THE DIFFUSION OF TRACE ELEMENT TECHNOLOGY: AN ECONOMIC ANALYSIS

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Agricultural Science.

by

Philip Pardey, B.Ag.Sc. (Adelaide)

Department of Economics

University of Adelaide

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SUMMARY

This study will endeavour to quantify the innovative and imitative aspects of copper-zinc adoption for chosen regions of the State of South Australia. This will be followed by attempts to 'explain' any observed inter-regional differences in the estimated adoption parameters.

Chapter 2 will provide a brief overview of the scientific investigations which uncovered the relatively dramatic impact of copper-zinc fertilizers on broad-acre crop and pasture production. This will be followed in Chapter 3 by a detailed consideration of the techniques used by previous studies to quantify observed adoption patterns. Particular emphasis will be given to the (symmetry) assumptions of the commonly employed logistic function as it relates to studies of the diffusion of new technologies.

The techniques used to aggregate the 24,000 observations, which constitute the raw data base of this study, will be detailed in Chapter 4. The subsequent Chapter will attempt to assess empirically the validity of the symmetry assumption with respect to the observed patterns of adoption. On the basis of these findings, Chapter 6 will outline the procedures used to quantify the innovative and imitative aspects of trace element adoption. The parameters so derived will be tabulated.

Chapter 7 will notionally consist of three parts. Part A will detail, at both the conceptual and empirical levels, those factors which on *a priori* reasoning may account for inter-regional differences in the parameters of adoption. Part B will present and discuss the multiple regression results which were obtained when attempting to 'explain' innovative aspects of copper-zinc adoption using the factors mentioned above. Multiple regression techniques will also be used to determine the 'explanatory' significance of these same factors in relation to the imitative aspects of copper-zinc adoption. This will account for Part C of Chapter 7.

The conclusions of this study will then be detailed in Chapter 8.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made in the text.

Signed________________________

Philip G. Pardey.

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CHAPTER 1

INTRODUCTION

The aim of this study is to use a large body of data in order to analyse cross-sectional differences in the temporal adoption patterns of trace element or, more specifically, copper-zinc (fertilizer) technology. The study will endeavour to quantify the innovative and imitative aspects of copper-zinc adoption for chosen regions of the State of South Australia. This will be followed by attempts to 'explain' any observed inter-regional differences in the estimated adoption parameters.

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CHAPTER 2

A BRIEF HISTORY OF TRACE ELEMENT TECHNOLOGY IN SOUTH AUSTRALIA

2.1 INTRODUCTION

Writing in 1974, Williams [p.324] concluded that,

> Looking back over the efforts of 130 years to change the rural landscape [in South Australia] it seems evident that the process of changing the character of the soil...[was] certainly more significant economically than all other activities put together.

However, despite the now obvious benefits[1] that the use of artificial fertilizers has conferred on agriculture in South Australia, their early use was marked by uncertainty and prejudice. Much of this initial prejudice stemmed from a feeling by farmers and agricultural writers of the time that the climate, and in particular the relatively low rainfall, rather than soil fertility, was the major limiting factor with respect to cereal yields.[2]

Custance, the first principal of the newly formed Roseworthy Agricultural College, commenced a series of experiments in 1882 which confirmed that the declining yields of the latter part of the 1800s were directly attributable to soil nutrient depletion. In 1885, after erratic results due to limitations in experimental techniques, he increased the yield of wheat from 12 to 22 bushels per acre with the application of superphosphate.[3]

Although superphosphate had been commercially available in South Australia since 1883, the encouraging experimental results of Custance

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1 Waring and Morris [1974, p.39], for example, argued that the use of superphosphate (on pastures) incr^ases the profitability of farm operations and is a major avenue of farm development.

2 In 1889, Grierson [p.128] summed up this feeling with the statement that ' We can never expect to get high averages, but it is not the fault of the land, it is the lack of moisture.'

3 See Donald [1964, p.87].

failed to have an immediate impact on the adoption of phosphatic fertilizers.[4] The relatively high per unit fertilizer costs combined with a lack of suitable application equipment were cited[5] as important constraints on superphosphate adoption. Kelly [1962, p.38] also attributed the failure by farmers to apply readily the experimental findings of Custance in part to the 'impetuous and hasty temper' which he displayed in his dealings with them.

One estimate[6] of the total tonnage of 'artificial manures' applied to cereal crops in 1897 was a lowly 3,000 tons. But the introduction of the seed drill[7] into the South Australian agricultural scene in the mid 1890s, combined with the appointment of Professor Lowrie as a successor to Custance,[8] gave renewed impetus to the use of superphosphate by cereal growers such that by 1900 the yearly tonnage was 24,600 and by 1906 had jumped to 59,000.

Yearly superphosphate tonnages for the period 1897 to 1973 are presented in Figure(2.1)below. This figure also details the yearly tonnages of total trace element fertilizer mixtures[9] along with the tonnage of copper-zinc mixtures delivered. These micro nutrients[10]

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4 Natural manures were also used in only small quantities prior to this date as they were 'dear, scarce and in a degree uncertain in their action' according to Williams [1974, p.280].

