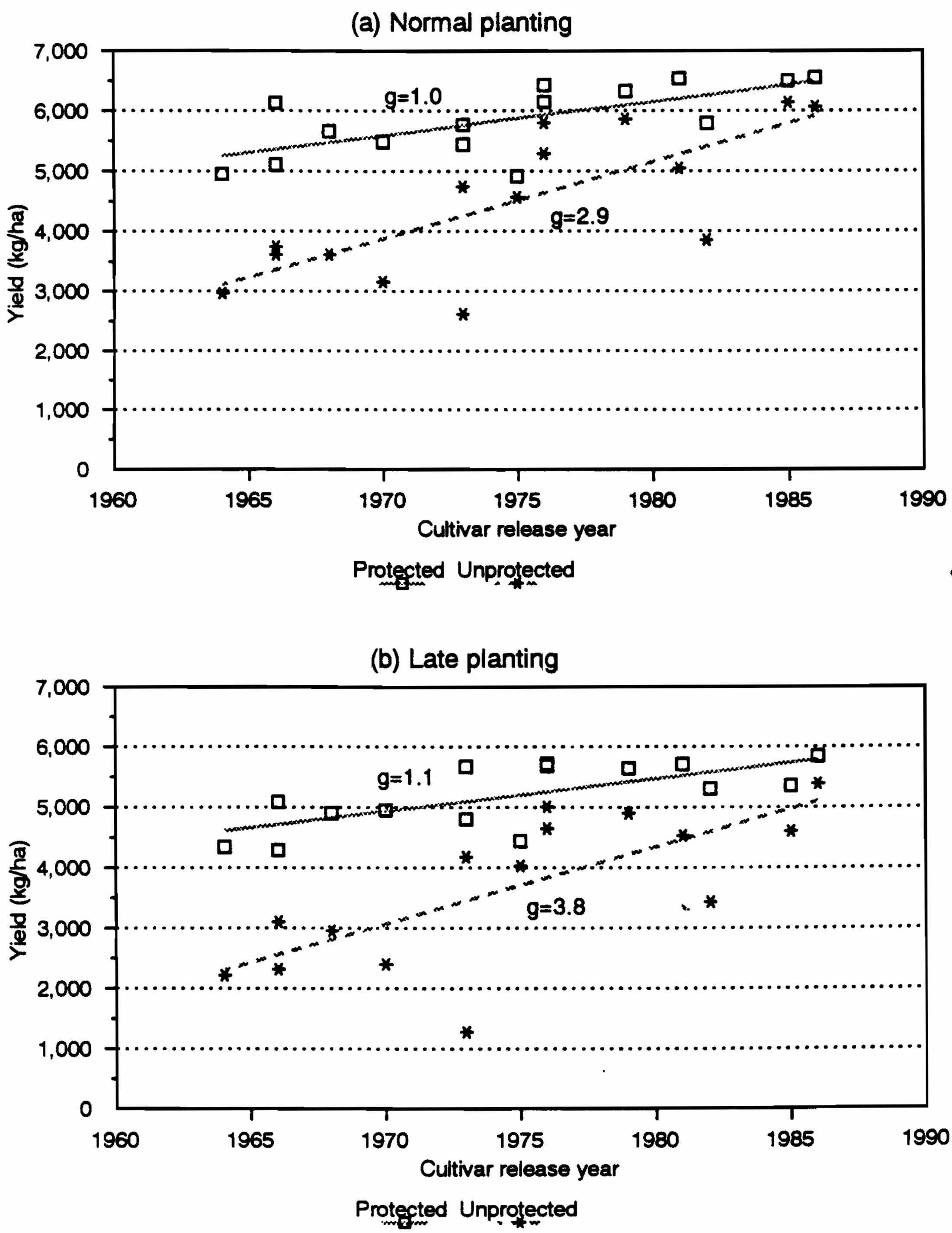
[7] The first three paragraphs in this section draw on Sayre et al.

[8] Worldwide, leaf rust is one of the most economically important bread wheat diseases (Samborski).

Figure 2. Yield loss due to leaf rust in 15 bread wheat cultivars in Sonora, Mexico (1990-91)



Source: Sayre, et al. (1991)

losses among all cultivars ranged from 5% to 55% for the normal planting date and 8% to 76% for the late planting date.

