TECHNOLOGY ADOPTION UNDER PRICE UNCERTAINTY

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Abstract

The paper examines the impact of changes in the variance of output prices on the bias and intrafirm rate of diffusion of technical change. The results indicate that a reduction in the variance of output prices will increase the rate of adoption and intrafirm speed of diffusion of yield-increasing technologies. The opposite is true for cost-reducing technologies.

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Technology Adoption Under Price Uncertainty

There is a large body of literature on the effects of government price stabilization programs on producer and consumer welfare and on economic indicators in the agricultural sector. To the authors' knowledge, nobody has yet examined how these programs affect the type of technologies that are adopted or the rate of diffusion of new technologies. That there should be some relationship between price stability and technological adoption is clear. The adoption of new technologies involves risk, and price stabilization programs are designed to remove risk. Also, some technologies are more risky than others. It seems reasonable to hypothesize that producers will rank new technologies differently under different price regimes.

There are several possible approaches to analyzing this problem. The approach taken here is motivated by the information contained in figures 1 and 2. Figure 1 plots the wheat yield per acre for selected countries for the past four decades. It is clear that wheat yields in Europe have been increasing at a faster rate than those in Canada and Australia. In fact, there is no evidence of any improvement in wheat yields in Australia. Also, it is interesting to note that the rate of growth of wheat yields in the United Kingdom picked up after its entry into the European Community (EC) in 1973. The rate of growth for France, which has been a member of the EC for a much longer period, is more even.

Without further information, it is difficult to determine whether these changes are due to movements along the supply curve or whether they reflect differences in technology adoption. It is possible, for example, that Australian researchers have improved yields at a similar rate to those in France and that the lack of progress on a national level reflects lower fertilizer use or the use of lower quality land. If one accepts the view that the EC has successfully stabilized prices via its intervention system and that producers in Australia and Canada have been open to the world market, then it also seems possible that these divergent rates of growth are due to differences in output price variation.