5 See Williams [op.cit., pp.282-283]. In fact, Williams points out that it was not only the high per unit cost but also the high (recommended) application rates of around 5 cwt/acre which led to the unprofitably high capital costs which were initially associated with superphosphate adoption.

6 See South Australian Statistical Register [1907, p.xii].

7 This drill allowed small quantities of superphosphate to be mixed and sown with the seed in a single operation.

8 Lowrie has been described by Donald [1964, p.87] as not only a keen experimentalist but also an effective advocate of superphosphate.

9 Trace elements are sold in mixture form with superphosphate.

10 As opposed to the macro nutrients of nitrogen, phosphorus and potassium. (The macro-micro prefix refers in part to the rate of application of the nutrient being discussed).

or trace elements first gained commercial significance as fertilizers of relevance for broad scale pasture and crop production during the late 1930s. Prior to this date, various trace elements including manganese, boron and zinc had been applied largely to horticultural crops as a cure for specific plant diseases such as corky-pit in apples or mottle leaf in citrus.[11]

The documented response of cereal yields to applications of copper and/or zinc which are cited in Donald and Prescott [1975, p.21] and detailed below (Table 2.1)reveals the dramatic impact that these fertilizers had on the productivity of trace element deficient soils.

TABLE 2.1

Effect of Copper-Zinc Applications on Grain Yields

Location	Cereal		Yield (Kg. grain/ hectare)		Percentage Yield Increase
Stokes, Eyre Peninsula, Sth. Aust.	Wheat		- Cu	+ Cu	
			2200	2908	32
Central Wheat Belt, W. Aust.	Wheat		- Cu	+ Cu	
		- Zn	618	934	51
		+ Zn	470	994	112
Darling Downs, Qld.	Maize		- Zn	+ Zn	
			1700	2998	76

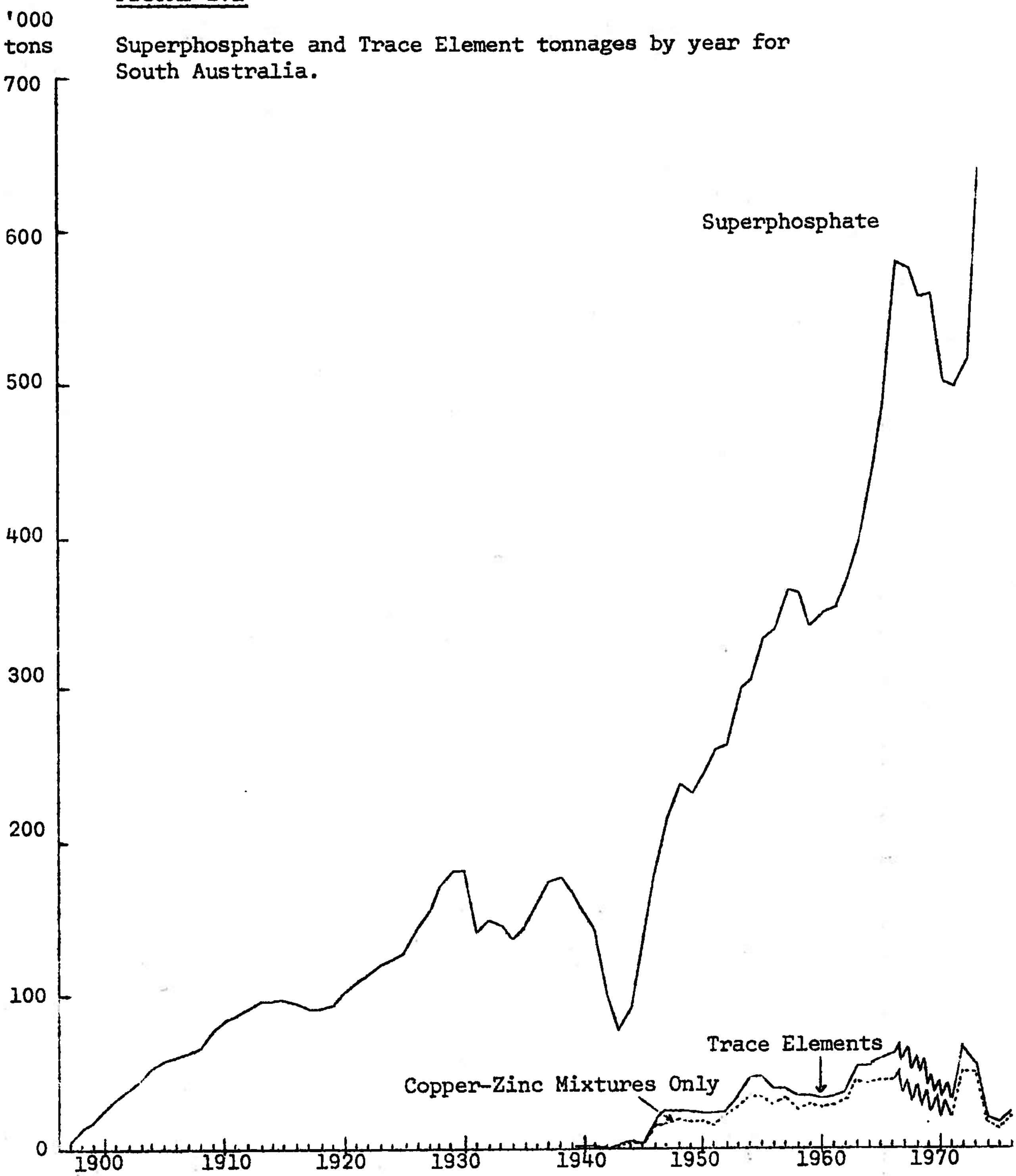
From these results, it can be seen that in some cases (depending on soil type, climate, etc.) the increase in cereal yields following the application of trace elements was of the order of magnitude which Custance achieved with the addition of superphosphate to the Roseworthy soils. The influence of copper-zinc additions on pasture growth was perhaps even more dramatic than that achieved with cereals. The results presented in Table 2.2 below give substance to this claim.

