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The impact of agricultural extension on adoption and diffusion of lupins as a new crop in Western Australia

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Abstract. The growth of the sweet white lupin industry in Western Australia is a classic case of the adoption and diffusion of a new innovation in agriculture. In 1979, following the release of the cultivar Illyarrie, and the development of effective agronomic practices, the Western Australian Department of Agriculture (Agriculture Western Australia) commenced a major extension campaign to promote lupins. Between 1978 and 1987, the area of lupins grown increased from 39 000 to 877 000 ha. However, the pattern of adoption varied widely between regions, with differences in starting time, rate and ceiling levels of adoption. In this paper, we examine regional differences in the start time of the adoption process, and estimate the impact of various factors by using multivariate regression analysis. Results suggest that both Agriculture Western Australia extension activities and the presence of private consultants contributed to earlier start times of the adoption process.

Introduction

The adoption and diffusion of innovations has an extensive literature history. Lindner (1987) classified the literature into studies principally concerned with adopter characteristics (adoption studies) and those principally concerned with innovation characteristics (diffusion studies), with each category having both cross-sectional and temporal studies. While the literature has expanded considerably in the intervening years, as reviewed by Feder and Umali (1993), the essential dichotomy described by Lindner (1987) still exists. Over time, analyses in these areas have been assisted by an increasingly sophisticated set of mathematical and econometric techniques. Lindner (1987) described the contradictory results typically associated with adoption studies, and pointed to methodological problems associated with many studies. He considered that the most powerful method of empirical research for adoption–diffusion was a temporal study of the diffusion process, as it addresses 'both the static issue of ultimate adoption levels as well as the determinants of the dynamic rate of adjustment to this new equilibrium state' (Lindner 1987, p. 147).

Griliches's (1957) study of the diffusion of hybrid corn is the classic agricultural temporal diffusion study. By fitting logistic functions to curves that plotted the area planted to hybrid corn over time in different states of the United States of America, he was able to estimate parameters that described the start time, rate and ceiling level of the adoption process. His methodology has since been used for many studies of this type, although in recent years dynamic models have been used in an attempt to adjust for the limiting assumptions of the logistic model (see Mahajan and Peterson 1985, for an explanation of these assumptions). As noted by Feder and Umali (1993: p. 226): "Diffusion has been modelled to account for changing equilibrium populations, changing technologies, changing rates of adoption, spatial differences, and the rate of abandonment. However, it is apparent that no general model perfectly fits all situations and that in some cases different diffusion models can describe a single event effectively."

Griliches's (1957) results have been reworked, for example by Dixon (1980) and Valente (1993), by using refinements of the general logistic model, but have generally stood the test of time. His results emphasised the overriding importance of profitability, determined in his work by yield and acreages planted, in accounting for differing rates and ceiling levels of adoption.

This paper discusses some of the results obtained from a temporal diffusion study (Marsh 1996) of a crop innovation that has been rapidly and successfully adopted in Western Australia. The reintroduction of lupins into Western Australian farming systems in 1979,

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and their subsequent wide adoption, provided an ideal framework for a temporal diffusion study designed to investigate the influence of extension activities on the adoption process. The research and development work associated with this new crop was largely confined to Western Australia, so the effects of external influences could be considered minimal. Information about the productive capabilities of lupins, their role in the rotation system and management techniques required to grow them successfully were extended vigorously by Agriculture Western Australia (AGWEST) and the new crop was adopted rapidly by farmers in the 1980s. This comparatively recent and concise history made it possible to access shire-level records of reasonable quality, covering the work associated with the development, associated basic and applied research, and extension of this crop. Furthermore, the diffusion process is largely complete for a considerable part of the State, preventing the type of methodological problems associated with studies based on incomplete diffusion patterns, as discussed by Lindner (1987).

The particular aim of Marsh's (1996) study was to investigate the impact of agricultural extension on the adoption process. Few empirical studies of this nature have been attempted, because of the time-consuming and difficult nature of the data collection involved. The study involves district-level comparisons of the adoption of sweet white lupins (*Lupinus angustifolius*) by farmers in WA, using a methodology similar to that pioneered by Griliches (1957) to estimate start times, rates and ceiling levels of adoption in different districts. These estimates were then used as dependent variables in multivariate regression analyses in an attempt to determine factors influencing the adoption process. In this paper, only the results from the start time analyses are presented as this was the variable most influenced by extension activities. Results from the analyses of rates and ceiling levels of adoption are presented and discussed in Marsh (1996).

Independent variables for the analyses were drawn from a number of sources. Using data provided by the Australian Bureau of Statistics, production data for lupins, including total area sown to lupins, percentage of crop sown to lupins, and tonnes produced, has been collated on a shire-level basis over time. Additionally,

