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A conceptual framework of adoption of an agricultural innovation

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Abstract

In this paper we present a conceptual framework of individual farmers' decisions on adoption of a new innovation, using the example of a new crop species. This framework overcomes the shortcomings of a number of previous studies. It represents the adoption of an innovation as a dynamic decision problem spanning at least several years. The model allows for generation of potentially valuable information from trialing the innovation. The value of such trials is due to development of skills (e.g. in agronomic management of a crop) as well as reduction in uncertainty about the innovation's long-term profitability. The framework also includes the farmer's personal perceptions, managerial abilities and risk preferences in order to properly represent the adoption decision process. The influences of socio-demographic factors within the framework are discussed.
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1. Introduction

The adoption of innovations in agriculture has been studied intensively since Griliches (1957) pioneering work on adoption of hybrid corn in the USA. The majority of the previous adoption research has been concerned with answering the questions: (a) what determines whether a particular producer adopts or rejects an innovation, and (b) what determines the pattern of diffusion of the innovation through the population of potential adopters (Lindner et al., 1982; Feder et al., 1985; Lindner, 1987; Tsur et al., 1990; Leathers and Smale, 1992; Feder and Umali, 1993; Saha et al., 1994; Marsh et al., 1995; Rogers, 1995). Overall, despite numerous studies, the results of research in this field have been disappointing. Most of the statistical models developed have low levels of explanatory power, despite long lists of explanatory variables (Lindner, 1987). Furthermore, the results from different studies are often contradictory regarding the importance and influence of any given variable.

Risk has often been considered as a major factor reducing the rate of adoption of an innovation (Lindner et al., 1982; Lindner, 1987; Tsur et al., 1990; Leathers and Smale, 1992; Feder and Umali, 1993). However the issue of risk in adoption has rarely been addressed adequately. The missing link is usually the dynamic nature of adoption decisions involving changes in farmers' perceptions and attitudes as information is progressively collected.

This study presents a framework that conceptualises adoption as a multi-stage decision process involving information acquisition and learning-by-doing by

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growers who vary in their risk preferences and their perceptions of riskiness of an innovation. In developing a conceptual framework of adoption, Lindner (1987) reached some important conclusions that are pertinent to this study. He highlighted the inconsistencies in the results obtained from most of the empirical studies on adoption of agricultural innovations and identified some reasons for shortcomings observed in many of those studies. These included the failure to account for the importance of the dynamic learning process in adoption, biases from omitted variables, poor model specification, and failure to relate hypotheses to a sound conceptual framework. He argued that weaknesses such as these were the prime cause of findings in some studies that farmers behave against their own best-interest in adoption decisions. He concluded that,

> "As long as the findings of methodologically flawed studies are ignored, there is compelling empirical support for this emerging consensus that the final decision to adopt or reject is consistent with the producer's self-interest". (p. 148)

> "The finding that the rate of adoption as well as ultimate adoption level are determined primarily by the actual benefits of adoption to the potential adopters is by far and away the most important result to be culled from the empirical literature on adoption and diffusion." (p. 150)

The framework presented in this paper builds on Lindner's approach and overcomes the shortcomings of many previous studies. Here the adoption process of a farmer considering a new crop is modelled as a dynamic decision problem spanning at least several years. The model allows for generation of potentially valuable information from trialing the crop. The value of such trials is due to development of skills in agronomic management of the crop as well as due to reduction in uncertainty about its long-term profitability. The former of these appears not to have been adequately recognised in previous literature and the latter has often been neglected. In order to properly represent the process, the framework must include the farmer's personal perceptions, managerial abilities and risk preferences. In the first part of this paper, the decision to adopt a new crop is represented as a simple static portfolio problem under certainty with the objective of profit maximisation. This simple model is then extended to include adoption decisions over time and the increase in crop profitability resulting from skill development, which comes from experience in growing the crop. The model is further expanded to include the farmer's uncertainty about the long-term profitability of the crop. The value of on-farm trials and experimentation to obtain information for reduction in uncertainty about the profitability of the crop is included. We discuss the relevance of Bayes' theorem to the framework and discuss the role of farmers' risk preferences. Finally the roles played in the framework by social and demographic factors are discussed.