From the yearly tonnage data presented in Figure 2.1, it is

11 See Donald and Prescott [1975, pp.8-9].

FIGURE 2.1

Superphosphate and Trace Element tonnages by year for South Australia.



Source: Superphosphate tonnages - South Australian Statistical Register (Various vols.)
Trace element and copper-zinc tonnages - Adelaide and Wallaroo Fertilizers Ltd. (unpublished statistics).

Notes: (1) Superphosphate tonnages for the period 1897 to 1942 are recorded as Artificial manures (superphosphate, bone-dust etc.) used for cereal crops and for 1943 onwards as total superphosphate used.

(2) Trace element and copper-zinc figures are unavailable for the period 1967 to 1971.

(3) The trace element and copper-zinc mixtures (i.e. mixed with superphosphate) were aggregated for all trace element concentrations.

(4) Trace element tonnages include copper, zinc, molybdenum, cobalt, manganese and boron mixtures.

TABLE 2.2

Effect of Copper-Zinc Applications on Legume Growth.

	Sub-Clover (kg/ha)	Lucerne (kg/ha)
No Fertilizer	187	62
Superphosphate	625	937
Superphosphate + Cu	875	2,000
Superphosphate + Cu + Zn	3,250	2,000

Source: Riceman [1948b], quoted in Donald and Prescott [1975, p.24]

evident that copper-zinc mixtures accounted for nearly all commercial trace element sales from 1939 to 1944. In 1944/45 commercial sales of molybdenum (Mo) began with approximately 2,300 tons of molybdenum-superphosphate mixture being sold in the first year. Initial studies revealed that Mo deficiency inhibited nitrogen fixation by the *Rhizobium* bacteria of the legume (root) nodule. This meant that the use of Mo in pasture establishment and maintenance programs was primarily seen as a means of attaining satisfactory levels of growth for both clovers and other pasture legumes such as lucerne.[12]

In the period 1939/40 to 1951/52 for which disaggregated data was available, Mo tonnages peaked in 1947/48 at approximately 9,970 tons. In the same period 'other' trace element mixtures (which include cobalt, manganese and boron) peaked at 1,680 tons in 1950/51. This is not to imply that these tonnages represented the maximum yearly usage of such trace elements for that period through to the present. Indeed, copper-zinc tonnages for which a reasonably extensive data series was obtained, did not peak until 1972/73, when sales in that year equalled 49,989 tons.

12 Non-legumes were later shown to respond to Mo. See Donald and Prescott [1975, p.31].

A word of caution should be entered here. Trace element tonnages do not present a comprehensive picture concerning trace element usage. Firstly, the marked residual effect of trace elements means that the tonnages applied in any one year do not accurately reflect the total acreages which are responding to trace elements.[13] Secondly, the degree of on-farm mixing increased with the advent of bulk (superphosphate) handling in the 1960s. This would be reflected in lower pre-mixed trace element tonnages being recorded for the period following the early 1960s than would otherwise have been the case. These tonnages can therefore only be taken as an indication of the level of trace element usage at any particular point in time.

In order to give some historical perspective to this study of trace element or in particular copper-zinc usage, a brief synopsis of the scientific investigations of coast disease[14] will be undertaken below. It is hoped this will serve to indicate the inter-relatedness of research carried out on the disease and the subsequent studies by Riceman[15] and others, which focused specifically on the impact of trace elements on crop and pasture production.

2.2 COAST DISEASE RESEARCH

The relationship between nutrient deficiency and coast disease was first elucidated in the latter part of 1848 by Ferdinand von Mueller, a chemist who had recently arrived in Adelaide. He was asked by Sir Samuel Davenport and George Glen to investigate the cause of bad stock losses on their property which was situated at the northern end of Lake Bonney. Mueller found no noxious plants, but offered the conclusion

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[13] See Section 4.4 for a more detailed discussion of this point.

[14] Coast disease is a disease of grazing ruminants (mainly sheep), whereby stock exhibit a wasting effect which can ultimately result in death. The disease derived its name from the observation that it was commonly found amongst sheep grazing on or near coastal areas.