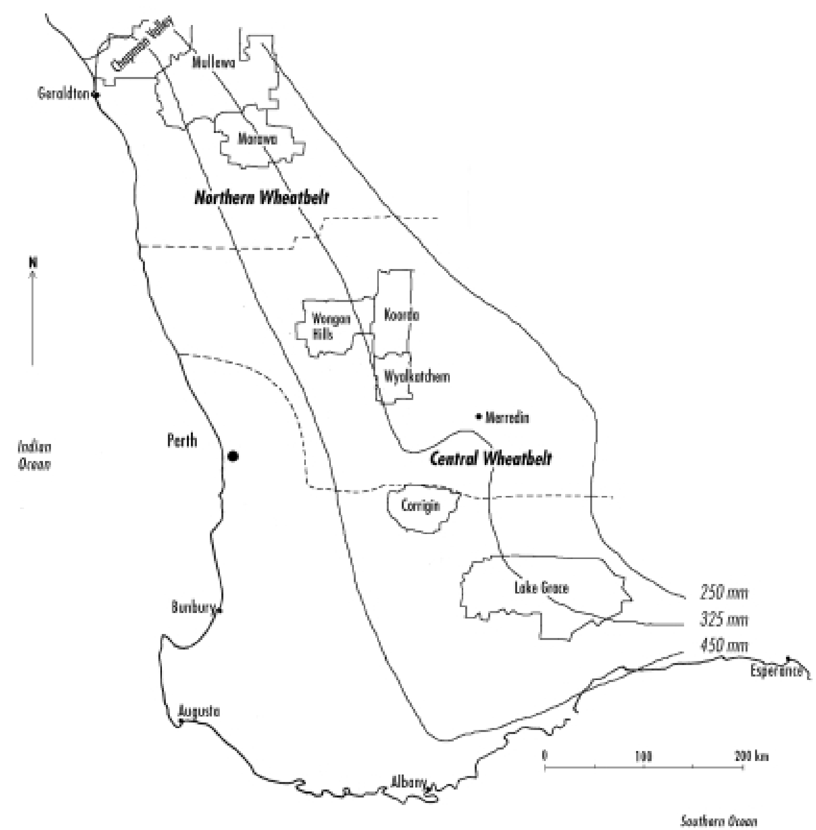

Figure 1. Map of the study area showing representative shires and rainfall isohyets.

the number of farmers growing lupins has been collated by shire and by year. An effort has been made to quantify and classify soil types suitable for lupins on a shire basis, as the availability of suitable soil types affects both the maximum area of lupins that can be grown and the profitability of the lupin enterprise. Yields and yield variance for individual shires have been ascertained. These factors, as well as the profitability of competing enterprises, can be expected to influence adoption rates of lupins. Rather than the usual aggregate data on national or state-level extension expenditures, the study has attempted to disaggregate extension activities related to lupins to a shire level, in both physical and financial terms. Data on detailed extension and field-research activities undertaken by AGWEST have been collated for 43 shires in the northern and central wheatbelt (i.e. those shires in the Geraldton, Three Springs, Moora, Northam, and Lake Grace AGWEST advisory districts). Additionally, extension activities undertaken by private sector agencies operating in these areas have been incorporated into the data set. A map of the study area, illustrating representative shires, is shown in Figure 1.

Background

Few new industries have been taken up so rapidly and successfully as the lupin industry in Western Australia. The area planted to sweet narrow-leafed lupins (*Lupinus angustifolius*) in Western Australia has grown from less than 100 000 ha in 1980 to an initial peak of 877 000 ha in 1987, before falling away slightly and then increasing again in the mid-1990s. The first sweet white lupin (cultivar Uniwhite) was released in 1967 (for a history of the development of the sweet white lupin see Gladstones 1982), and promoted as a legume crop especially suitable for sandplain soils in the heavier rainfall areas of the northern wheatbelt. By 1973, the area planted to lupins was 120 000 ha, but a combination of poor management practices by farmers and droughts in 1976 and 1977 saw lupins lose favour. By 1978, the area planted had fallen to 40 000 ha. In 1979, a higher yielding cultivar (Illyarrie) was released and a major extension effort commenced in the northern wheatbelt area by AGWEST's Geraldton district office. The extension effort focussed on demonstrating to farmers, by using trial sites, why lupin crops had failed in the past. With low seed densities, old varieties, late sowing and poor weed control, lupin crops were demonstrably abysmal failures. By using the new varieties, higher seed densities, earlier planting and good weed control, it was shown that good lupin yields could be obtained. Extension officers, working closely with researchers, promoted this 'agronomic package' which contributed to the rejuvenation of the lupin industry during the 1980s as described above. This story has been documented by Nelson (1987).

The uptake of the new crop varied widely between regions. Figure 2 shows the percentage of farmers in the shire growing lupins over time for 5 shires in the Western Australian wheat belt, from Chapman Valley in the north, then progressively south-east through Wongan-Ballidu, Wyalkatchem, Corrigin and Lake Grace. All the shires illustrated, except Lake Grace, appear to have gone through a complete diffusion

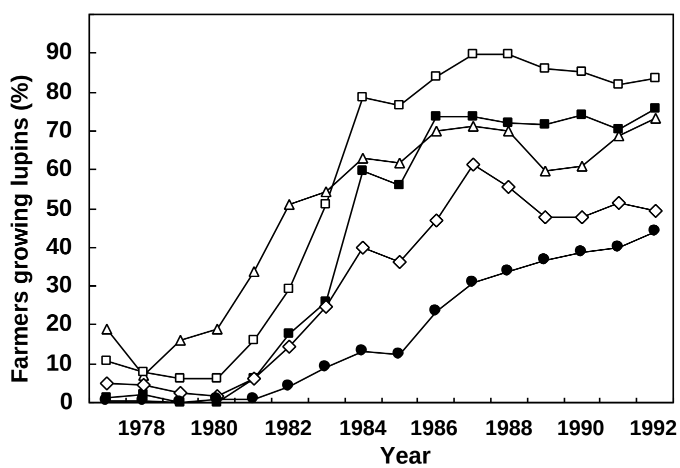

Figure 2. The percentage of farmers growing lupins over time in the Western Australia shires of Chapman Valley (△), Wongan Hills (□), Wyalkatchem (■), Corrigin (◇) and Lake Grace (●).

process, and reached a ceiling level of adoption. This is the case for the majority of the 43 shires in the study. The shires shown in Figure 2 illustrate differences in the adoption of lupins that can be seen in different areas of the state. For each of the 5 shires, there are differing times when the adoption process commenced, differing ceiling levels of adoption reached and differing rates of adoption over time to reach the ceiling. Obviously, a great number of factors influence these differences, and 1 of the purposes of this study was to attempt to segregate and quantify the effect of extension activities on the adoption process.

Qualitatively, at least, it would seem that there is some evidence that extension effort was instrumental in influencing the start time of the adoption process. The influence of the major extension effort in the Geraldton region (northern wheat belt) in 1979 can be seen in the data for Chapman Valley shire, which is served by the Geraldton AGWEST office. For Chapman, and other high-rainfall northern wheat belt shires, the percentage of farmers in the shire growing lupins increased in 1979. Despite the amount of general information on lupins available to farmers throughout the state, lupin production did not increase in shires of the central and eastern wheat belt. As can be seen in Figure 2, the percentage of farmers growing lupins in Wongan, Wyalkatchem and Corrigin shires did not start to increase until 1981. It was not until 1981, that trials and extension activities in the Merredin region (eastern wheat belt) set out to demonstrate that lupins could play a valuable role in farming systems in drier areas, previously thought ’unsuitable‘ for lupin production.