2. A static model of the individual adoption decision

We start with a simple static model representing the farmer's decision problem regarding the allocation of resources to a new enterprise. To ground the framework in the real-world problem that motivated its development, the presentation of the framework is based around a particular example: allocation of land to production of a new crop, chick peas, and an alternative traditionally-grown crop. In this initial model, for simplicity it is assumed that there is only a single alternative crop, that there is no uncertainty or risk in the decision, and that the farmer's objective is to maximise profit for the coming season only.

Let A_c = Area of chick peas, A_A = Area of the alternative enterprise, A_T = Total arable area on the farm $= A_c + A_A$, G_c = Gross margin of a hectare of chick peas, G_A = Gross margin of the alternative enterprise, F_c = Fixed cost of producing chick peas, which is independent of A_c provided that $A_c > 0$, F_A = Fixed cost of producing the alternative enterprise, which is independent of A_A provided that $A_A > 0$.

Assume that the farm's land is heterogeneous (e.g. in soil structure, chemical composition of the soil, weed species present) so that G_c and G_A vary within the farm. Now suppose that we have calculated for all areas of the farm the difference in gross margin between chick peas and the alternative enterprise, $G_c - G_A$, and have ranked the paddocks according to this difference. Assume that whatever value of A_c the farmer selects, it will be allocated to the land on

which $G_c - G_A$ is greatest. Then profit for the farm is given by:

$$\Pi = \int_0^{A_c} G_c \mathrm{d}x + \int_{A_c}^{A_T} G_A \mathrm{d}x - F_c - F_A \quad (1)$$

For any given value of A_c it is possible to calculate $\overline{G}_c$ and $\overline{G}_A$, the mean gross margin of chick peas and the alternative enterprise respectively, across the whole areas on which they are grown. Then:

$$\Pi = \overline{G}_c A_c + \overline{G}_A A_A - F_c - F_A \quad (2)$$

This second representation will be useful later. For now we continue from Eq. (1). The optimal area of chick peas, A_c^*, occurs where the first derivative of profit with respect to A_c is equal to zero or, in other words, where there is no further gain in profitability by any incremental increases in the area of chick peas:

$$\frac{\mathrm{d}\Pi}{\mathrm{d}A_c} = G_c + G_A \frac{\mathrm{d}A_A}{\mathrm{d}A_c} = 0 \quad (3)$$

but $A_A = A_T - A_c$, so $\mathrm{d}A_A/\mathrm{d}A_c = -1$ and A_c^* is where $G_c - G_A = 0$ or $G_c = G_A$.

At A_c^* the gross margins of chick peas and the alternative enterprise on the marginal unit of land are equal. It is necessary to check that the second derivative is negative to ensure a maximum.

Now consider the question of whether to adopt chick peas or not. In other words, is A_c^* larger than zero?

From Eq. (2)

$$\Pi(A_c^*) = \overline{G}_c A_c^* + \overline{G}_A (A_T - A_c^*) - F_c - F_A \quad (4)$$

(assuming that $A_T > A_c^*$), and

$$\Pi(0) = \overline{G}_A A_T - F_A \quad (5)$$

so

$$\Pi(A_c^*) - \Pi(0) = \overline{G}_c A_c^* - \overline{G}_A A_c^* - F_c \quad (6)$$

thus

$$\Pi(A_c^*) > \Pi(0)$$
$$\Rightarrow \overline{G}_c A_c^* - \overline{G}_A A_c^* - F_c > 0$$
$$\Rightarrow \overline{G}_c - F_c / A_c^* > \overline{G}_A$$

In other words, A_c^* (rather than zero) hectares of chick peas will be grown so long as the average gross margin of chick peas minus average fixed costs is greater than the average gross margin of the alternative crop on the A_c^* hectares of the farm that most favours chick peas. This simple portfolio model does not account for time in the adoption process, nor for the farmer's ability to learn by doing to improve his or her technical efficiency in growing and marketing the crop more successfully. These weaknesses are addressed in Section 3.

A summary of the symbols used here and their description are provided in Appendix A.

3. A dynamic adoption model with skill development

Our simple static portfolio model can now be adapted to allow for changes in the gross margin of chick peas from year to year through changes in yield and price as the farmer gains skill in growing or marketing the produce. We still assume that the decision is free of risk and uncertainty. The improvements in chick pea gross margin over time are completely deterministic and predictable.