[15] See Section 2.3 of this chapter.

that the grass was deficient in nutrients and recommended the removal of stock from 'infected' to 'unaffected' pastures - this proved beneficial, if done frequently enough.[16]

Despite Mueller's observation, speculation on the cause of the disease continued well into the late 1800s. A poisonous herb theory persisted at least until 1861 when the Government Inspector of Runs wrote,

> On the coastline from about 10 to 15 miles back, stock on many of the runs are subject to what is termed the coast disease, generally attributed to a poisonous herb, but I believe it has never been determined what it is.[17]

Given the abundance of surface water over large areas of the South-East, Goyder observed that the disease was unknown near parts of the coast'where there are well defined water courses or natural outlets to drain the country.'[18] He further noted that '...it is only necessary to experience the effusion arising from the disturbed surface at the edge of the swamp to readily comprehend how injurious such exhalations must necessarily be to animal life.'[19] From such observations it was concluded around the 1860s,that the 'vegetable putridity of the surface of the soil'[20] was the causal factor with respect to coast disease. This led to the subsequent drainage of large areas of the South East over the following five years. However, interviews held by the Select Committee on Drainage Works in 1872 indicated that 'the coast disease is as bad as ever.'[21]

Further 'theories' on the cause of the disease included the idea that animals grazing near the coast were affected with a 'miasma from

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16 See Williams [1974, p.276].

17 South Australian Parliamentary Papers, S.A.P.P., [1861, Vol.101, p.4] quoted in Williams [1974, p.275].

18 (S.A.P.P.) [1865-66, Vol.137, p.1], quoted in Williams [1974, p.276].

19 Ibid.

20 The Border Watch [1866, 24 March and 3 Nov.] quoted in Williams [1974, p.278].

21 S.A.P.P.[1872, Vol.34, p.660ff.]quoted in Williams [loc.cit.].

the sea.'[22] Another suggestion was that the malady was due to parasitic infestations. However, various vermifuge treatments were found to exert at best only a transient benefit. R.G. Thomas, an officer of the Council for Scientific and Industrial Research (C.S.I.R.), discounted this theory when he wrote

> The line of demarcation between the 'coasty' and healthy land is often so sharply defined as to eliminate all possibility of the suggestion, which had been often put forward, that coast disease symptoms were directly attributable to parasitic infestation of the sheep affected.
>
> [Thomas, 1938, p.28].

Investigations into the occurrence of coast disease at Hawk's Nest,[23] Kangaroo Island, saw Thomas in December 1930 return to the thoughts of Mueller nearly a century earlier with the finding that

> ...coast disease was directly caused by certain mineral deficiencies in the soil which were reflected as a mineral deficiency in the pasture which that particular soil supported.

In June, 1933,[24] a committee consisting principally of C.S.I.R. personnel was established and charged with the task of directing an inquiry into the various maladies included in the term coast disease. With the help of the South Australian Department of Agriculture, Murnane, during three months of 1937, carried out a disease survey of the coastal areas of the State and his results confirmed those of Thomas in that the incidence of the disease was highly correlated to country derived from aeolian shell sands of recent geological origin.

Murnane also reported finding that on Rob Dawson's property situated a few miles from Robe in the South-East of South Australia, coast disease could virtually be produced 'at will'. Consequently, in April 1935, studies on the problem were moved to Robe from Hawk's

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22 See C.S.I.R.O. [1968, p.47].

23 The name of the property owned by Major H. Seager.

24 See C.S.I.R. Seventh Annual Report [1938, p.48].

Nest where Lines had found that sheep were not as prone to the disease as was first suggested.

At the time Murnane was carrying out his survey, Lines was proceeding with laboratory experiments using coasty sheep from Hawk's Nest. In early 1934, Thomas suggested that,

> The administration of cobalt compounds might counteract the anaemia characteristics of coast disease as salts of this metal have been shown...to have a specific pharmacological action in causing polycythemia [an excess in the number of red corpuscles in blood] in rats.
>
> [Thomas, 1938, p.39].

In April of that year, six ewes in an advanced stage of coast disease were brought from American River, Kangaroo Island, to the nutritional laboratory in Adelaide. The sheep were kept in concrete lined pens and fed on chaffed hay obtained from cereals grown on 'coasty' Island country. The disease progressed, and after 18 weeks one of the surviving sheep was given 1 mg. of cobalt per day, and after three days the animal had improved in health.[25] This was the first vital clue to the importance of cobalt with respect to coast disease.

Further work by Marston and McDonald at Robe, South Australia, from April 1935[26] to April 1936,[27] culminated in the suggestion that the primary cause of coast disease was a dual deficiency of cobalt and copper in the pasture of affected areas.

2.3 RICEMAN AND THE COPPER-ZINC STORY

The establishment of a field station on Rob Dawson's property in April 1935 to investigate the problem of coast disease was soon followed by attempts to establish improved sown pastures, 'in order that the effect of superior nutrition on the incidence of the disease might be

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25 See Lines [1935, p.117].

