A Conceptual Framework of Adoption of an Innovation Including Dynamic Learning, Personal Perceptions and Risk Attitudes

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Summary

In this paper we present a conceptual framework of the adoption decision for individual farmers. This framework overcomes the shortcomings of a number of the 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 crop. The value of such trials is due to development of skills in agronomic management of the crop as well as reduction in uncertainty about its long term profitability. In this framework we also include the farmer's personal perceptions, managerial abilities and risk preferences in order to properly represent the adoption decision process. We show how Bayes' theorem can be incorporated as a logical way of capturing the proces. of belief revision and calculating the value of information generated from the farmer's subjective estimates of the profitability of the crop. We also explain the socio-demographic factors that are likely to influence farmers' adoption decisions. The conceptual framework described in this paper is being used to develop a longitudinal survey of around 130 farmers in the wheatbelt of Western Australia which will provide the necessary information for building a dynamic model of adoption of grain legumes under uncertainty.

Introduction

The adoption of innovations in agriculture has been studies 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 regard 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 farmers' perceptions and attitudes especially in the information gathering stage of adoption.

This study presents a framework that conceptualises adoption as a multi-stage decision process involving information acquisition and learning-by-doing by growers who vary in their risk preferences and their perception of riskiness of an innovation. It has been developed in the course of a case study of adoption of new grain legume crops in Western Australia but we believe it to have wide applicability. The aim is to understand how risky grain legumes are perceived to be amongst farmers and how risk attitudes and perceptions affect their adoption.

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, omitted variable bias through 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)

and that,

> "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 overcomes the shortcoming of a number of the 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. 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. Next we describe the incorporation of Bayes' theorem as a logical way of capturing the process of belief revision and calculating the value of information generated from previous experience of growing the crop. Inclusion of farmer's personal risk preference further enhances the framework. Finally the roles played in the framework by social and demographic factors are discussed.

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 land to production of chick peas and an alternative 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 = The gross margin of a hectare of chick peas
G_A = The gross margin of the alternative enterprise
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:

$$\Pi = \int^{A_c} G_c \, dA_c + \int_{A_c}^{A_T} G_A \, dA_A \qquad (1)$$

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:

$$\Pi = \overline{G}_c \cdot A_c + \overline{G}_A \cdot A_A \qquad (2)$$

This second representation will be useful later. For now we continue from equation (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:

$$\frac{d\Pi}{dA_c} = G_c + G_A \cdot \frac{dA_A}{dA_c} = 0 \qquad (3)$$

but $A_A = A_T - A_c$, so $\frac{dA_A}{dA_c} = -1$ 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 (2)

$$\Pi(A_c^*) = \overline{G}_c \cdot A_c^* + \overline{G}_A \cdot (A_T - A_c^*) \qquad (4)$$

and

$$\Pi(0) = \overline{G}_A \cdot A_T \qquad (5)$$

so

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

thus

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

In other words, some chick peas will be grown so long as the gross margin of chick peas is greater than that of the alternative crop on any part of the farm. This simple portfolio model does not account for time in the adoption process, nor for the farmer's ability to learn by doing and improve his or her technical efficiency in growing and marketing the crop more successfully. These weaknesses are addressed in the next section.

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

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:

$$Max\ \Pi = NPV_{t=1}^{n}\left[\int_{0}^{A_{ct}} G_{ct}\, dA_{ct} + \int_{A_{ct}}^{A_T} G_A\, dA_{At}\right] \quad (7)$$

or

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

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.

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.

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

Finding the optimum 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 $0 \le A_{ct} \le A_T$. 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 improvements 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:

$$\Pi\big|_{A_T, A^*_{c1}} = \Pi^* = \bar{G}^*_{c1} \cdot A^*_{c1} + \bar{G}_A \cdot \left(A_T - A^*_{c1}\right) + NPV^n_{t=2}\left[\bar{G}^*_{ct} \cdot A^*_{ct} + \bar{G}_A \cdot \left(A_T - A^*_{ct}\right)\right] \quad (10)$$

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

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

The difference between the two (equations 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.

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

Where I_S represents the difference between NPV of profits for years subsequent to year one.

$\bar{G}_{c1} \cdot A^*_{c1}$ = net returns from chick peas in year one.

$\bar{G}_A \cdot A^*_{c1}$ = 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 here as 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.