The objective is to maximise profitability over a period of n years:

$$\max \Pi = \mathrm{NPV}_{t=1}^{n} \left[\int_0^{A_{ct}} G_{ct} \mathrm{d}x + \int_{A_{ct}}^{A_T} G_A \mathrm{d}x \right] \quad (7)$$

or

$$\max \Pi = \mathrm{NPV}_{t=1}^{n} \left[\overline{G}_{ct} A_{ct} + \overline{G}_A A_{At} \right] \quad (8)$$

Note our assumption that G_A is constant over time, unaffected by further experience with the crop. This reflects an assumption that the farmer has substantial experience already in growing the alternative crop. Also, for simplicity of presentation, the fixed cost variables are excluded from these and subsequent equations. The deterministic influence of fixed costs remains important, as outlined in the previous section. A stochastic influence will also be outlined later.

Suppose the farmer chooses to grow chick peas in the coming year (year one). It is convenient to express the profit function as follows, with terms for the first year separated out.

$$\Pi = \overline{G}_{c1} A_{c1} + \overline{G}_A (A_T - A_{c1}) + \mathrm{NPV}_{t=2}^{n} \left[\overline{G}_{ct} A_{ct} + \overline{G}_A (A_T - A_{ct}) \right] \quad (9)$$

Finding the optimal area of chick peas for every year from $t = 1$ to $t = n$, is a deterministic optimisation problem of n decision variables subject to constraints that $0 \leq A_{ct} \leq A_T$. Let A^*_{ct} signify the optimal areas which are the solution to this problem.

Now consider the question of whether the farmer would be better off not to grow chick peas in the first year. A^{**}_{ct} is the optimal set of chick pea areas over time subject to the additional constraint that $A_{c1} = 0$.

Note that G_{ct} depends on A_{ct} in previous years since we assume that experience improves the farmer's skill. The improvement in G_{ct} depends on the number of years of experience and the aggregate prior area grown. For a given vector A_{ct} there is a corresponding vector G_{ct}. Thus considering whether or not to grow chick peas in year one implies differences in G_c in later years, and this then influences the optimal chick pea area in later years.

Consequently, even though A^{**}_{ct} is formed only by constraining the chick pea area in the first year, this constraint influences the optimal area in subsequent years (potentially all of them). Understanding this is important for the question of whether or not the farmer is better off growing chick peas in the first year; is $\Pi(A^*_{ct}) > \Pi(A^{**}_{ct})$?

If the farmer grows chick peas in the first year then the dynamic profit function can be expressed as:

$$\Pi\Big|_{A_{c1}=A^*_{c1}} = \Pi^* = \overline{G}^*_{c1}A^*_{c1} + \overline{G}_A(A_T - A^*_{c1}) + \mathrm{NPV}^n_{t=2}\left[\overline{G}^*_{ct}A^*_{ct} + \overline{G}_A(A_T - A^*_{ct})\right] \quad (10)$$

If the farmer chooses not to grow chick peas in the first year then the dynamic profit function can be expressed as:

$$\Pi|_{A_{c1}=0} = \Pi^0 = \overline{G}_A A_T + \mathrm{NPV}^n_{t=2}\left[\overline{G}^{**}_{ct}A^{**}_{ct} + \overline{G}_A(A_T - A^{**}_{ct})\right] \quad (11)$$

The difference between the two (Eqs. (10) and (11)) indicates whether income from the chick pea crop in year one plus the value of improving the farmer's skill in growing future chick pea crops outweighs the loss of income from the alternative crop.

$$\Pi^* - \Pi^0 = (G^*_{c1} - \overline{G}_A)A^*_{c1} + I_S \quad (12)$$

where I_S represents the difference between NPV of profits for years subsequent to year one. $\overline{G}_{c1}A^*_{c1}$ = net returns from chick peas in year one. $\overline{G}_A A^*_{c1}$ = opportunity cost of land used to grow chick peas in year one. I_S is a monetary value which arises from the improvement in the farmer's skills at growing the crop due to experience and information learnt in year one. It is a value of information which differs from that usually discussed in the decision theory literature (e.g. Anderson et al., 1977). The value is in changing the technical parameters of the production function, rather than in better decision making. It encompasses any adjustment in area of chick peas and the alternative enterprise in the future years as a result of the farmer's higher skill level after the first year.