On simple observation, the results show a marked difference between yield losses in older and newer cultivars. The difference in yields between protected and unprotected treatments can be used to estimate the deterioration effect. A priori, the hypothesis is that pairs of treatments (protected vs. unprotected) involving older cultivars will exhibit a significantly greater yield difference than pairs of treatments involving newer cultivars, due to a more serious breakdown of leaf rust resistance in older cultivars or slow rusting properties of some cultivars. The following equation was estimated:

$$\ln(Y_{pi} - Y_{ui}) = \alpha + \beta R_i + \mu, \qquad (2)$$

where Y_{pi} and Y_{ui} are, respectively, protected and unprotected yield levels of cultivar i, R_i is the release year of cultivar i, and μ is an error term. Equation (2) was estimated for normal planting, late planting, and both planting dates combined. The least square estimates for the three runs are (standard error in parenthesis):

a. Normal planting: $\ln(Y_{pi} - Y_{ui}) = \underset{(47.6)}{132.9} - \underset{(0.024)^{**}}{0.064}R_i,$

$$R^2 = 0.35, \quad F = 6.99$$

b. Late planting: $\ln(Y_{pi} - Y_{ui}) = \underset{(44.9)}{117.14} - \underset{(0.022)^{**}}{0.056}R_i,$

$$R^2 = 0.32, \quad F = 5.99$$

c. Combined: $\ln(Y_{pi} - Y_{ui}) = \underset{(31.7)}{125.02} - \underset{(0.016)^{***}}{0.060}R_i,$

$$R^2 = 0.33, \quad F = 13.8$$

The expected negative coefficient on the release year is confirmed in all three equations and is statistically significant at the 5% level (**) in all three cases (the β estimate for the combined regression is significant at the 1% level(***)). These results indicate that the research information embodied in the wheat cultivars has lost its value over time. The importance of rust resistance breeding is reinforced by these findings, and the role of maintenance research in avoiding productivity depreciation due to biological changes in the environment is evident here.

3.2. Nepal

This section estimates yield degradation rates for RR21, a semidwarf wheat variety grown in Nepal since the late 1960s. RR21 is the name given in Nepal to Sonalika, the Indian cultivar developed from CIMMYT germplasm (mentioned above). Data for this analysis were obtained from Morris et al. and consist of trial data from six agricultural research stations over 1976-1990. Not all stations have data for all 15 years, and none of the stations has data for 1978.

Ideally, yield should be modelled as a function of cultural practices, weather variables, and time, as Swallow et al. did in their analysis of depreciation of soybean breeding research in Virginia.[9] However, for the present analysis, cultural practices were assumed to show little variation over the years and data could not be obtained for weather variables. Thus, yield is modelled only as a function of time in order to estimate its depreciation rate. The following model was estimated

$$\ln(Y_{st}) = \alpha + \beta T_t + \epsilon, \tag{3}$$

[9] In their study the estimate of the coefficient on the time trend variable was negative but not statistically significant.

where Y_{st} is the yield of RR21 in research station s and year t, T_t is the year of the experiment and ϵ is an error term. The least squares estimation of (3) yielded the following results (standard error in parenthesis):

$$\ln(Y_{st}) = \underset{(16.5)}{139.4} - \underset{(0.008)^{***}}{0.066T_t},$$

$$R^2 = 0.47, \quad F = 63.9.$$

Due to changing environmental factors (e.g., declining soil fertility in experiment station plots), the coefficient on the time trend was expected to be negative. The size and statistical significance (1% level) of the time trend coefficient estimate indicate that the deterioration of research embodied in RR21 has been significant.[10] Morris et al. attribute the decline in yield to RR21's decreased resistance to leaf rust and Helminthosporium leaf blight, as well as crop and resource management problems. Whereas in the Mexican case, the primary cause for decreases in yield was biological change, in the Nepal case a combination of biological changes (disease susceptibility) and physical changes (resource degradation) provoked yield declines.

4. Conclusion

Neglecting to incorporate the benefits from productivity maintenance research can lead to underestimation of research benefits for both consumers and producers. In fact, it is likely that many agricultural research evaluation studies have underestimated returns from research investments as previous studies have only used yield gains as a measure of research benefits.

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[10] Morris et al. found very similar results, but their regression included a cultivar which is replacing RR21 in farmers' fields. Their objective was to estimate the gains from adoption of the newer cultivar.

Furthermore, the process of deterioration in research information was shown to be significant in two distinct examples for wheat. These results strengthen the importance of giving adequate attention to issues related to productivity maintenance research.

As Swallow et al. pointed out, many policymakers do not recognize that research depreciation occurs and therefore do not pay much attention to productivity maintenance research issues. Because returns to research have been underestimated in previous studies, further underinvestment in agricultural research is likely. This may especially be true for investments in productivity maintenance research, even though the need for productivity maintenance research will become increasingly important. Such research is needed to address three kinds of problems: greater potential for resource degradation because of increasing intensification of agricultural production systems, increased probability of disease epidemics because of narrow genetic crop base, and post-Green Revolution yield gains lower than those of the Green Revolution, implying lower productivity gains from yield increases that could offset productivity declines from technology deterioration.

The discussion and results presented in this paper provide a strong motivation for policymakers to realize the potential importance of research deterioration and the gains that can accrue from investments in productivity maintenance research. Currently further work is underway to estimate rates of return from productivity maintenance research.

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