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

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:

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

Then substituting for A^{*}_{ct} in equation (14) we have:

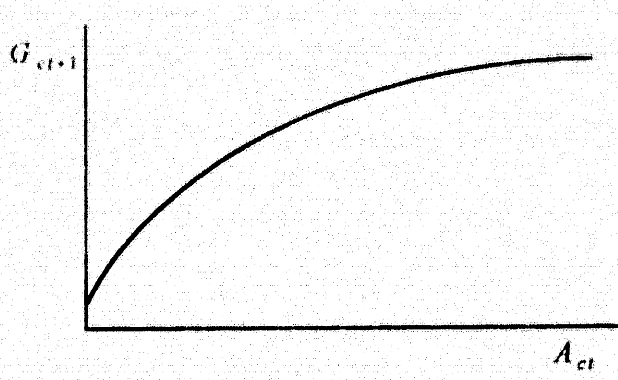
$$I_S = NPV^{r,n}_{t,2}\left[\overline{G}^{*}_{ct}\cdot\left(A^{**}_{ct}+\Delta_{At}\right)+\overline{G}_{A}\cdot\left(A_T-\left(A^{**}_{ct}+\Delta_{At}\right)\right)-\overline{G}^{**}_{ct}\cdot A^{**}_{ct}-\overline{G}_{A}\cdot\left(A_T-A^{**}_{ct}\right)\right] \quad (15)$$

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

Equation (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, $\left(\overline{G}^{*}_{ct}-\overline{G}^{**}_{ct}\right)\cdot A^{**}_{ct}$, 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, $\left(\overline{G}^{*}_{ct}-\overline{G}_{A}\right)\cdot\Delta_{At}$.

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 whole farm 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 G_{ct+1}; it appears more likely that G_{ct+1} would decrease at a decreasing rate with increases in A_{ct}. In fact there would probably be a relationship that showed an increase in the gross margin of future chick pea crops with incremental increases in the trial areas but at a decreasing rate as shown in Figure 1.

Figure 1 A possible relationship between G_{ct+1} and A_{ct}



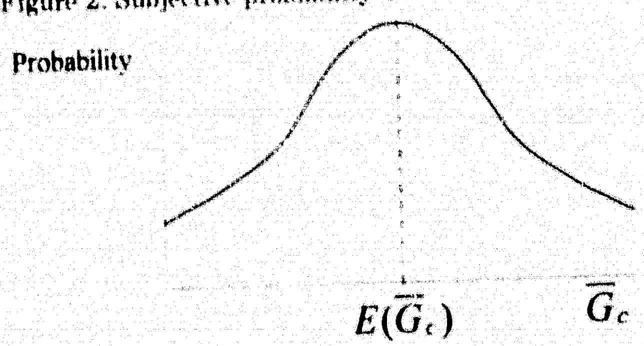
If the farmer is growing a trial area of chick peas primarily to enhance his or her skill level, diminishing marginal returns to the area of the trial would tend to encourage the farmer to trial a small area of chick peas since for larger areas, the value of I_S per hectare is smaller and may not offset 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 hectares.

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. Although this was mentioned briefly in the previous section, it was not included in the model there. We will consider it in detail in this section.

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 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 $\overline{G}_c$. Gross margin of chick peas, $\overline{G}_c$, 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, as illustrated in Figure 2.

Figure 2. Subjective probability distribution of $\overline{G}_c$.



As shown in Figure 2, this distribution has a mean, $E(\overline{G}_c)$. Given the farmer's objective to maximise expected NPV, this mean of means would be the value used in a standard decision theory model to represent the pay-off from chick peas in each of the years.

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 chick peas in any given season, 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

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

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

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

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

$$\Pi'' = \overline{G}_A \cdot A_T + NPV^n_{t,2}\left[\overline{G}^{**}_{ct} \cdot A^{**}_{ct} + \overline{G}_A \cdot (A_T - A^{**}_{ct})\right] \qquad (19)$$

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.

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

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

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

and rearrange it to give:

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

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

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

Therefore, 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.

Like I_s, I_p is likely to increase but at a decreasing rate. Again, in cases where the income generated from the trail does not outweigh its cost $\left(\overline{G}_{c1} \cdot A_{c1}^{*} \langle \overline{G}_{A} \cdot A_{c1}^{*}\right)$, the shape of the relationship between A_{t} and I_p will strongly influence the optimal trial area, similar to the optimal sample size in standard decision theory (Anderson et al. 1977).