It is recognised in the literature that collection of information which reduces uncertainty and improves decision making (denoted in the next section I_D) provides an incentive for farmers to plant a trial of a new crop even if they expect to lose money on the trial in the short run. I_S provides a similar incentive, with higher profits in future having the potential to offset losses in the short term as skills are developed.

Let us consider the value of information from skill development, I_S, in more detail.

$$I_S = \mathrm{NPV}^n_{t=2}\left[\overline{G}^*_{ct}A^*_{ct} + \overline{G}_A(A_T - A^*_{ct}) - \overline{G}^{**}_{ct}A^{**}_{ct} - \overline{G}_A(A_T - A^{**}_{ct})\right] \quad (13)$$

In every year after year one there is potentially a change in the area of chick peas due to the decision to grow chick peas in year one. If the farmer's skill level had not been increased by growing the crop, the optimal area of chick peas in subsequent years would probably have been lower. It is convenient to represent this change in optimal areas as:

$$\Delta_{At} = A^*_{ct} - A^{**}_{ct} \quad \text{or} \quad A^*_{ct} = A^{**}_{ct} + \Delta_{At} \quad (14)$$

Then substituting for A^*_{ct} in Eq. (13) we have:

$$I_S = \mathrm{NPV}^n_{t=2}\left[\overline{G}^*_{ct}(A^{**}_{ct} + \Delta_{At}) + \overline{G}_A(A_T - (A^{**}_{ct} + \Delta_{At})) - \overline{G}^{**}_{ct}A^{**}_{ct} - \overline{G}_A(A_T - A^{**}_{ct})\right] \quad (15)$$

$$I_S = \mathrm{NPV}^n_{t=2}\left[(\overline{G}^*_{ct} - \overline{G}^{**}_{ct})A^{**}_{ct} + (\overline{G}^*_{ct} - \overline{G}_A)\Delta_{At}\right] \quad (16)$$

Eq. (16) above shows that the value of information from skill development can be decomposed into two elements: the gain in profitability on the area which would have been cropped to chick peas in future years even without chick peas being grown in year one, $(\overline{G}^*_{ct} - \overline{G}^{**}_{ct})A^{**}_{ct}$, plus the gain in profit on the area

converted from the alternative crop to chick peas in future years as a result of growing chick peas in year one, $(\overline{G}^*_{ct}-\overline{G}_A)\Delta_{At}$.

It is likely that as the area of chick peas in the first year increases, so does the gross margin of the chick pea crops in the future years since larger trial areas are more likely to be representative of the full scale production of the crop and hence result in larger improvements in farmer's skill in growing the crop. However it is unlikely that there would be a linear relationship between A_{ct} and subsequent gross margin, G_{ct+1}; it appears more likely that G_{ct+1} would increase at a decreasing rate with increases in A_{ct}.

If the farmer is growing a trial area of chick peas primarily to enhance his or her skill level, diminishing marginal returns to the area of the trial would tend to encourage a small trial area since for larger areas, the value of I_S per marginal hectare is smaller and may not offset the opportunity cost of the alternative crop. On the other hand, if the trial is too small to represent a realistic experience of growing the crop, the gain in skill may also be too small to be worthwhile. Anecdotal evidence indicates that extensive dryland farmers in Western Australia typically trial new crops on 20 to 40 ha.

4. A dynamic adoption model with uncertainty and experimentation

Up to this stage in the development of the conceptual model of adoption it has been assumed that yields, prices and costs of chick peas in current and future years are known by farmers with certainty. However, in reality the farmer is uncertain about the values of some or all of these variables. This means that as a result of a trial of the crop, information about its yield and price performance are likely to reduce the farmer's uncertainty for future years and allow better decision making. The value of this information for improved decision making is denoted I_D.