26 Marston and McDonald [1938a, pp.72-78].

27 Marston and McDonald [1938b, pp.79-85].

investigated.'[28] The link between coast disease and trace element research was highlighted even further by Riceman who wrote,

> In 1937, the field trials were extended to include a number of treatments suggested by the more recent developments in the investigations on 'coast disease'.
>
> [Riceman and Donald, 1938, p.7].

Over the three years of experimental work at Robe from 1935 to 1938, Riceman and Donald had demonstrated conclusively that the majority of plant species growing on the coasty type soils suffered from a deficiency of copper. Practical recommendations in a paper published by these two researchers in June 1939[29] advised growers of cereal crops in coasty areas to test the value of the application of 28 lbs. of copper sulphate (bluestone) per acre to oats, wheat, barley or pasture mixtures.

However, although dramatic, the yields obtained after the addition of copper sulphate (up to 112 lbs. per acre) in conjunction with liberal dressings of phosphorus, potassium and nitrogen, were much lower than could be expected under the particular condition of climate which prevailed. Whilst the Robe experiments were being carried out, Dr. C.R. Millikan of the Victorian Department of Agriculture at Winion East, Victoria, obtained the first field responses to zinc.[30] Using this result, Riceman and Anderson[31] in experimental work in 1939 at Robe, obtained considerable increases in the grain yield of Mulga oats - a result they confirmed by further work during 1940. As with coast disease, the problem of cereal and pasture production on the calcareous aeolian sands of the South East was revealed as a dual deficiency of micro elements - in this case copper and zinc.

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[28] See Riceman and Donald [1938, p.7].

[29] See Riceman and Donald [1939, p.959].

[30] See Millikan [1938, pp.409-16].

[31] See Riceman and Anderson [1941, p.82].

In 1944, investigations moved from Robe to Mr. J.E. Becker's property eight miles south-west of Keith, where it was proposed to study the mineral nutrition of plants grown on the heath sands of the Ninety-Mile Desert in the Upper South East of South Australia.[32] The soils were known to be extremely low in phosphorus but even large applications of superphosphate did not enable improved pastures to be established successfully.[33] Riceman noted that, compatible with his findings at Robe, a deficiency of copper and zinc was confirmed, with responses to their application depending upon the species of plant concerned. For example,

> The yield of oats was considerably increased by a dressing of zinc sulphate; lucerne showed a response to copper sulphate; and the yield and particularly the seed production of subterranean clover was improved by the addition of zinc and copper sulphate together.
>
> [Riceman, 1945, p.336].

He also pointed out with accurate foresight that

> ...the trace elements of zinc and copper will play an important part in the development of the vast area of this and related soils in the Ninety-Mile Desert in South Australia and Victoria.
>
> [Riceman, 1945, p.336].

Further work by Riceman[34] on the Laffer sands of the Upper South East from 1944 to 1948 clarified the role of zinc and copper in relation to the establishment and management of mixed pastures.

2.4 SUMMARY

In an article published in 1965, Loftus-Hills largely attributed the dramatic post-war increase in cereal yields and livestock numbers[35] in Australia to the introduction of sown pastures based on

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[32] See Riceman [1945, p.336].

[33] See Taylor [1933].

[34] See Riceman [1948a] and [1948b] and [1949].

[35] He stated that the increase in livestock numbers since mid-1930s has been in the order of 1/3 in sheep-equivalent terms. [Loftus-Hills, 1965, p.629].

(imported) grasses and pasture legumes. Having to a large degree corrected the nearly ubiquitous phosphorus deficiency in Australia by the broad scale application of superphosphate, he saw the use of trace elements as the 'key factor' in effecting this 'pasture revolution'.

In terms of tonnage sold, copper, zinc and molybdenum mixtures have been the most important of the micro nutrients; nevertheless, the other trace elements, including boron, cobalt and manganese, have been used quite extensively. Probably the single most dramatic application of trace element technology was the development of the 'desert' regions of Southern Australia by the Australian Mutual Provident Society.[36] The area was not a desert in the true sense of the word, with the average yearly rainfall ranging from eleven inches in the north to seventeen in the south. It was perhaps better described as a 'chemical desert' in that it was the application of trace elements, especially copper and zinc, which transformed this once barren landscape into an agricultural area of significant productivity.

Loftus-Hills [1962] cited an undocumented estimate that trace elements had by the early 1960s been applied to more than one-third of the total area receiving fertilizer of any kind in the State of South Australia. The prime motivating factors for undertaking the present study were the importance of trace elements, and in particular copper-zinc mixtures, to rural production in South Australia, and the availability of a comprehensive data set covering all the deliveries of trace elements made in this State for the period 1939/40 (year of first commercial availability) to 1951/52. The ready availability of secondary data also directed the thesis towards the rather aggregated approach it employs. The following chapter will review the methodology which has been applied to innovation diffusion studies in the past and will attempt to lay the theoretical foundation for the empirics which follow it.

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[36] The total area developed by the society was approximately 755,000 acres (an area approximately the size of Belgium). Details concerning the development of the area held by the A.M.P. are well outlined in Fry [1974], Buttfield [1958] and Bell and Cairns [1958].