Also like I_s, the value of I_p 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 their own best interests.

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 certain 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. They describe the decision problem as a chain consisting of several interlinked components. These components are states, prior probabilities, consequences, choice criterion, experiments, likelihoods probabilities and strategies. We shall follow their notations and briefly describe each one before using the concepts to describe Bayes' theorem and its application.

Acts, are mutually exclusive choices of actions available to the decision maker (e.g., different areas of chick peas in the coming year). States are the possible events in the decision maker's world which are also mutually exclusive and about which there is uncertainty (e.g., the yield of chick pea). Prior probabilities are the probabilities of the occurrence of different states of nature as perceived by the decision maker prior to the trial. A consequence is what an act leads to, depending on which state occurs. The choice criterion or objective function is the means by which the consequences are measured and evaluated (e.g., the resulting profit or utility). Experiments, such as conducting an on-farm trial or buying an expert's advice, provide information about the probabilities of states which the decision maker can use to update their knowledge. Likelihoods are often subjectively held beliefs about the probability of observing each possible outcome of the experiment given that a particular state prevails. Prior probabilities are modified through the likelihoods and Bayes' theorem to become posterior probabilities. Finally a strategy is the set of actions to be taken in future in response to different outcomes of an experiment or new information. We summarise these components of a risky decision problem by denoting them as follows:

a_j = the j^{th} act or risky prospect

θ_i = the i^{th} state of nature

$P(\theta_i)$ = the prior probability of occurrence of θ_i

$P(a_j \mid \theta_i)$ = the utility that results if a_j is chosen and θ_i occurs

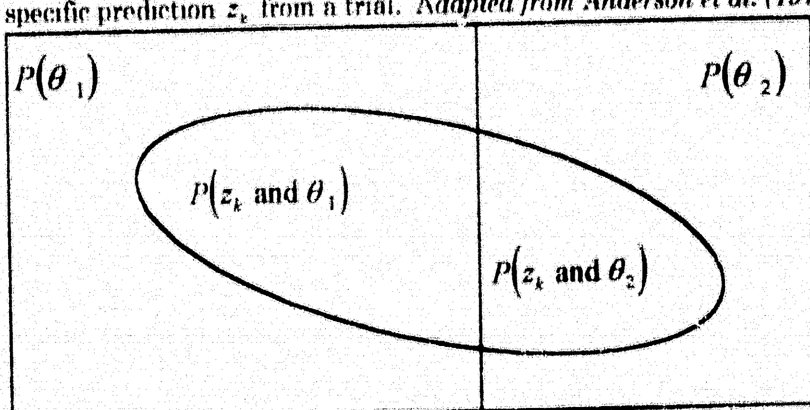
z_k = the k^{th} possible outcome from an experiment or trial

$P(z_k \mid \theta_i)$ = the likelihood probability of z_k occurring given that θ_i prevails

s_t = the t^{th} strategy, implying choice of some particular act if some particular experimental outcome occurs.

Bayes' rule is an important component of the conceptual framework. For the purpose of illustration let us use a simple two-state situation θ_1 and θ_2 and assume that we have a specific prediction or trial result indicating z_k as shown in Figure 3.

Figure 3. Visual representation of probabilities with two states θ_1 and θ_2 and a specific prediction z_k from a trial. *Adapted from Anderson et al. (1977).*



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. From probability theory, conditional probability refers to the probability of a particular event *(A)* given information about the occurrence of another event *(B)* and is defined by the joint probability of event *(A)* and *(B)* divided by the marginal probability of *(B)*. Therefore we have:

$$P(z_k \mid \theta_1) = \frac{P(z_k \text{ and } \theta_1)}{P(\theta_1)} \qquad (24)$$

so that

$$P(z_k \text{ and } \theta_1) = P(\theta_1)\cdot P(z_k \mid \theta_1) \qquad (25)$$

The same applies to the second state, θ_2:

$$P(z_k \text{ and } \theta_2) = P(\theta_2)\cdot P(z_k \mid \theta_2). \qquad (26)$$