We will assume that the farmer's objective is to maximise the expected value of the net present value of profits. Therefore the farmer is concerned with the gross margins of the crops in year one and future years. (Risk aversion on the part of the farmer in not considered here but is in a later section). Before conducting the trial, the farmer has a subjective perception of the possible values of G_c, the gross margin of chick peas on each hectare of his or her land. For a given area of chick peas, the gross margin varies from hectare to hectare and the mean over the area is denoted by $\overline{G}_c$. $\overline{G}_c$ varies according to the area of chick peas grown. Now, the farmer is uncertain about the value of $\overline{G}_c$, but is able to subjectively state a probability distribution for it. Given the farmer's objective to maximise expected NPV, $E(\overline{G}_c)$ would be the value used in a standard decision theory model to represent the payoff from chick peas in each of the years. The E operator in $E(\overline{G}_c)$ signifies the expectation over uncertain states of nature, while $^-$ signifies the mean across all the area devoted to chick peas.

Regardless of the farmer's objectives and decision process, it is clear that the decisions to trial and ultimately adopt chick peas are based on subjective perceptions of the probability distribution of the profit for chick peas. From the information generated from the trial, the farmer revises his or her subjective beliefs about the profitability of the crop. Based on this revised (hopefully more accurate) perception, the farmer decides whether or not to continue growing chick peas and, if so, what area of the farm to devote to them.

A trial in year t provides information which allows improved estimates of $\overline{G}_{ct}$ for subsequent years. This in turn allows improved selection of A_{ct} for subsequent years. The gain in expected profit $E(\overline{G}_{ct})$ as a result of the changes in A_{ct} constitutes the value of I_D. I_D should be evaluated using the improved estimates of $\overline{G}_{ct}$ to assess the values of A_{ct} with and without the trial.

It should be clear that I_D is different to I_S but the two interact because both are related to changes in the area of the innovation in later seasons, A_{ct}. In the case of I_S, improvements in G_c encourage increases in A_c, while for I_D, better knowledge of the crop's performance may either increase or decrease the area selected to be grown.

Mathematically, including I_D in the decision of whether to trial chick peas in the coming year (i.e., whether $A^*_{c1} > 0$) gives

$$\Pi^*-\Pi^0 = \overline{G}_{c1}A^*_{c1}-\overline{G}_A A^*_{c1} + I_S + I_D \qquad (17)$$

Given the close interaction between I_S and I_D, it may be better to refer to the combined value of the information as I_{S+D}. However, in order to simplify the

conceptualisation of I_D, let us ignore at this stage the value of I_S by assuming that the farmer's skill at growing chick peas is not increased by experience. Recall that if the farmer decides to trial chick peas, the dynamic profit function can be expressed as:

$$\Pi^* = \overline{G}^*_{c1}A^*_{c1} + \overline{G}_A(A_T - A^*_{c1}) + \mathrm{NPV}^n_{t=2}\left[\overline{G}^*_{ct}A^*_{ct} + \overline{G}_A(A_T - A^*_{ct})\right] \quad (18)$$

While if the farmer chose not to trial chick peas in that year, the profit function is:

$$\Pi^0 = \overline{G}_A A_T + \mathrm{NPV}^n_{t=2}\left[\overline{G}^{**}_{ct}A^{**}_{ct} + \overline{G}_A(A_T - A^{**}_{ct})\right] \quad (19)$$

These were given previously in relation to I_S, but the same equations apply to I_D. As before, there would probably be differences in A_c in subsequent years as result of the trial in year one, so that $A^*_{ct} \neq A^{**}_{ct}$. Because we are assuming that there are no benefits from increasing skills, the impact of the trial on A_{ct} is not caused by actual changes in G_{ct}, but rather by changes in the farmer's perception of G_{ct}.

As before the difference between the two equation indicates whether the value of producing the crop in year one and of the information it generates outweigh the opportunity costs.

$$\Pi^* - \Pi^0 = \overline{G}^*_{c1}A^*_{c1} - \overline{G}_A A^*_{c1} + I_D \quad (20)$$

In a similar way as we did for I_S we can expand I_D.

$$I_D = \mathrm{NPV}^n_{t=2}\left[\overline{G}^*_{ct}A^*_{ct} + \overline{G}_A(A_T - A^*_{ct}) - \overline{G}^{**}_{ct}A^{**}_{ct} - \overline{G}_A(A_T - A^{**}_{ct})\right] \quad (21)$$

and rearrange it to give:

$$I_D = \mathrm{NPV}^n_{t=2}\left[(\overline{G}^*_{ct} - \overline{G}^{**}_{ct})A^{**}_{ct} + (\overline{G}^*_{ct} - \overline{G}_A)\Delta_{At}\right] \quad (22)$$

However for I_D, $\left[(\overline{G}^*_{ct} - \overline{G}^{**}_{ct})A^{**}_{ct}\right]$ is zero since we are assuming that the trial does not alter G_{ct}, only the farmer's perception of it. Therefore I_D can be reduced to:

$$I_D = \mathrm{NPV}^n_{t=2}\left[(\overline{G}^*_{ct} - \overline{G}_A)\Delta_{At}\right] \quad (23)$$

Thus, the value of information from trialing in the model is the gain in profit on the area converted from the alternative enterprise to chick peas in future years as a result of the trial.