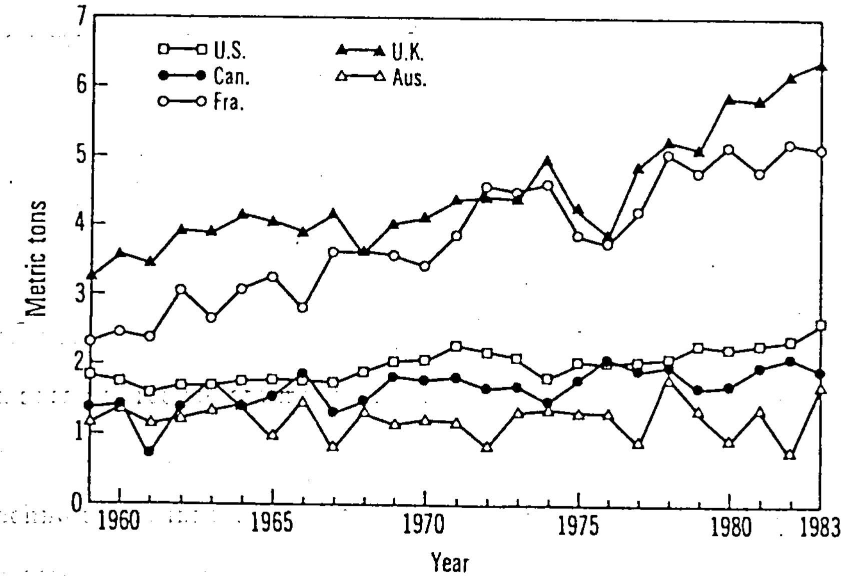

Figure 1. Wheat yield per harvested hectare for various countries

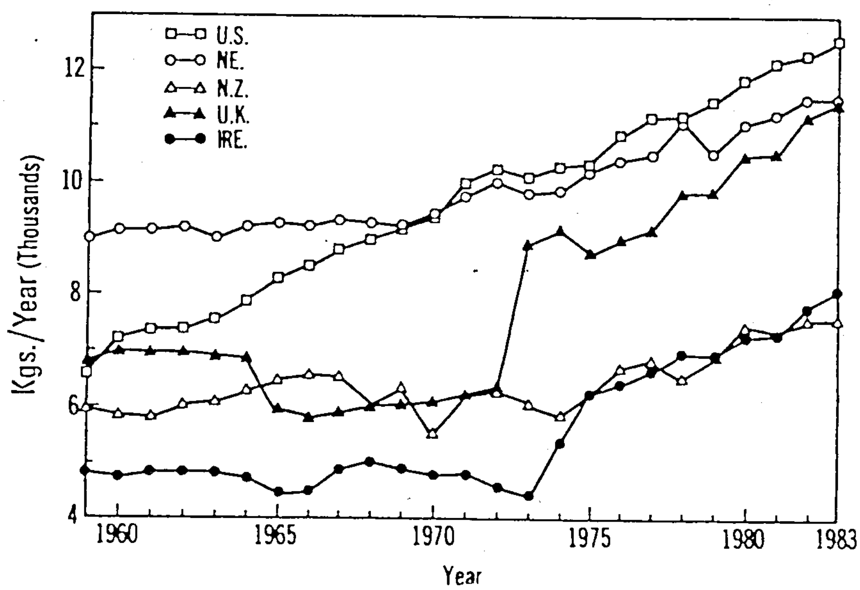

Figure 2. Milk yield per cow for various countries

Source: Hayes and Schmitz

Figure 2 presents information on the milk yield per cow in selected countries. Keeping in mind that the United Kingdom and Ireland joined the EC simultaneously and that milk producers in the Netherlands and the United States have had relatively stable output prices, these data lend support to the hypothesis that price stabilization programs tend to increase "yields."

This is as far as we can get with a graphical analysis. In order to examine these concepts more formally, we need to define yield-increasing technical change. In keeping with the policy focus of this paper, we define technical change in a manner that is tractable and yet that will produce results that are directly interpretable by policy makers. From this perspective, one might group together those technologies that are yield increasing, i.e., which are biased towards the land or other fixed assets. A useful alternative grouping would include those technologies that reduce the variable costs of production per unit of output. These we call cost-reducing technologies.

Governments that wish to increase food self-sufficiency or to maximize the returns to fixed assets would presumably like to promote yield-increasing technical change. Governments interested in reducing the costs of food or in maximizing the returns to variable factors such as farm labor will want to encourage cost-reducing technologies. An example of yield-increasing technical change would be the switch from spring wheat to winter wheat or the adoption of irrigation methods, while cost-reducing technical change would include the development of no-till grain production methods or disease or drought resistant varieties.

The dichotomy between cost-reducing and yield-increasing technologies is obviously a simplistic way to categorize technical change. Many technical changes exhibit aspects of both. In the more formal analysis presented here, only the two simplistic definitions motivated above are used. The inclusion of technologies which had both yield-increasing and cost-reducing effects would needlessly complicate the derivations.

The paper is organized as follows. First, we define the cost-increasing and yield-reducing technologies more formally and use these definitions in a standard Just-

Zilberman model of technology adoption under risk. We derive a proposition relating price variability with technical change. We then incorporate this adopted model into Stoneman's model of technology diffusion under risk to see how adjustment costs alter the relative rates of adoption and the diffusion process for both technologies. We finish with a brief review of the principal results.

Definitions

A technological innovation is said to be yield-increasing if it has a higher yield per acre and does not reduce optimal variable costs per acre.

A technological innovation is said to be cost-reducing if it reduces optimal variable costs per acre but does not increase yields per acre.

The adoption of yield-increasing technologies implies variable input using technical change while the adoption of cost-reducing technologies implies variable inputs saving technical change.

The two types of technologies discussed previously have similar effects on the profit function. Both reduce average total costs and therefore increase profits. The source of these cost reductions is different, however. Yield-increasing technologies reduce the average fixed cost while cost-reducing technologies reduce the average variable cost. As we shall see, these effects are different under price uncertainty for risk-averse producers. The intuition here can be developed with the following analogy. Canadian wheat farmers are endowed with land and some labor. The purchase of fertilizer in this case is similar to the purchase of a lottery ticket where the payoff is related to total revenue. In bad years, the producer may wish he or she had used less fertilizer or simply planted the seed without any fertilizer. The number of "tickets" purchased will depend on the expected variability of profits and the producer's risk aversion. The decision as to how many acres to plant is a much less risky proposition, especially if the opportunity cost of land and labor is low. Apart from the seed, producers will not regret incurring fixed costs even in bad years. The greater the price risk, the less willing the producer will be to adopt technologies that require more variable costs and the more willing they will be to adopt technologies that reduce variable costs. This is because yield-increasing technologies force them to purchase more "lottery tickets" while cost-reducing technologies reduce this number.

The Model

This study employs and modifies the microeconomic model developed by Just and Zilberman (1983). Consider the decisions made by the owner of a single farm with fixed landholdings, $\overline{L}$, with a sale price of P_L who uses a traditional technology, T_O. Assume that the farmer discovers two technological innovations, one of which is yield increasing, T_1, and the other which is cost reducing, T_2. Also assume that the farmer must allocate his landholdings between technology 1 and technology 2.

Let π_{it} represent net returns per acre for technology i at time t. This can be represented as

$$\pi_{it} = P_t Y_{it} - C_{it}[Y_{it}, \omega_t], \qquad \text{for } i = 0, 1, \text{ and } 2,$$

where

P = unit price of output,
Y = yield per acre,
C[•] = the variable cost function,
ω = a vector of variable input prices.