Although adopting the successful ‘agronomic package’ from the northern wheat belt, the extension effort in the eastern wheat belt emphasised the role lupins could play in the farming system by virtue of their rotation effects. The lupin crop resulted in a build-up of nitrogen in the soil, provided a ‘disease break’ for the following cereal crop and reduced the overall cost of weed control by allowing the use of different, cost-effective herbicides for control of grass weeds in the lupin phase. Lupin yields might be low in the drier areas but, grown in rotation with cereals, lupins provided a benefit to the farming system that extended beyond the simple measure of yield from the crop itself. Extension officers worked closely with researchers and farmers to adapt the agronomic package to the eastern wheat belt and overcome problems that arose on farm. Considerable interest in the extension and trials was shown by farmers and private consultants from higher-rainfall central wheat belt shires where little district-specific lupin extension had been undertaken and lupins were not yet grown to any great extent (Trevenen and Ewing 1992). The data suggest that shires such as Wongan (central wheat belt) were influenced by the extension program conducted by AGWEST’s Merredin office, whereas the earlier program in the northern wheat belt had had little impact on this region.

Figure 2 illustrates the adoption of lupins 1–2 years earlier in the northern wheat belt shire, Chapman, than in the similar-rainfall central wheat belt shire, Wongan. Figure 3 then further illustrates how this situation is reversed for lower-rainfall shires, Morawa and Koorda, in the northern and eastern wheat belt, respectively. Lupins

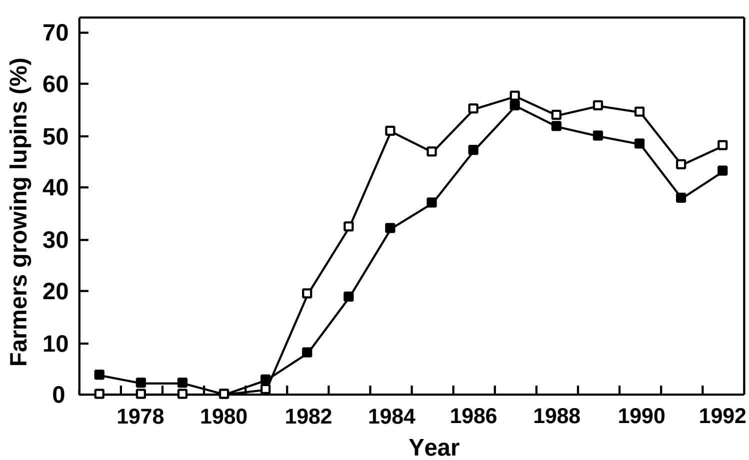

Figure 3. The percentage of farmers growing lupins over time in the Western Australian shires of Morawa (■) and Koorda (□).

were not extended in the northern region as a crop for dry land areas until a meeting in eastern Mullewa in 1982. Nelson's (1987) documentation of the lupin extension effort in the Geraldton region shows that, while recognising the value of lupins in rotation farming, the extension effort emphasised the potential value of lupins as a cash crop, the rationale being that current varieties and agronomic knowledge were sufficient to grow high-yielding lupin crops. In contrast, extension in the Merredin region emphasised the role of lupins as a legume in the farming system, despite the problem of low and variable yields in low-rainfall areas. Hence Morawa, although closer to Geraldton but considered too dry for lupins as a cash crop, lagged behind eastern wheat belt 'dry' shires where lupins were extended as part of a profitable farming system from 1981.

The impact of AGWEST's Merredin office extension effort of lupins for dry land farming may also be reflected in figures such as the following comparison between adjoining wheat belt shires Koorda (Merredin AGWEST district) and Wongan (Moora AGWEST district). Wongan is now one of the largest lupin-producing areas and has production statistics far superior to the drier Koorda shire (1982–90 average yield—Wongan 1.06 t/ha, Koorda 0.68 t/ha). However, in 1982 and 1983 Koorda had areas sown to lupins that were about 20 and 55%, respectively, of peak 1987 hectares sown, whereas those in Wongan were about 10 and 27%.

Qualitative evidence such as the above encouraged us to use the lupin adoption data to see if some quantitative support could be obtained for the impact of extension activities on adoption.

Methods

Estimation of parameters describing the diffusion data

The cumulative adoption patterns for individual shires approximated the classical S-shaped curve associated with diffusion data, with parameters that can be estimated by using a logistic model. A standard logistic function, Gompertz function and Richards function, were fitted to the data for individual shires, giving estimates of the ceiling level of adoption attained, the intrinsic rate of adoption, and the time at which the maximum rate (i.e. the point of inflection in the curve) of adoption is reached. The data was described well by both the standard logistic and Gompertz functional forms, with R^2 being, in most cases, in excess of 0.9. Based on the work done by Dixon (1980), it was decided to use the Gompertz estimates, as his reworking of the Griliches (1957) data suggests that the Gompertz function, with its earlier point of inflection and longer tail, better describes the diffusion of agricultural technologies.

Estimation of dependent variables

The parameters obtained from fitting a Gompertz function to the diffusion data were used to estimate the start time, rate and ceiling level of adoption for the shires in the study area. The function describes the number of farmers, y, growing lupins at time, t:

$$y = A + C/\exp[\exp(-bt - bm)]$$

where C is the ceiling (or maximum) level of adoption attained, b is the 'intrinsic rate of adoption', m is the time at which the maximum rate (i.e. the point of inflection in the curve) of adoption is reached, and A is the number of farmers growing lupins before the commencement of the diffusion process. (Many shires had a residual number of farmers still growing lupins following the release, adoption and disadoption of early varieties in the 1970s.)