The marginal probability of z_k is found by summing its joint probabilities for the two states,

$$P(z_k) = P(z_k \text{ and } \theta_1) + P(z_k \text{ and } \theta_2) \qquad (27)$$

and since by definition

$$P(\theta_1 \mid z_k) = \frac{P(z_k \text{ and } \theta_1)}{P(z_k)} \qquad (28)$$

we can see that

$$P(\theta_1 \mid z_k) = \frac{P(\theta_1)\cdot P(z_k \mid \theta_1)}{P(\theta_1)\cdot P(z_k \mid \theta_1) + P(\theta_2)\cdot P(z_k \mid \theta_2)} \qquad (29)$$

This is the Bayes' theorem for a two state example. But Bayes theorem expressed in more general terms is:

$$P(\theta_i \mid z_k) = \frac{P(\theta_i)\cdot P(z_k \mid \theta_i)}{\sum_i P(\theta_i)\cdot P(z_k \mid \theta_i)} \qquad (30)$$

The application of Bayes' theorem to the revision of perceptions about an innovation's profitability following a trial is illustrated here using a simple example. This simple example demonstrates a method for estimating the value of I_D summarised in equation (30) as $NPV''_{t,2} = \left[\left(\overline{G}^{*}_{ct} - \overline{G}_{A}\right)\cdot \Delta_t\right]$.

A farmer has one hectare of land on which wheat is normally grown, and is considering switching to chick peas. The farmer's objective is to maximise the expected gross margin totalled over the next two years, after which the land will be sold. For ease of management, all of the hectare must be sown either to wheat or chick peas. From experience, the farmer knows that expected gross margin from wheat, $E(G_w)$, is \$140/ha/year and is unaffected by whether chick peas are grown the previous year. It is known that in any given year, chick peas give a profit, G_c, of \$0, \$125 or \$250 per hectare, but the probability of these different outcomes are uncertain. The farmer judges that there are three possible probability distributions for G_c, labelled as good, moderate and poor, as shown in Table 1, with expected profits of \$175, \$125 and \$75 per hectare. Although uncertain which of these three distributions is the actual one, the farmer is able to subjectively assign probabilities to the three possibilities, as shown in Table 1.

Table 1 The subjective probabilities of the gross margins of chick peas (Cp) and the profit per hectare $\Pi(Cp|D_i)$ for each distribution

Gross margin distributions D_i	Probability of the three possible gross margins $P(G_n)$			Mean gross margin $\overline{G}_e$	"Prior" distribution of distributions $P(D_i)$	weighted mean gross margin $P(D_i)\cdot\overline{G}_e$
	\$0 G_{e1}	\$125 G_{e2}	\$250 G_{e3}			
Good	0.10	0.40	0.50	\$175	0.3	\$52.50
Moderate	0.25	0.50	0.25	\$125	0.5	\$62.50
Poor	0.50	0.40	0.10	\$75	0.2	\$15.00
Expected "prior" mean gross margin $E(\overline{G})$						\$130.00

Note that the problem includes both risk and uncertainty. The farmer is ***uncertain*** which of the three probability distributions actually applies to chick peas, and whichever of the distributions applies, the gross margin is ***risky*** in that the gross margin may take any of the three values with particular probabilities. When the risk and uncertainty are combined, the expected value of the gross margin for chick peas is \$130/ha/year, \$10 per hectare less than for wheat, as shown in Table 1. Therefore, even though there is some chance of chick peas being more profitable than wheat, the "best bet" option would be to grow wheat. This is referred to as the farmer's "prior optimal act" as it is based on subjective probabilities "prior" to the collection of more information about chick peas. The way the farmer would collect more information would be to grow chick peas on a trial basis.

Relating this problem to the notations given earlier, the acts, (a_i), are to grow either wheat or chick peas; the states of nature, (θ_i), are the three possible profit distributions, good, moderate and poor; the prior probabilities, $P(\theta_i)$, are 0.3, 0.5 and 0.2; the possible outcomes from a trial, (z_k), are \$0, \$125,and \$250/ha; the likelihoods, $P(z_k|\theta_i)$, are the probabilities of different gross margins for a given distribution - e.g. the likelihoods for the "good" distribution are 0.1, 0.4 and 0.5; and the utilities for each state of nature, $U(a_j|\theta_i)$, are the expected value of the gross margin of chick peas for the three distributions- \$175, \$125 and \$75/ha.