CHAPTER 3

DIFFUSION STUDIES AND THE LOGISTIC

3.1 INTRODUCTION

This chapter will concern itself with an investigation of the logistic function as it relates to studies of temporal diffusion processes. Following a brief overview of the early development of the logistic is a detailed consideration of the assumptions of such formula which are relevant when applied to temporal studies of innovation adoption. The management aspects of adoption will be stressed, particularly in relation to the symmetry assumption that has pervaded many diffusion studies to date.

The final section of the chapter will review those diffusion models which exemplify the development of modelling attempts to quantify the diffusion process. Griliches' 1957 seminal study in the area was not outlined in this section as it was felt that the important aspects of his work are dealt with in sufficient detail throughout many other sections of the thesis.

3.2 DEVELOPMENT OF THE LOGISTIC

It is recognized [Jones, 1967, p.11] that the simultaneous adoption of an innovation by potential adopters is an unrealistic expectation and that the acceptance of a new process is more likely to conform to a specific pattern of diffusion over time or space. Empirical analyses, including Griliches' [1957] study of the diffusion of hybrid corn in the United States and Mansfield's [1968] examination of the rates of imitation by the major firms of several United States' industries, have indicated the tendency for diffusion trends to approximate an S-form.

Such studies have generally utilized the logistic function in an attempt to obtain a mathematical expression for the observed diffusion of an innovation over time. The choice of the logistic in preference to alternative S-shaped functions such as the cumulative normal was seen by Brown and Cox [1971, p.552],

> ...to stem from the fact that its parameters can be readily estimated by least squares methods applied to a minimal amount of data and that these parameters can be treated as descriptive measures of diffusion processes and employed as dependent variables for further analysis.

This in no way implies that the underlying concepts relating to logistic growth curves are adequate explanators of all diffusion processes, but that their use is justifiable on the grounds of analytical expediency. Griliches [1957, p.503] concurs with Brown and Cox on this point when he reveals that his 'choice of a particular algebraic form for the trend function is somewhat arbitrary' and that 'the logistic was chosen because it is easier to fit than the cumulative normal and in our context easier to interpret.'

Initial use of the logistic arose out of attempts to formulate adequate mathematical representations of biological growth phenomena. Early population growth studies, such as Pritchett's [1891] investigation of the normal rate of growth of the population of the United States, utilised third order parabolas of the form

$$P = A + Bt + Ct^2 + Dt^3 \quad \ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

where P represents population and t the time from some arbitrary origin.

Although such a formula could account for an exponential-like increase in population levels, it was considered unsatisfactory over long time periods as it tended to over-estimate population growth. In response to such inaccuracies, Pearl [1924] fitted a logarithmic curve of the form

$$P = A + Bt + Ct^2 + D\log t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

to United States population data from 1790 to 1910 and showed that the logarithmic parabola gave a distinctly better graduation than a third order parabola. Even this formulation did not appear entirely adequate to Pearl [1924, p.566] when he stated,

> Satisfactory as the empirical equation [3.2] considered above is from a practical point of view, it remains a fact that it is solely an empirical expression, and states no general law of population growth.

Pearl considered that a primary requirement of such a law was the recognition of the Malthusian concept that eventually the rate of population increase per unit time must be reduced to zero. Following on from this concept, he concluded that in the long run population growth proceeding within some finite area is constrained within some upper limit, the magnitude of which is determined by the impact of scientific developments. This led Pearl [1924, p.568] to offer the following description of the process of population growth as it 'has apparently occurred generally and indeed almost universally.'

> At first, population grows slowly, but the rate constantly increases to a certain point where it, the rate of growth, reaches a maximum...This point of maximum rate of growth is the point of inflection of the population growth curve. After that point is passed, the rate of growth becomes progressively slower, till finally the curve stretches along nearly horizontally, in close approach to the upper asymptote which belongs to the particular cultural epoch and area involved.

The logistic function was subsequently hypothesised as a mathematical expression which may conform to the above description, with its ability to converge asymptotically to an upper limit making it a superior formulation to its predecessors.

It was on this theoretical and analytical foundation that Griliches [1957, p.503] adopted the logistic for his work on the diffusion of hybrid corn, 'as a summary device, perhaps somewhat more sophisticated than a simple average, but which should be treated in the same spirit.' His technique consisted of 'fitting trend functions (the logistic) to the data, reducing thereby the differences among areas to differences in the values of a few parameters.' [Griliches, 1957, pp.502-3] Using the estimated parameters of his chosen logistic, he then proceeded to analyse, and attempt to explain, cross sectional differences in the diffusion of hybrid corn between the 31 States and 132 crop reporting districts for which he had adequate data.

Griliches stressed the opinion in his study that the use of a logistic was a means to an end. Although, from *a priori* reasoning, the development should have followed an S-shaped growth curve with a lower band of zero and an upper limit of 100 per cent adoption, [Griliches, 1957, p.503, n.6], the core of his analysis related to a detailed study of the parameters which he derived from an application of the logistic to his data. As such, he failed to include an investigation of the assumptions encompassed in the specific formulation of the logistic which he employed in his analysis. This omission is of import in that *significant* real world departure from these assumptions may ultimately be reflected in the estimated parameters which are deemed to represent the diffusion process itself.