Unlike the process of trialing for skill development, trialing for reduced uncertainty can lead to a reduction in the perception of the profitability of the crop. In such cases it does not mean that the information has negative values, since the reduction in planted area which results is a better decision.

The shape of the relationship between A_{c1} and I_D may strongly influence the optimal trial area. Like I_S, I_D is likely to increase but at a decreasing rate with increasing A_{c1}. Also like I_S, the value of I_D is likely to decline over time as the farmer gains experience with the crop. This is because the more accurate are the farmer's current perceptions about the crop, the less scope there is for improved decision making by further refinement of the perceptions.

In summary, then, the introduction of uncertainty into the model brings the possibility of a trial generating information which is of value in reducing the uncertainty. Such reductions mean that the farmer is more able to make decisions which are in his or her own best interests.

5. Using Bayes' Theorem in Valuing Trial Information

One approach to modelling the changes in perception following a trial is to assume that farmers use Bayesian learning rules to update their perceptions (Anderson et al., 1977). Although there is some evidence that people do not behave exactly in accord with Bayes' rule (Lindner and Gibbs, 1990), this theory does provide a convenient and rigorous framework that may be a reasonable approximation of actual human learning process. Anderson et al. (1977) argue that the most important feature of Bayes' theorem is that it provides a logical mechanism for the consistent processing of additional information. From a Bayesian perspective, a farmer who enters the trial phase with a perceived distribution of the profitability of the crop carries out the trials in order to narrow the gap between their perception and the crop's true or objective distribution of profit.

Anderson et al. (1977) provide a good explanation of Bayes' theorem and its application in decision analysis. Essentially, Bayes' theorem allows us to revise probabilities based on new information and to determine the probability that a particular effect was due to a particular cause. This allows us to refine the optimal decision, and to calculate the expected value of benefits from this refinement.

The adoption problem includes both risk and uncertainty. The farmer is uncertain about which of the possible probability distributions actually applies to chick peas, and whichever of the distributions applies, the gross margin is risky in that it may take any of a number of values with particular probabilities.

A notable feature of this example, which differs from standard text-book examples of decision theory, is that the likelihoods are built into the definitions of the states. The likelihoods for a state are from the probability distribution which is the state. To illustrate, the alternative states in our chick pea problem are different probability distributions of chick pea gross margin. Whichever of these distributions is the objectively correct one describes the probabilities of G_{ct} taking different values. In other words, the alternative states are alternative sets of likelihoods of G_{ct}. This feature applies generally to the type of problem being addressed here-a decision on adoption of an innovation where the decision is influenced by an on-farm trial of the innovation. In more realistic examples, the likelihoods would be adjusted to account for the representativeness of the trial to the situation in which the innovation would ultimately be used (e.g., after an improvement in the farmer's skill at applying the innovation).

We do not incorporate Bayes' theorem formally in the algebraic model, since the exact process of probability revision is not the point at issue here. Rather the important task is to recognise the consequences of revising the probabilities, as outlined in the previous sections.

6. Risk attitudes in the adoption model

Decisions by an individual about the optimal combination of actions or practices depend on the individual's perception of expected profit, perception of risk and attitude to risk. Often there is a trade-off between profit and risk. Empirical evidence (e.g., Binswanger, 1980; Bond and Wonder, 1980; Bardsley and Harris, 1987) indicates that individual farmers vary widely in their attitudes to risk with the most common being slight risk aversion. By adding risk attitude and utility, the adoption model can be improved to capture another level of sophistication where the farmer maximises expected utility of profit, $E(U(\Pi))$, rather than the expected profit, $E(\Pi)$.