A notable feature of this example, which differs from standard text-book examples of decision theory, is that the likelihoods are built in to the definitions of the states. The likelihoods for a state are from the probability distribution which *is* the state. This feature applies generally to the type of problem being investigated in this study - 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).

Now consider the expected value to the farmer from trialing chick peas this year. In considering the possibilities of a trial, the farmer used his or her subjective estimates of the probabilities of different outcomes to asses the value of the trial. In the current year, we can already see that the expected value of growing chick peas rather than wheat is a loss of \$10, since the expected gross margins for wheat and chick peas are \$140 and \$130/ha.

The question is whether there is a sufficient chance that decision making will be improved by enough in the second year for it to be worth making this sacrifice in the current year. Thus we need to calculate the dollar value of the information generated in year one. This is illustrated in Tables 2, 3 and 4. Table 2 shows the subjective probabilities (or likelihoods) of observing any one of three trial outcomes, T_k, given any one of the three possible distributions, D_i. These figures are the same as the corresponding columns of Table 1 but have been relabelled to emphasise that they are potential outcomes from a trial. From these likelihoods and the priors we can calculate the joint probabilities: The probabilities of each combination of distribution type and trial outcome:
$P(D_i \text{ and } T_k) = P(D_i) \times P(T_k \mid D_i)$. For example, the probability of chick peas having a good distribution and a trial outcome with a gross margin of $125 per hectare is $0.4 \times 0.3 = 0.12$.

Table 2 "Likelihoods" of observing any one of the trial outcomes or $P(T_k \mid D_i)$ and the joint probabilities of each distribution and trial outcome

Gross margin distributions D_i	Likelihood of trial outcomes T_k			Joint probabilities of each distribution and each of the trial outcomes $P(D_i \text{ and } T_k)$		
	$0 T_1	$125 T_2	$250 T_3	$0 T_1	$125 T_2	$250 T_3
Good	0.10	0.40	0.50	0.030	0.120	0.150
Moderate	0.25	0.50	0.25	0.125	0.250	0.125
Poor	0.50	0.40	0.10	0.100	0.080	0.020
Probability of trial outcome $P(T_k)$				0.255	0.450	0.295

We can now calculate the probability of a particular distribution given a particular outcome of the trial: $P(D_i \mid T_k) = P(D_i \text{ and } T_k)/P(T_k)$, also called the "posterior" distribution of the gross margin distributions (Table 3). For example the probability that the "good" distribution is the true distribution given a trial outcome with a gross margin of $125 per hectare is $0.12/0.45 = 0.27$. As one would expect, a high trial outcome increases the probability that the distribution is "good", and vice versa.

Table 3 The "posterior" probabilities of distributions given each trial outcome.

Gross margin distributions D_i	Posterior probabilities of each of the distribution given each of the trial outcomes T_k		
	$0 T_1	$125 T_2	$250 T_3
Good	0.12	0.27	0.51
Moderate	0.49	0.55	0.42
Poor	0.39	0.18	0.07
Expected posterior gross margin $E(\overline{G}_c)$	$111.50	$129.50	$147.00

In Table 3, the posterior probabilities have been used to calculate the revised expected profit of chick peas given each of the three possible trial outcomes:

$$E(\overline{G}_c) = P(D_1 \mid T_k) \times E(\overline{G}_c \mid D_1) + P(D_2 \mid T_k) \times E(\overline{G}_c \mid D_2) + P(D_3 \mid T_k) \times E(\overline{G}_c \mid D_3) \qquad (31)$$

For example the expected profit or gross margin from growing chick peas given a trial outcome of a gross margin of $125 per hectare is (0.27 * $175) + (0.27 * $175) + (0.55 × $125) + (0.18 × $75) = $129.50

This shows that if the first trial outcome is a gross margin of $125 then the posterior optimal act is to grow wheat the next year instead of chick peas since its gross margin at $140 per hectare is $10.50 higher than the posterior expected gross margin of chick peas. However if the trial resulted in a gross margin of $250 per hectare, the best strategy would be to grow chick peas since its posterior expected profit is $7 per hectare larger than wheat. Therefore, the net gain in year two from trialing given this outcome is $7 per hectare. The net gain from trialing when the outcome of the trial was a gross margin of either zero or $125 is zero since the prior optimal act was not to grow chick peas, and the trial does not alter this.