When pressed on this point by rural sociologists such as Havens and Rogers, [1961],[1] Griliches [1962, p.327] revealed that,

> True, it [the model] did not explain it [the process of diffusion]. It just assumed that this is the sensible way in which *any* adjustment, adoption, or spread of information process works...(My emphasis)

What Griliches fails to communicate effectively is that there are implicit and explicit assumptions inherent in his approach. Brown and Cox [1971, p.552] made reference to this point in relation to diffusion studies when they wrote,

> An S-shaped graph can also be produced by a number of other functions, each of which implies a different set of assumptions concerning social processes than does the logistic.

An investigation of these assumptions, in the hope of determining their relevancy or otherwise when attempting to model diffusion processes, is attempted below.

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1 The debate highlighting this point can be found in Havens and Rogers [1961, pp.409-14], Griliches [1962, pp.327-30], Havens and Rogers [1962, pp.330-32], Babcock [1962, pp.332-38].

3.3 THE ASSUMPTIONS OF THE LOGISTIC

Following its initial use in population growth studies, the logistic function was applied by Chapin [1928] to analyse the spread of certain new ideas of public administration among American cities. These functions then found extensive application in models of innovation diffusion processes.

The term logistic is essentially generic in that it can be applied to a range of mathematical formulae. Despite this heterogeneity these functions all incorporate, to one degree or another, the basic assumption that,

> ...the diffusion rate at a given point in time is proportional to the remaining distance to some predetermined saturation level as well as to the instantaneously attained diffusion level.
>
> [Lekvall and Wahlbin, 1973, p.363]

The differential form of the logistic which is commonly employed in diffusion studies is given by,

$$\frac{dx}{dt} = ax\,(K - x)/\,K \qquad \qquad (3.3)$$

where x is the (cumulative) number of adopters,

K is the ceiling or saturation value representing the maximum number of adopters,

t denotes the time from initial adoption, and

a is a parameter estimated in fitting the equation or, as Coleman [1964, p.494] has indicated, it represents the coefficient of conversion from the 'have-not' (non-adopter) to the 'have' (adopter) state.

Integrating (3.3) with respect to t yields the following diffusion function,

$$x = \frac{K c e^{at}}{1 + ce^{at}}$$

$$= \frac{K}{1 + be^{-at}} \quad \ldots\ldots\ldots\ldots \quad (3.4)$$

where $b = c^{-1}$ a constant, and e is the exponential constant. The interaction, symmetry and potential adopter group[2] constancy assumptions inherent in this specification of the logistic are dealt with below.

3.3.1 Interaction:

As indicated above, the commonly employed form of the logistic requires that the rate of diffusion be proportional to the product of the number of adopters and non-adopters. In the narrowest specification of a logistic, this implies that information concerning an innovation flows only within a potential adopter group [3] (P.A.G.), which represents the total *potential* number of adopters at the start of the adoption period.[4] A consideration of the existence and mechanism of such information flows is crucial to an accurate specification of a diffusion function. This was recognized by Rogers [1962, pp.13-14] who stated,

> ...the diffusion process consists of (1) a new idea, (2) individual A who knows about the innovation, and (3) individual B who does not yet know about the innovation. The social relationships of A and B have a great deal to say about the conditions under which A will tell B about the innovation, and the results of this telling.

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2 For a definition of this concept, see Section 3.3.1 below.

3 This assumes that we are only considering temporal adoption patterns *within* a group of pre-defined dimensions and not the adoption pattern *between* different groups.

4 This requires that at the start of the adoption period at least one member of the group is an adopter, otherwise (excluding any external influences as we have done in this case) the innovation will fail to get off the ground, i.e. at $t=0$, $x \geq 1$. Such a requirement is usually met by assumption rather than explanation.

Rural sociologists refer to this communication (or 'telling') process as the interactive effect whereby,

> The *interactive effect* is the process through which individuals in a social system who have adopted an innovation influence those who have not yet adopted.
>
> [Havens and Rogers, 1961, p.411]

The first point worth noting is that the mode of *influence* may be either verbal or non-verbal and all that is really required is transmission of information about the innovation to non-adopter(s). For example, a non-adopter may obtain information concerning a particular innovation by discussing it with an adopter or alternatively by 'over the fence' observation of the use of an innovation by an adopter. Secondly, any implication that an exchange of information concerning an innovation takes place *only* between adopters and non-adopters is misleading. For example, as will be seen later, a lack of randomness with respect to information transmission may be due to the fact that, at any particular point in time adopters tend to interact with other adopters to a greater degree than they interact with the remaining non-adopters.