By definition, $Y_{1t} > Y_{2t} = Y_{0t}$ and $C_{1t} \geq C_{0t} > C_{2t}$. Also assume that output price is the only random variable[1] with known mean, $\overline{P}$, and variance, σ_{pt}^2.

Now assume that the producer has a von Neumann-Morgenstern utility function U[•] defined on wealth where U′ > 0 and U″ < 0. End of harvest wealth, W_t, can be written as the sum of the land value and the profitability from farming.

$$W_t = P_L\overline{L} + L_{1t}\pi_{1t} + L_{2t}\pi_{2t},$$

where L_{it} is the amount of land allocated to technology i at time t. Note that if adoption costs are zero, the farmer will not use the old technology.

The a priori land allocation decision is determined by maximizing the following objective function.

$$\text{(1)} \quad \max_{L_{1t}L_{2t}} \; V(L_{1t}, L_{2t}) = EU[P_L\overline{L} + L_{1t}\pi_{1t} + L_{2t}\pi_{2t}],$$

subject to $L_{1t} + L_{2t} = \overline{L}$, $L_{1t}, L_{2t} \geq 0$.

The first-order condition for land allocation is

$$\text{(2)} \quad \frac{\partial V}{\partial L_{1t}} = E[U'(\pi_{1t} - \pi_{2t})] = E\{U'\,[P_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t})]\} = 0.$$

By specifying a first-order Taylor series approximation to $U'(W)$.

$$\text{(3)} \quad U'(W) = U'(\overline{W}) + U''(\overline{W})[(P_t - \overline{P}_t)\{Y_{2t}\overline{L} + (Y_{1t} - Y_{2t})L_{1t}\}],$$

and using this approximation in (2), the following expression is obtained.

$$\text{(4)} \quad \frac{1}{U'(\overline{W})}\frac{\partial V}{\partial L_{1t}} = \overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t}) - \overline{\phi}\sigma_{pt}^2[Y_{2t}(Y_{1t} - Y_{2t})\overline{L} + (Y_{1t} - Y_{2t})^2L_{1t}] = 0,$$

where $\overline{\phi} = -U''(\overline{W})/U'(\overline{W})$ is the Arrow-Pratt measure of absolute risk aversion at mean wealth.

The approximation of the first-order condition, (4), can be solved for the optimal level of L^*_{1t} and L^*_{2t}.

$$(5)\quad L^*_{1t} = \frac{\overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t}) - \overline{\phi}\sigma_{pt}^2 Y_{2t}(Y_{1t} - Y_{2t})\overline{L}}{\overline{\phi}\sigma_{pt}^2(Y_{1t} - Y_{2t})^2},$$

$$(6)\quad L^*_{2t} = \overline{L} - L^*_{1t}.$$

Note that as σ_{pt}^2 or $\overline{\phi}$ tends to zero, L^*_{1t} will tend to $\overline{L}$ so long as $\overline{P}_t(Y_{1t} - Y_{2t}) > (C_{1t} - C_{2t})$. Also, if $\overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t})$ is less than $\overline{\phi}\sigma_{pt}^2 Y_{2t}(Y_{1t} - Y_{2t})\overline{L}$, then the producer will allocate all of his land to the cost-reducing technology. Assuming that neither of the above conditions is true, we can see that the proportion of the land allocated to the yield-increasing technology is inversely proportional to the degree of price variability, σ_{pt}^2. The opposite is true for cost-reducing technologies. This relationship motivates the following proposition.

Proposition 1: A higher (lower) level of price variability will be one of the reasons for variable input saving (using) technological change.

From a policy perspective, this proposition tells us that under the conditions outlined above, increases in price variability will encourage the adoption of cost-reducing technologies or variable input saving technologies. Reductions in the level of price variability will lead producers to favor yield-increasing or fixed factor saving technical change.

The Introduction of Adjustment Costs

One obvious extension of the model outlined above is to introduce positive adjustment costs. Stoneman (1983) has developed an intra-firm diffusion model under uncertainty that can be readily adapted to this purpose. Assume that the cost of adjustment A_{it} of technology i at time t is related to the rate of change in L_{it} according to

$$(7)\quad A_{it} = \Phi_i \frac{(L_{it} - L_{it-1})^2}{2L_{it-1}}.$$

If it is assumed that adjustment costs for the alternative technology are zero, we can rewrite the first-order condition (4) can be rewritten as

$$(8)\quad \frac{1}{U'(\overline{W})} \frac{\partial U}{\partial L_{1t}} = \overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t}) - \frac{\partial A_{1t}}{\partial L_{1t}} - \overline{\phi}\sigma_{pt}^2[Y_{2t}(Y_{1t} - Y_{2t})\overline{L} + (Y_{1t} - Y_{2t})^2 L_{1t}] = 0.$$