In Table 4 we calculate the expected value of information in the second year from a trial of chick peas in the current year. The improvement in expected gross margin of each trial outcome is weighted by the probability of that outcome to give us an expected value. Table 4 illustrates that the trial only generates benefits if it results in a change in management. If either of the two lower trial outcomes were to occur, the optimal strategy would not change, so there would be no improvement in profit resulting from the trial.

Table 4. Calculation of the expected value of the benefit from the trial

	Trial outcome gross margin		
	$0 T_1	$125 T_2	$250 T_3
Expected gross margin of chick peas	$111.50	$129.0	$147.00
Expected gross margin of wheat	$140.00	$140.00	$140.00
Prior optimal act	Wheat	Wheat	Wheat
Pre-posterior optimal act	Wheat	Wheat	Chick peas
Net gain in year two from trialing in year one	$0.00	$0.00	$7.00
Probability of trial outcome	0.255	0.45	0.295
Weighted expected net gain from trailing	$0.00	$0.00	$2.06
Expected value of benefits from the trial	$2.06		

In this example, the expected benefits from improved decision making in the second year ($2.06) are not as great as the expected profit foregone in the first year in order to conduct the trial. Given the farmer's perceptions, the optimal strategy is to grow wheat both years. Ignoring discounting, for simplicity, the expected profit over two years would be ($140 x 2 = $280). If a trial of chick peas was conducted the expected profit over two years would be
$280 - $10 + $2.06 = $272.06.

The value of the net benefits from trialing chick peas varies with assumptions about the expected profitability of the alternative enterprise and the farmer's prior perceptions about chick peas. If we assume a greater degree of prior certainty about the distribution, setting the probabilities to 0.05, 0.9 and 0.05, the expected benefits of trialing chick peas are always less than the cost regardless of the trial outcome. This indicates that when the farmer is highly certain about the distribution of profits from the innovation, the trial is unlikely to be of any benefit except for improving his or her skills. On the other hand if we assume that the expected gross margin for wheat is similar to the prior expected gross margin of chick peas i.e. close to \$130/ha then it is worth trialing chick peas because the expected value of net benefits from trialing outweighs the opportunity cost of growing wheat.

This example with only two periods was used as a demonstration of Bayesian decision analysis in the context of this study. We will extend it in varies ways in future analyses in this project and report the results in subsequent papers.

Risk Attitudes in the Adoption Model

The adoption decision process conceptualised so far has only dealt with risk as it relates to the perceived probability distribution of profit or gross margin. In this model the grower chooses from a portfolio of enterprises to maximise the expected whole-farm profit. This objective of maximising expected profit implicitly assumes a "risk-neutral" attitude on the part of the farmer, meaning that the farmer is unconcerned with the degree of risk or uncertainty of an enterprise, only with the mean of the probability distribution. Empirical evidence (Bond and Wonder 1980; Bardsley and Harris 1987) indicates that individuals vary widely in their attitudes to risk with the most common being slight risk aversion. 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.

To account for risk-averse preferences, a Bernoullian, rank ordering system, referred to as the expected utility criterion, is used to capture decision makers' subjective psychological values of the probability distributions of outcomes (Smidts 1993). The expected utility criterion is denoted by $E[V(x)]$ where $V(x)$ is the transformation function of outcomes x into subjective values or utilities. The transformation function $V(x)$, used by Bernoulli, was a logarithmic function implying diminishing marginal utility. In principle, a rational decision maker would choose the option giving the highest expected utility.

The degree curvature of the utility function reflects the degree of risk aversion. This is reflected in the Arrow-Pratt coefficient of absolute risk aversion which is calculated as $R_A = -W \cdot \frac{U''}{U'}$, where W is wealth (Hey 1979).