The inclusion of risk attitudes in the dynamic adoption model is, in principle, straight forward. Instead of assuming that the farmer maximises $E(\text{NPV})$, we now have a model where the farmer maximises $E(U[\text{NPV}])$. Within this modified adoption model I_S and I_D affect the distribution of NPV which is used to calculate $E(U[\text{NPV}])$. From here we can proceed to solve this adoption model to find the optimal investment in the innovation if the farmer chose to trial in the first year, evaluated using $E(U[\text{NPV}])$ as the objective, rather than $E(\text{NPV})$.

Including this approach in the algebraic model does not change its essential features or insights about information and learning, so for simplicity this has not been done. The key difference from including risk aversion would be that adoption of innovations with relatively high levels of risk and/or uncertainty would be less likely, or on a smaller scale. Given that high uncertainty is a normal attribute of innovations before they have been trialled, risk aversion is generally a negative influence on rapid adoption.

7. Fixed costs and option values

The fixed costs included in Section 2 were independent of the scale of use of the innovation, but in the static model, the issue of time did not arise. For some innovations, the nature of the fixed costs is such that they must be borne in advance to allow use of the innovation over a number of production periods, (e.g. purchase of specialised new machinery for a new crop type). In such cases, the dynamics and uncertainty of the adoption problem interact to generate an 'option value' associated with postponing the investment (e.g. Dixit and Pindyck, 1994). In other words, the uncertainty about whether the investment will continue to pay off over the whole period covered by the fixed costs creates an incentive to delay the adoption decision.

It is interesting to note that farmers often attempt to trial an innovation without investing in the 'correct' machinery, but by making do with their existing machinery and making allowances for this in their interpretation of the results. In this way they can obtain some of the information value from trialling

without sacrificing the option value from delaying investment in the machinery.

Note that the option value referred to here does not arise from risk aversion (although risk aversion may influence its magnitude) but from the value of information obtained by waiting.

8. Demographic and social factors

As noted earlier, there is an abundance of adoption literature which has identified many factors that may influence the adoption process. The framework presented here has emphasised the farmer's personal subjective perceptions of the innovation's profitability and riskiness, the farmer's uncertainty about the innovation and the farmer's attitude to risk and uncertainty. In this section, the way that various other factors fit into the framework is described. These factors all influence the adoption decision by influencing the farmer's subjective perceptions, uncertainty and/or attitudes.

Availability of labour is likely to influence the gross margin of the innovation, $\overline{G}_c$, through its effect on the yield or output of the product. Additional working family members or trusted employees provide the opportunity for the farm to develop the technical know-how required to trial a small area of a new crop. The potential need for extra care and patience at times of peak labour demand when trialing an innovation highlight the importance of the availability of skilled and committed labour. Therefore a farm with larger number of workers per hectare is more likely to be in a position to trial and continue using a potentially profitable innovation.

Equity, as a measure of wealth, is likely to be a positive influence on the initial scales of a trial of an innovation as this wealth allows the farmer to invest a relatively smaller proportion of their wealth to venture into an uncertain enterprise. The impact of this factor may be partly through its relaxation of financial constraints, as well as through decreasing risk aversion with increasing wealth (Anderson et al., 1977).

Age and experience of the farmer, as indicated by the number of years that the farmer has been farming in the region, is likely to have a range of influences on adoption. The farmer's previous experience with other innovations may have been either positive or negative, and this will likely influence his or her perception of $\overline{G}_c$. Age may influence risk aversion, with the traditional view being that older farmers are more risk averse. If true, this would probably mitigate against adoption. Experience will improve the farmer's skill at production. Again this has positive and negative possibilities. Higher skill increases the opportunity cost of not growing the traditional enterprise. On the other hand it may enhance the profitability of the innovation. Finally, a more experienced grower may have a lower level of uncertainty about the innovation's performance. In this case, the value of information due to reductions in uncertainty would be lower.

A farmer's personal discount rate and time preference is likely to influence adoption. The higher the discount rate or the shorter the time horizon considered, the less likely the farmer is to invest in the initial trial years for a new enterprise in order to develop the necessary skills and to identify its long term profitability. This factor is likely to influence I_S, and to be influenced by the farmer's age and financial situation.