Additionally, estimates of start time and rate were calculated directly from the data. These various estimates of start, rate and ceiling were used as the dependent variables (in turn) for multivariate regressions that expressed, for example, the start time of adoption as a function of cropping intensity, soil type, rainfall, previous experience, AGWEST extension. The estimates of start times of the adoption process were made as follows:

SG10. The time in years when 10% of the ceiling estimate (as calculated by the parameters of the Gompertz function) of percentage farmers in the shire growing lupins was reached, calculated by substituting $y = 0.1 \times (A + C)$ in the Gompertz function and solving for t.

SA10. The time in years when the percentage of farmers in the shire growing lupins was equal to a level calculated as the minimum (i.e. residual) percentage of farmers growing lupins plus 10% of the difference between the minimum and the maximum percentage of farmers that grew lupins. This was calculated by substituting for y, as calculated, in the function describing the straight line between 2 known data points, each describing the percentage of farmers growing lupins in a given year.

When used as dependent variables in the analyses, start times are expressed in year fractions (e.g. a start time of 80.45 means a time between 1980 and 1981). This was done partly because the range of start time differences in the study region was only a matter of 3–4 years, and the fractional expression of start times enabled a greater differentiation to be made. Technically speaking, the actual planting of a crop occurs only once in a specific year, but a start time expressed as a continuous variable could be said to recognise the information gathering and decision making processes that occur before the actual planting decision is carried out.

Explanation of independent variables

A considerable number of possible independent variables have been investigated. Only those used in the regression analyses with start time as the dependent variable are detailed here. It was hypothesised that factors affecting start times would be those that reflected the agronomic suitability of the shire for lupins, such as rainfall, the percentage of soils suitable for lupins, and the relative importance of cropping in the shire; and those that reflected awareness of the innovation either through early experience with growing lupins in the 1970s, or closeness to, and amount of, district-specific information. It was suspected that the activities of private consultants could also be a significant factor in some regions. Variables pertaining to the yield characteristics of lupins in different areas were not used in the adoption start time analyses, as these variables were calculated over time (e.g. average yields and associated variances). It was considered that these variables would affect the rate and the ceiling level of adoption, rather than start times.

Variables considered at various times in the multivariate regression analyses conducted with start time as the dependent variable were the following:

Variables to capture potential profitability. The results obtained by Griliches (1957), illustrating the importance of profitability on the rate of adoption, have been supported by other work. For example, Ruttan's (1977) review of the adoption of high-yielding rice varieties indicated that they were adopted more rapidly in areas where they were more profitable. Similarly, Feder and Umali (1993) report that recent studies of complete adoption patterns for high-yielding rice varieties indicate that the production environment was the most important factor in explaining differential adoption patterns.

(i) *Soils%*. Estimate of percentage of suitable lupin soils. A number of estimates of suitable lupin soils, all based on the classification of Northcote *et al*. (1960), were made. The estimate used here adjusted the areas in some shires using an adaptation of the Northcote data done by Wilkinson (1994). This estimate had the highest correlation of all the estimates with the estimated ceiling level of adoption (i.e. R^2 of 0.16, compared with R^2 of less that 0.03 for other estimates).

(ii) *Rainfall (mm)*. Estimate of shire rainfall. This measure has inherent difficulties as some shires (e.g. Mullewa) have widely varying rainfall within the shire.

(iii) *Rainfall (dry)*. A dummy variable intended to capture shires with very low rainfall. All shires with about 50% or more of their area outside the 350-mm rainfall isohyet were scored as 1.

(iv) *Northern*. A dummy variable intended to capture the shorter growing season in the northern wheat belt. All shires north of a line running east–west through the bottom of Dandaragan shire were scored as 1.

Variables to capture extent of cropping intensity in shires. This variable was included to capture the relative importance of cropping, and hence the profitability of competing grazing enterprises, in different shires.

(i) *Crop%*. The percentage of farmland in a shire that is cropped, averaged for the years 1980–84 (i.e. the period covering the start time).

Measure of farm scale. The classic studies of Griliches (1957) and Mansfield (1961) both identified that the size of the business, and hence expected return from the new innovation, was related to earlier adoption and faster rates of adoption.

(i) *Farmsize 1980*. The average size of farms in the shire in 1980 calculated for each shire by dividing the area of farm land in a shire in 1980 by the number of farmers in the shire in 1980.

Variable to capture farmer experience with growing lupins. Farmers in some shires (mostly in the northern wheat belt) grew lupins in the 1970s after the initial release of Uniwhite and other early cultivars. Poor seasons and management problems led to disadoption of lupins in the late 1970s. This variable is intended to capture the experience and knowledge gained by those farmers. Feder and Slade (1984) briefly review studies that support the conclusion that level of knowledge is important in explaining adoption behaviour. Although most studies emphasise the benefit of the accumulation of favourable experiences, which was not generally the case for farmers who grew the early lupin varieties, it was hypothesised that experience gained would shorten the readoption decision once farmers were convinced that agronomic problems had been overcome. The model developed by Feder and Slade (1984) suggested that a certain critical level of cumulative information must be attained before adoption takes place. Farmers who grew the early lupin varieties had already accumulated much of the technical knowledge needed, and only needed to be convinced of the superiority of the new variety and alternative management techniques.

(i) *Lupin farmers 1978*. The percentage of farmers in the shire growing lupins in 1978 (before the release of higher-yielding varieties).

Measures of distance from information sources. Distance from information sources has been shown to be a significant factor influencing adoption. In their study of the adoption of trace element fertilisers, Lindner *at al*. (1982) concluded that distance to the source of the innovation was a barrier to adoption. They debated whether advances in communication technology would make distance irrelevant, but suspected that potential adopters would still face problems relating to distance from information source when trying to assess whether innovations were suitable for their specific area. A survey of wheat growers in the Western Australian wheat belt (Noonan and Gorddard 1995) indicated that growers place more credibility on information from local trials and field days than on trials and field days conducted further from their district.

Both AGWEST district offices and research stations are treated as information sources. The former being the base location of research officers and advisers with district-specific information, and the latter being the location of much district-specific trial work. Griliches (1960) explains some of the unexpected deviations in his data in terms of the contributions made by specific agricultural research stations.