Suppose that a risk-averse farmer is offered an exchange in which the risky return for one of his or her investments can be exchanged for a known, fixed sum of money. A risk averse farmer would choose to swap a distribution of profits for a certain or non-random profit of the size of the expected value of the distribution. The sum of money at which the farmer is indifferent between the two options is called the certainty equivalent. For a risk averse decision maker, the certainty equivalent of a risky prospect is always less than its expected profit. The difference between the two is called the "risk premium". 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 that involves skill development and experimentation is, in principle, straight forward. Instead of assuming that the farmer maximises $E(NPV)$ we now have a model where the farmer maximises $E(U[NPV])$. Within this modified adoption model that incorporates personal risk attitudes, the value of information from skill development, I_s, and the value of information from experimentation and trialing, I_t, affect the distribution of NPV which is used to calculate $E(U[NPV])$. From here we can proceed to solve this adoption model to find the optimal area of chick peas if the farmer chose to trial in the first year, A_{c1}^*, and the optimum area of chick peas, including short-term returns and information value, evaluated using $E(U[NPV])$ as the objective, rather than $E(NPV)$.

Demographic and Social Factors

As noted earlier, there is an abundance of adoption literature which have 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 chick peas, G_c, through its effect on the yield of the crop. 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 need for extra care and patience at times of peak labour demand when trialing a new crop 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 growing a potentially profitable innovation.

Equity, as a measure of wealth, is likely to be a positive influence on the initial trial area of a new crop 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 mitigate against adoption. Experience will improve the farmer's skill at crop production. Again this has positive and negative possibilities. Higher skill increases the opportunity cost of not growing the traditional crop. 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 new crop's performance. In this case, the value of information due to reductions in uncertainty would be lower.

Farmer's personal discount rate and time preference is likely to influence adoption. The higher the discount rate or preference for shorter investment horizons the less likely the farmer is to invest in the initial trial years for a new crop in order to develop the skills required for growing the crop and identify its long term profitability. This factor is likely to influence I_S, an 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. Experience with other grain legumes 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 slower to trial values I_S and I_D lower than someone who rushes in or generally has lower perceptions of the profitability of innovations in general. It could also be that some farmers may put a social status value to 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 negatively 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 crop, improve their skill and reduce their uncertainty about the crop. 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 is also likely to have more expectations of the distribution of the profitability of the crop. 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.

The number of positive and negative attributes that the farmer associates with growing a new legume crop like chick peas will directly influence adoption. This factor is the reflection of the perceptions they hold about the crop and hence will influence the values of $\overline{G}_c$, I_S and I_D.

Interactions between the various enterprises are captured in the gross margin of each enterprise. Examples include nitrogen fixation by the grain legume or pasture phase in a rotation and the break in disease cycle of the various phases of a rotation

Conclusion

In this paper we developed a conceptual framework of adoption of an agricultural innovation that includes the dynamic nature of adoption decisions and accounts for learning by doing, personal perceptions of riskiness of the innovation, individual's attitude toward risk and socio-demographic factors. Inclusion of such factors in our conceptual framework of adoption overcomes the common shortcomings of previous adoption studies. The conceptual framework is being used to develop a longitudinal survey of around 130 farmers in the wheatbelt of Western Australia which will provide the information necessary for building a dynamic model of adoption of grain legumes under uncertainty. The surveys are personal interviews conducted from 1994 to 1997 and they will provide a unique opportunity to gather empirical evidence for this model and validate it. We will describe the results of the survey in subsequent papers.

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Appendix A. A Glossary of the variable names used in this paper and their description

Variable	Description of the variable name
G_c	Gross Margin of chickpea crop
G_A	Gross margin of the alternative enterprise
A_T	Total arable area of the soils of a farm suitable for chick peas
A_c	Area of chick peas
A_A	Area of the alternative enterprise
Π	Net profit
$\bar{G}_c$	Mean gross margin of chick peas over the area planted
$\bar{G}_A$	Mean gross margin of the alternative enterprise over the area planted
A^{*}_{ct}	Optimal area of chick peas in season t if the farmer trialed the crop in the first year
A^{**}_{ct}	Optimal area of chick peas in season t if the farmer did not trial the crop in the first year
$\bar{G}^{*}_{ct}$	Gross margin of chick peas if the farmer uses A^{*}_{ct} as the planting rule.
$\bar{G}^{**}_{ct}$	Gross margin of chick peas 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 area of chick peas as result of the trial in year one
$\sigma_{\bar{G}^{*}_{ct}}$	Variance of gross margin of chick peas if trialed in year one
$\sigma_{\bar{G}^{**}_{ct}}$	Variance of gross margin of chick peas if trialed in year one
$NPV^{n}_{t=2}$	Net present value of the profits from year 2 to year n
E	Expected value
U	Utility