Experience with innovations of similar types will most likely influence adoption in a positive sense because it will improve the technical and management skill of the individual farmer. This factor will probably influence the initial size and the rate of skill development through trialing. It will also mean that adoption decisions based on trial information may have a higher chance of correct interpretation. This factor is most likely to reduce I_S and increase $\overline{G}_c$.

Farmers are sometimes categorised as being 'innovative' or 'conservative' in their approach to management. What lies behind these descriptions is not clear, but it is reflected in observations that different farmers require a greater or lesser number of observations of success by other farmers before trialing an innovation. This may be due to differences in any or all of the other factors discussed here. For whatever reason, it is likely that someone who is generally slower to trial has relatively low perceptions of the profitability of innovations in general or else has low values of I_S and I_D (e.g due to small farm size). It could also be that different farmers put different social status values on being seen to be innovative.

The number of years taken for the farmer to hear of the new crop is likely to be negatively correlated with adoption. This suggests a lack of interest on the part of

the farmer and hence is likely to influence the value of information for learning, I_D.

Distance to the nearest adopter of the innovation and the frequency of contact that the farmer maintains with them is likely to influence adoption of the innovation. The closer they are to the nearest adopter and the higher the frequency of contact with them, the more likely it is that the farmer will receive valuable information about growing the innovation, improving their skill and reducing their uncertainty. Therefore the impact of this variable is through its effect on $\overline{G}_c$, I_S and I_D.

Access to sources of technical knowledge and information such as extension officers and industry-related media is likely to improve the profitability of the initial trial area through its impact on the farmer's knowledge. The farmer with access is also likely to have more accurate expectations of the distribution of the profitability of the innovation. This will in turn reduce the number of years required before full adoption takes place. Again the impact of this factor is through its impact on $\overline{G}_c$, I_D and I_S.

9. Concluding Comments

A detailed conceptual framework of adoption of an agricultural innovation has been presented. It includes the dynamic nature of adoption decisions and emphasises the role of learning by doing and the impact of that learning on personal perceptions of the innovation. It has been shown that information from trialling an innovation has two aspects: skill improvement, and better decision making. In a formal model, the factors influencing the economic values of these two aspects have been derived and explained.

Less formally, the roles of Bayesian-style probability revision and of the individual farmer's attitude toward risk have been discussed and related to the framework. A wide range of socio-demographic attributes have also been found to be related to adoption. These were also outlined and related to the framework. In the context of the framework it is clearer why there have been inconsistencies between past studies in the measured influences of some of these socio-demographic variables.

Including all of the factors in this conceptual framework in an empirical study will pose considerable challenges to researchers. However, we consider that the framework overcomes shortcomings commonly present in previous adoption studies. It provides a comprehensive view of the adoption process and should help researchers to formulate future research in the area.

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Appendix A. Glossary of the variable names used in the paper

Variable	Description of the variable name
G_c	Gross margin of the innovative enterprise
G_A	Gross margin of the alternative (traditional) enterprise
F_c	Fixed cost of producing chick peas, which is independent of A_c provided that $A_c > 0$
F_A	Fixed cost of producing the alternative enterprise, which is independent of A_A provided that $A_A > 0$
A_T	Total resources available (total area of the farm)
A_c	Resources allocated to the innovation (area of chick peas)
A_A	Resources (e.g. land area) allocated to the alternative enterprise
Π	Net profit
$\overline{G}_c$	Mean gross margin of chick peas over the area planted
$\overline{G}_A$	Mean gross margin of the alternative enterprise over the area planted
A^*_{ct}	Optimal allocation of resources to the innovation in season t if the farmer trials the innovation in the first year
A^{**}_{ct}	Optimal allocation of resources to the innovation in season t if the farmer does not trial the innovation in the first year
$\overline{G}^*_{ct}$	Gross margin of the innovation if the farmer uses A^*_{ct} as the planting rule.

$\overline{G}_{ct}^{**}$	Gross margin of the innovation if the farmer uses A_{ct}^{**} as the planting rule.
t	Time in yearly increments
n	Number of years in the farmer's planning horizon
I_S	Value of information from trialing for skill development
I_D	Value of information from trialing for decision making
Δ_{At}	Change in the allocation of resources to the innovation in year t as result of a trial in year one
$NPV_{t=2}^{n}$	Net present value of the profits from year 2 to year n
E	Expected value
U	Utility

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