If the firm chooses L_{it} given L_{it-1}, the rate of adoption can be derived from (7) and (8).

$$(9)\quad \frac{dL_{1t}}{d_t} \frac{1}{L_{1t}} = \frac{1}{\Phi_1}[\overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t}) - \overline{\phi}\sigma_{pt}^2 Y_{2t}(Y_{1t} - Y_{2t})\overline{L}]\,(1 - \frac{L_{1t}}{L^*_{1t}}).$$

Solving (9) for L_{it} gives

$$(10)\; L_{1t} = \frac{L^*_{1t}}{1 + EXP(-\alpha_1 t - \beta_1)},$$

where

$$(11)\; \alpha_1 = \frac{1}{\Phi_1}[\overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t}) - \overline{\phi}\sigma_{pt}^2 Y_{2t}(Y_{1t} - Y_{2t})\overline{L}],$$

and β_1 equals the log of L_1 at time zero, i.e., when the producer discovers the technology divided by the difference between L^*_1 and the initial level, i.e.,

$$(12)\; \beta_1 = \log \frac{L_{10}}{L^*_{1t} - L_{10}}.$$

Note that if $\alpha_1 > 0$, the intra-firm diffusion process will be logistic. This is true even though no learning mechanism was incorporated. This result is in agreement with almost all studies of this process which have found that new technologies tend to be adopted in a sigmoid pattern through time. It is also consistent with Stoneman's result where he generates a logistic diffusion curve in the case where only one new technology is available.

Using an adjustment cost function, Stoneman's model, however, considers the diffusion path of a single technology. It is therefore useful to see whether the result can be repeated when the producer might choose between two technologies. If we repeat the above analysis for the second technology, we get

$$(13)\ L_{2t} = \frac{L^*_{2t}}{1 + \exp(\alpha_2 t - \beta_2)},$$

where

$$(14)\ \alpha_2 = \frac{1}{\Phi_2}[\overline{P}_t(Y_{1t} - Y_{2t}) - (C_{1t} - C_{2t}) - \overline{\phi}\sigma_{pt}^2 Y_{1t}(Y_{1t} - Y_{2t})\overline{L}],$$

and

$$(15)\ \beta_2 = \log \frac{L_{20}}{L^*_{2t} - L_{2t}}.$$

Note that in order to motivate the existence of a standard logistic diffusion process, α_2 must be negative. The variable α_1 in logistic curve (10) is directly proportional to the speed of diffusion (see Mansfield [1986], Stoneman [1981]). While the variable α_2 in (13) is the inverse of the speed of diffusion, obviously σ_p^2 is negatively related to α_1 and α_2. This leads to proposition 2.

Proposition 2: A lower (higher) level of price variability will increase the speed of diffusion for the yield-increasing (cost-reducing) technology.

This proposition implies that price stabilization policies increase the rate of diffusion of yield-increasing technologies and reduce the speed of diffusion of cost-reducing technologies.

Summary and Concluding Remarks

This paper provides some results concerning technology adoption patterns and technological change for two innovations that are assumed to be introduce simultaneously: one is yield-increasing, the other is cost-reducing. The analysis assumes that the output price is the only random variable and the farmer is risk averse. The results show that a higher level of price variability will be one of the reasons for variable inputs saving technological change. On the other hand, a lower level of price variability will lead to variable input using technological change.

The relationship between price variability and the speed of technology diffusion can be also determined by this model. The result is that a higher level of price variability will be associated with a lower (higher) speed of diffusion for yield-increasing (cost-reducing) technology.

One of the important implications of this paper is the linkage between government price stabilization policies and technology adoption and technological change. One tentative conclusion that can be drawn is that the introduction of a price stabilization policy will encourage producers to adopt yield-increasing technologies while the removal of one of these schemes will increase the development and adoption of cost-reducing technologies. This implies that countries that wish to develop or encourage the adoption of technologies that increase returns to the fixed factors of production (yield-increasing) may find that price stabilization programs work for them. On the other hand, countries that wish to encourage the adoption of technologies that reduce average variable costs (cost-reducing) may find that price stabilization programs work against them.

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Notes

[1]This restrictive assumption is justified on two fronts. First, it is possible to derive the following results in the situation where quantity is variable. The methodology is, however, more complex and would greatly extend the length of this paper. These results are available from the authors on request. Second, governments that alter the variance of output prices might be justified in assuming that the variance of output will remain unchanged. Consequently, this assumption is in keeping with the policy focus of this paper.