(i) *Distance (DO)*. The distance in kilometres of the shire from the AGWEST district office to which the shire belongs. In most cases, this has been measured from an approximate midpoint of the shire, except where there is reason to do otherwise (e.g. eastern shires such as Yilgarn where much of the shire is outside the agricultural area).

(ii) *Distance (RS)*. The distance in kilometres of the shire from the nearest AGWEST Research Station — measured as before. Only Chapman, Wongan Hills, Badgingarra, Merredin and Newdegate Research Stations are considered, as the annexes attached to Chapman and Merredin Stations (i.e. East Mullewa and South Carrabin) were not operational until the mid-1980s.

Measures of AGWEST extension activities. These variables capture a range of activities conducted by AGWEST, including Research Station trials and on-farm trials (often used as a focus for field days and field walks), seminars and meetings, and AgMemo information. In the 1980s, AgMemos were published regularly by individual AGWEST district offices, giving brief district-specific information, and mailed to all farmers within the advisory district. Additionally, some variables measure the number of advisers working in different areas related to the number of farmers in that area and the distances they have to travel to service farmers in the district.

These variables are intended to capture variation in information available to farmers in different areas through the activities of extension personnel. Most of the information measures are cumulative, to capture the on-going exposure of farmers to information. This is in recognition that adoption is essentially a dynamic learning process as described by Lindner (1987). As individuals accumulate information, they are able to reassess their beliefs about an innovation and review their decision of whether or not to adopt. As mentioned previously, work by Feder and Slade (1984) suggests that a certain critical level of cumulative information must be attained before adoption takes place.

Extension workers have been found to be influential in providing information to farmers. Feder *et al*. (1987) report that the rate of return to investment in an intensified extension programme (a training and visit system in north-west India) has been acceptable, and that this is largely because of the increased availability of farmers to extension agents as a result of the programme. Similarly, Hussain *et al*. (1994) report that training and visit systems in Pakistan have increased the quantity of extension contact, and this has increased farmers' knowledge and adoption of technology. Polson and Spencer (1991) report that the activities of extension workers in Nigeria were significant in the early adoption process. Strauss *et al*. (1991) report on a Brazilian study that attempted to measure the quality of extension personnel by measuring their experience, and concluded that there was benefit in investing in the human capital of extension workers.

The impact on adoption of farmers' participation in trials and field days is less well established. Harper *et al*. (1990) concluded that farmers' attendance at specific field days was significant in the adoption of insect management technologies. Abler *et al*. (1992) were unable to say whether farmers' participation in field trials had any effect on adoption of new technologies in Swaziland, although Grisley (1994) concluded that on-farm trials may be an effective, but limited, method for diffusing new varieties in Uganda.

Variables used in the start time analyses were the following:

(i) *Adviser density 1979*. This is a measure of AGWEST adviser density in the shire for the year 1979. It has been calculated by simply dividing the number of farmers in the AGWEST district by the number of advisers working in the district office. Officers-in-Charge and advisers, but not Research Officers, veterinarians and technical support staff, have been counted as advisers for this purpose.

(ii) *Adviser distance 1979*. This is a measure that attempts to account for the interaction between number of advisers servicing a district and the distances they have to cover to service the farmers in their area. It has been calculated by dividing the distance of the shire from the district office by the number of advisers working in that district (in this case, for the year 1979).

(iii) *Field days 1980*. This is a cumulative measure of field days, meetings and seminars, featuring lupins either wholly or partly, held in the shire up to and including the year 1980. This variable attempts to measure the level of extension activity about lupins in a shire in the form of AGWEST field days, meetings and seminars, and Research Station field days. All these activities have been tabulated separately in the database, but numbers are small, hence it was necessary to aggregate, especially for the start time analysis. Research Station field days are counted for the shire in which the Research Station is located plus all directly adjoining shires.

(iv) *Farm trials 1978*. This is a cumulative count by year of the number of on-farm lupin trials in the shire conducted by AGWEST up to and including the year 1978. On-farm trials are those conducted by AGWEST on farmers' properties. Mostly these are conducted by advisers working out of individual district offices, but some are conducted by research staff from AGWEST's head office. Crop variety trials (i.e. those evaluating different cultivars of a crop) have not been counted as on-farm trials, even when they occur on farmers' properties. Trials have been counted as having a value of 1 in the shire in which they were located, and as having a value of 0.75 in adjoining shires. This is to attempt to account for information leakage across shire boundaries.

(v) *Farm trials 1980*. A cumulative count by year of the number of on-farm lupin trials conducted by AGWEST up to and including the year 1980.

(vi) *Research Station trials 1978*. A cumulative count of the number of Research Station trials up to and including the year 1978. The trials are counted for the shire in which the Research Station is located plus adjoining shires.

(vii) *Research Station trials 1980*. A cumulative count of the number of Research Station trials up to and including the year 1980.

(viii) *Research Station*. A dummy variable for shires with, or adjacent to a shire with, a Research Station within their boundaries.

(ix) *Geraldton*. A dummy variable intended to capture the major extension effort by AGWEST in the Geraldton district. All shires in the AGWEST Geraldton district are scored as 1, except Morawa. This shire is predominantly a low-rainfall shire, and was not considered suitable for lupin production in the initial years of the extension effort in the Geraldton district.

(x) *Merredin*. A dummy variable intended to capture the major extension effort by AGWEST in the Merredin district. All shires in the AGWEST Merredin district, plus Tammin and Wyalkatchem (from the Northam district), are scored as 1. Taped interviews with AGWEST personnel who worked in Merredin at this time frequently mentioned that farmers from Tammin and Wyalkatchem shires travelled to field days in the Merredin area and were visited (unofficially) by AGWEST advisers and research officers based in the Merredin area.

Measures of private extension activity. In the late 1970s and early 1980s, a number of private farm management consultants were active in some shires (although far fewer than are operating today). Survey and anecdotal data indicated that they were actively promoting lupins in the areas they serviced. There is little work on the impact of private extension consultants on adoption, although Lazenby *et al*. (1994) report that evidence from Western Australia suggests that farmers employing private consultants adopt new varieties about twice as quickly as those who do not use consultants. This may, however, be because of differences in the types of farmers who use consultants (e.g. they may have bigger or more profitable farms), rather than any influence attributable to the consultants.

Although the involvement of agribusiness companies in extension is now quite considerable (e.g. Elders Ltd, Westfarmers Rural, SBS Rural Iama each employ agronomists to service technical inquiries from farmers), this is a comparatively recent development in WA and was not the case in the early 1980s. However, information from AGWEST staff based in Merredin in the early 1980s indicated that a field officer with an agrochemical company worked closely with AGWEST staff in setting up and monitoring trials in the Merredin area, and was used as an 'expert' speaker at AGWEST field days and meetings in the area.

(i) *Consultants*. This is a dummy variable to account for shires where private consultants had a significant number of farmer clients. Shires with more than 20 farmers using a consultant (in the late 1970s–early 1980s) are scored as 1. A degree of subjective estimation was involved as some prominent consultants working at this time declined to give details on the locations of their clients.

(ii) *Consultant 1*. This is a dummy variable to account for the activities of a particular private consultant working in the Dowerin and Cunderdin shires. This consultant indicated that he conducted lupin trials and field days in the early 1980s, and Merredin AGWEST personnel mentioned (in taped interviews) that this consultant was in regular contact with them with regard to information about lupins.

These independent variables used in the analyses of start time are listed, along with their expected sign, in Table 1.

Results

The data was analysed by multivariate regression analysis using MICROFIT. Both SG10 and SA10 were used as dependent variables. Considerably better values for R^2 were obtained using SA10 (for an explanation see Marsh 1996) and only results using SA10 as the dependent variable are reported here.

Variables which appear in a number of final models are lupin farmers 1978, crop%, field days 1980, adviser distance 1979, adviser density 1979, Geraldton, consultant 1, Merredin and consultants. The most consistently appearing significant variables (not including dummy variables) are lupin farmers 1978, field days 1980 and adviser distance 1979. Real data values for field days 1980 were very small (ranging from 0 in many shires to a maximum of 3 in 1980). Recognising that increasing information opportunities has potential to have a greater than linear impact, this variable was squared and called squared field days 1980 to give more weight to the impact in shires where a number of extension activities had occurred. The decision to include field days 1980 or squared field days 1980 was subjected to non-nested tests. Results for some final models are given in Table 2.

Models 1 and 2 compare models with field days 1980 and squared field days 1980, respectively. All variables, except crop%, are significant at 10% or lower, and coefficient signs are as expected. Non-nested tests show that Model 2 (with squared field days 1980 replacing field days 1980) is preferred to Model 1. Nested tests indicate that crop%, despite being an insignificant variable, should not be dropped from Model 2. Model 4 shows results for this model when the 3 dummy variables are omitted. Values for R^2 are only 0.1 lower, and the coefficients appear to have behaved as might be expected, taking on more impact to compensate for the absence of the dummy variables. Crop% becomes significant at 1% in this model.

Model 3 shows results when a different approach was taken, substituting the field days 1980 variable with adviser density 1979, the variable that describes the ratio of farmers to AGWEST advisers working in the area. These 2 variables have, as might be expected, a high negative covariance. This model was first run with

Table 1. Description of variables used in the analysis of start time

Variable	Description	Expected sign
Soils%	Estimate of percentage of suitable lupin soils	Negative
Rainfall (mm)	Rainfall in millimetres	Negative
Rainfall (dry)	A dummy variable for shires with low rainfall	Positive
Northern shires	A dummy variable for northern wheat belt shires	Negative
Crop%	Percentage of farmland in crop, averaged for years 1980–1984	Negative
Lupin farmers 1978	Percentage of farmers growing lupins in 1978	Negative
Farm size 1980	The average farm size in the shire in 1980	Positive
Distance (DO)	Distance from the district AGWEST office	Positive
Distance (RS)	Distance from the nearest AGWEST Research Station	Positive
Adviser density 1979	Ratio of number of farmers to number of advisers in 1979	Positive
Adviser distance 1979	Ratio of distance from district office to number of advisers in 1979	Positive
Field days 1980	Cumulative meetings, seminars and field days up to and including 1980	Negative
Farm trials 1978	Cumulative on-farm trials up to and including 1978	Negative
Farm trials 1980	Cumulative on-farm trials up to and including 1980	Negative
Research Station trials 1978	Cumulative research station trials up to and including 1978	Negative
Research Station trials 1980	Cumulative research station trials up to and including 1980	Negative
Research Station	A dummy variable for shires with or adjoining a Research Station	Negative
Consultants	A dummy variable for shires with more than 20 farmers using a private farm consultant	Negative
Consultant 1	A dummy variable for the shires in which consultant 1 was operating	Negative
Merredin	A dummy variable for shires in the Merredin advisory district (plus Tammin and Wyalkatchem)	Negative
Geraldton	A dummy variable for shires in the Geraldton advisory district (except low rainfall shire Morawa)	Negative

Table 2. Parameter estimates for diffusion of lupins (*n* = 40)

Regressors	Coefficient	*T*-ratio	Signif.
Model 1 (R^2 = 0.84; R-bar^2 = 0.80)			
Crop%	–1.4684	–1.5260	n.s.
Lupin farmers 78	–3.7991	–3.4776	**
Field days 80	–0.2251	–1.9614	†
Adviser distance 79	0.017679	2.2091	*
Geraldton	–1.4585	–5.4475	**
Consultant 1	–0.67502	–2.1929	*
Merredin	–0.43980	–2.4407	*
Model 2 (R^2 = 0.85; R-bar^2 = 0.82)			
Crop%	–1.5452	–1.6822	n.s.
Lupin farmers 1978	–4.5024	–4.2265	**
Squared field days 1980	–0.11179	–2.7009	*
Adviser distance 1979	0.017340	2.2816	*
Geraldton	–1.2784	–4.6471	**
Consultant 1	–0.70137	–2.3828	*
Merredin	–0.43609	–2.5616	*
Model 3 (R^2 = 0.82; R-bar^2 = 0.79)			
Lupin farmers 1978	–2.8338	–2.7313	**
Adviser distance 1979	0.016462	2.2625	*
Geraldton	–1.6534	–6.8837	**
Consultant 1	–0.78760	–2.5421	*
Merredin	–0.73366	–3.2680	**
Adviser density 1979	0.0023756	1.7313	†
Model 4 (R^2 = 0.72; R-bar^2 = 0.68)			
Crop%	–3.8539	–3.7319	**
Lupin farmers 1978	–6.5301	–5.5142	**
Squared field days 1980	–0.21283	–5.3186	**
Adviser distance 1979	0.021370	2.1708	*
Model 5 (R^2 = 0.42; R-bar^2 = 0.37)			
Lupin farmers 1978	–4.2067	–2.3986	*
Adviser distance 1979	0.015736	1.2557	n.s.
Adviser density 1979	0.0025423	1.6337	n.s.

† P<0.10; *P<0.05; **P<0.01; n.s., not significant.

crop% included, but nested tests indicated that it should be dropped from the function. Non-nested tests indicate that Model 3 is actually a preferred model to Model 2, despite a slightly lower value for R^2. However, when this model is run without the 3 dummy variables (see Model 5 in Table 2), the value for R^2 drops considerably, and both adviser distance 1979 and adviser density 1979 become insignificant variables. Model 2 seems to be the most stable description of factors that impact on the start times of the adoption of lupins in different areas. Diagnostic tests, for heteroscedasticity (based on the regression of squared residuals on squared fitted values) and functional form (using Ramsey's RESET test which uses the square of the fitted values) indicated that heteroscedasticity and functional form were not problems for any of the models described in Table 2.

The estimations highlight the importance of prior experience in influencing the start time of adoption. The value for lupin farmers 1978 (i.e. the percentage of farmers in the shire growing lupins in 1978) has a big impact for shires where it is high. It is consistently the most significant variable (in the sense of having the highest *T*-ratio). To further test the stability of the model, it was estimated with a data set in which shires with large values for lupin farmers 1978 had been removed. Seven shires had values for lupin farmers 1978 greater than 0.1, and an additional 10 had values greater than 0.05. The 7 shires with values for lupin farmers 1978 greater than 0.1 (Greenough, Irwin, Mingenew, Dandaragan, Moora, Coorow and Three Springs) were removed from the data set and the analysis conducted on the remaining 33 shires. Results are given in Table 3.

Table 3. Parameter estimates for diffusion of lupins (*n* = 33)

Regressors	Coefficient	*T*-ratio	Signif.	*T*-ratio (White's adjusted)	Signif.
Model 6 (R^2 = 0.54; *R*-bar^2 = 0.41)					
Crop%	–1.6128	–0.9430	n.s.	–1.0837	n.s.
Lupin farmers 1978	–5.5216	–1.1201	n.s.	–1.0204	n.s.
Squared field days 1980	–0.13676	–0.91796	n.s.	–1.4468	n.s.
Adviser distance 1979	2.1652	0.80136	n.s.	0.55675	n.s.
Geraldton	–0.56141	–0.49697	n.s.	–0.71414	n.s.
Consultant 1	–1.0229	–2.1478	*	–4.5684	**
Merredin	–0.73247	–2.4321	*	–2.4899	*
Model 7 (R^2 = 0.38; *R*-bar^2 = 0.29)					
Crop%	–3.4247	–2.0845	*		
Lupin farmers 1978	–2.4026	–0.48828	n.s.		
Squared field days 1980	–0.1816	–2.8956	**		
Advisor distance 1979	1.6457	0.56334	n.s.		
Model 8 (R^2 = 0.57; *R*-bar^2 = 0.51)					
Advisor density 1979	0.00464	2.2513	*	2.1443	*
Squared field days 1980	–0.20176	–3.6020	**	–4.9208	**
Consultants	–1.0632	–3.4790	**	–3.7910	**
Merredin	–1.5457	–4.3893	**	–3.8713	**

*P<0.05; **P<0.01; n.s., not significant.

Models 6 and 7 correspond with Models 2 and 4 in Table 2, respectively. Values for R^2 have fallen considerably. This is to be expected because much of the variation in the data set that the model was explaining has been removed. The earliest start times were associated with shires that had previously grown considerable areas of lupins in the 1970s and so had the highest values for lupin farmers 1978. Looking at Model 7, with dummy variables excluded, coefficients remained correctly signed and, except for adviser distance 1979 and lupin farmers 1978, of comparable magnitude. Crop% and squared field days 1980 remained significant variables. It could be expected that lupin farmers 1978 would no longer be a significant variable, as the shires where this variable was high have been removed from the data set. Adviser distance 1979 becoming insignificant was unexpected, and this must cast some doubt on the validity of the statistical significance of this variable. When dummy variables were added to the regression (see Model 6), consultant 1 and Merredin became the only significant variables, indicating the importance of the Merredin extension effort for the shires which had not grown lupins in the 1970s.

Model 8 is a different approach to try to account for the different information sources in these shires. This approach should be valid as diagnostic tests show a structural break between the 2 data sets, but sample sizes are possibly too small to test this. As lupin farmers 1978 and Geraldton could be expected to have less impact on the regression (3 of the 5 shires in the Geraldton dummy have been excluded from the data set), these were omitted as variables. Private consultants were active in a number of shires in the restricted data set, so the consultant variable was used instead of the more specific consultant 1 variable. The absence of private consultants in the Geraldton area, where the earliest start times were, had prevented this variable from featuring in the original regressions. Variables describing extension activity, distances covered by advisers and the farmer/adviser ratio (i.e. field days 1980, adviser distance 1979 and adviser density 1979) were included. It was hypothesised that farmers in these areas would be more dependent on knowledge gained from adviser activity, rather than their previous experience growing lupins. Adviser distance 1979 and crop% were not significant variables, and a variable deletion test showed that they could be dropped. As shown in Table 3, all other variables in Model 8 were significant.

Models 6 and 8 had significant heteroscedasticity at 10%. The *T*-ratios were recalculated using White's heteroscedasticity-consistent standard errors (this still uses OLS to estimate the coefficients and the variance, but does so with a consistent estimator of the variance–covariance matrix) (Table 3). For Model 6, *T*-ratios associated with squared field days 1980 and consultant 1 increased substantially, although squared field days 1980 was still not significant. For Model 8, there was some change in *T*-ratios but the level of significance of the variables remained unchanged.

Discussion

Did extension make a difference? Our work suggests that extension did make a difference, of about 1–2 years, in the start time of the adoption of lupins (Marsh 1996). About 70% of the variability in start time has been accounted for by 4 variables, 2 of which (squared field days 1980 and adviser distance 1979) are measures of extension activity. The third variable, lupin farmers 1978, describes the percentage of farmers with previous experience of the technology. The remaining variable, crop%, is a measure of the profitability of cropping in the area compared to alternative grazing enterprises. All variables are significant at 5%. The addition of 3 dummy variables which take account of major AGWEST extension efforts in the Geraldton and Merredin areas, and the activities of a private consultant, result in the model describing over 80% of the variability in start time. The significance of these variables suggests that concerted extension activity from either the public or private sector, as occurred in these areas, does influence adoption start times.

The specific lupin extension efforts by AGWEST in the Geraldton and Merredin districts in 1979 and 1981 were targeted to the district, concentrated on demonstrations, worked closely with farmers and researchers, and were conducted with a good degree of enthusiasm and commitment by the extension officers involved. It appears that enthusiasm has turned out to have measurable impacts! The success of these targeted extension efforts in measurably influencing adoption suggests that the development of the project approach to extension (e.g. crop monitoring, specialist grain legume officer) is an appropriate extension approach. The history of lupin diffusion in Western Australia demonstrates the importance of district-targeted extension, even for a profitable crop innovation such as lupins (e.g. the later start time of adoption in the major lupin-growing shire Wongan, as compared to Geraldton district shire, Chapman, illustrated in Fig. 1).

The acquisition of knowledge, either through previous experience or the activities of extension agents, seems to be important in influencing the start time of the adoption process. This supports previous findings, as outlined earlier in this paper. Results from the analysis (through the influence on the start time of adoption of the adviser distance 1979 variable) also provide some support for the need for extension agents to be active 'on the ground'. However, the influence of a private consultant (in the shires in which he was working) on the start time of adoption suggests that the need for 'people on the ground' can be equally effectively provided by the private sector.

No evidence was found to suggest that on-farm or research station trials influenced the start time of the adoption process. One reason for this, suggested by the data, is that many early trials took place in areas not especially suited to lupins, such as areas with specific production problems (e.g. potash rates required on poor coastal sands). However, many field days were centred around on-farm or research station trial sites, so it is probable that a degree of collinearity exists between these extension variables.

Although not reported in this paper, our results show that extension was not a factor influencing ceiling levels of adoption of lupins (Marsh 1996). Significant variables in this analysis were those describing yields, rainfall and percentage of the shire cropped. These are all variables which measure the production environment, and impact on profitability. These findings are also supported by previous research. Additionally, the methodology used in the analysis was unable to be clearly identify any influence of extension on the rate of adoption of lupins over time in different areas.

There is currently a great deal of interest in the evaluation of agricultural extension, and a recent Australian review by Dart *et al*. (1998) outlines the various approaches that can be taken. The research method used to measure the impact of extension reported in this paper is a form of summative evaluation. As discussed in the introduction, economists consider this type of ex-post analysis the most powerful way to assess the overall impact of an extension program. In this case, extension has been assessed by measuring adoption. Extension, however, can have an impact that extends beyond simple measures such as adoption. The study has not made any assessment of the changes in attitudes of farmers, the impacts of the extension on skills and knowledge of farmers (i.e. the effect on human capital), or explored reasons for non-adoption. A different type of analysis would be required for this, but would not be appropriate for this particular study, given the time that has passed since the extension activities were conducted.

Furthermore, extension often plays a role in linking farmers and researchers, helping to direct the nature and location of the research and development program and identifying research and development priorities in different regions. The extension effort to promote Western Australia's infant lupin industry in the 1980s clearly played that role. The difficulties in disaggregating the benefits of research and extension are well documented (Huffman 1978; Norton *et al*. 1984; Huffman and Evenson 1993). To minimise these difficulties, the approach taken in this study was to concentrate on the effect of specific extension activities (as did Feder *et al*. 1987). Nevertheless, we recognise that research and development activity was to a certain extent integrated within these extension activities.

These caveats aside, the study has some major limitations. The question of 'how to measure extension' is intrinsically difficult. Records of extension activities conducted by regional AGWEST offices are often incomplete, and activities such as field walks, which agents claim are one of their most effective methods for extending information, have been impossible to be count. Data for field days in the early 1980s has been difficult to collate, because of less than adequate records. The breakdown of data by shire is essentially artificial, and we expect that there would be significant information leakages across these artificial boundaries. We have major reservations about the validity of the soil estimates, as the Northcote classification is essentially ill-suited to this type of breakdown. Unfortunately, it is the only classification covering the entire area of the study that we are able to break down quantitatively on a shire basis.

The sample size (43 shires) is small, and this must cast some doubt on the validity of the statistical analysis. As mentioned previously, co-linearity between independent variables is another problem. Although this does not affect the validity of the statistical tests, it does reduce their power. Statistical difficulties also arise when estimates (with associated standard errors) are used as dependent variables.

The diffusion pattern associated with the adoption of lupins in Western Australia could well be considered as representing an extreme case. They have proved to be a very successful crop innovation, and the extension conducted by AGWEST was widely perceived to have been a very successful campaign. Considering this, the statistically detectable effects of extension might be considered surprisingly small. However, the overriding influence of economic factors on the adoption process is well established, and it is perhaps encouraging that any measurable benefit at all from extension activities, for such a profitable crop innovation, has been isolated using multivariate regression analysis.

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