This approach infers that the proposed mechanism whereby an innovation diffuses throughout a population or P.A.G. is a sociological phenomena and is propagated by an innovator influencing 'neighbours'[5] or non-adopters, who in turn influence their 'neighbours' and so on. Support for the idea that 'neighbours' are

(1) a primary source of information, and

(2) considered the most important influences leading to acceptance,

(specifically in relation to innovations in the agricultural sector) is found in the study by Ryan and Gross [1943] on the diffusion of hybrid corn seed in two Iowa communities.

Similar findings were reported by Czepiel [1974, p.178] for the diffusion of an innovation in the non-rural sector (specifically

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[5] Neighbours is the term used by Ryan and Gross [1943] and is used here in a broad sense to include all person(s) subject to the influence of an adopter.

the American steel industry) where he concluded that, 'the active use of friendships in information seeking concerning the innovation...makes real the concept of diffusion as a social process in the industry.'

3.3.2 Skewness:

Another significant assumption implicit in the widely applied function specified above (equation 3.4) is that the frequency distribution of adoption is symmetrical about the inflection point (i.e. where $\frac{dx}{dt}$ is at a maximum). An early attempt to give descriptive justification to any observed symmetry was given by Pearl in relation to population growth curves which were described by symmetrical logistics. He, [1924, p.570] stated that,

> This implies that the forces which during the latter part of the population history of an area act to inhibit the rate of population growth are equal in magnitude, and exactly similarly distributed in time, to the forces which in the first half of the history operate to accelerate growth.

The 'forces' operating in the more recent models of diffusion have been given various terms ranging from Mansfield's [1968, pp.137-8] 'band-wagon' effect through to Coleman's [1957, p.258] 'snowball' or 'chain reaction' process. However, the influence of at least one of the skew inducing factors discussed below may result in a non-symmetrical diffusion pattern. In other words, constancy in the 'forces' of adoption which has been implicitly assumed in previous diffusion studies may no longer be upheld. A failure to uphold such an assumption may result in a temporal diffusion pattern which will best[6] be modelled by a non-symmetric (or skewed) diffusion curve.

Visual representation of such skew is offered in the diagrams below, where figures 3.1, 3.2 and 3.3 indicate respectively positively skewed, symmetrical and negatively skewed diffusion functions for the

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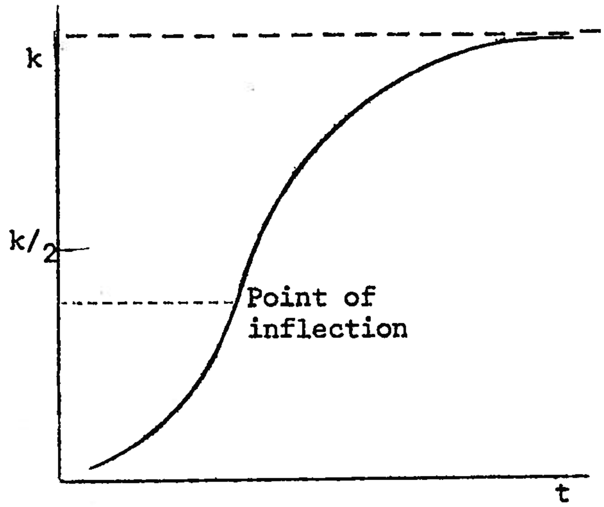
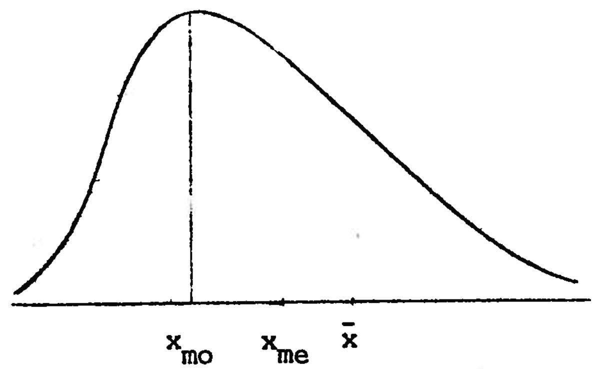
6 Best is taken to mean that a non-symmetric diffusion curve will give a better (minimum variance) fit than a symmetric curve.

FIGURES 3.1, 3.2, 3.3. CUMULATIVE AND NON-CUMULATIVE DIFFUSION CURVES

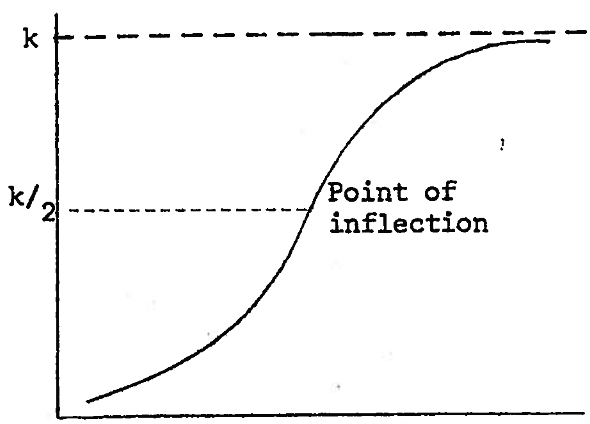
3.1 Positively Skewed (a. Cumulative)



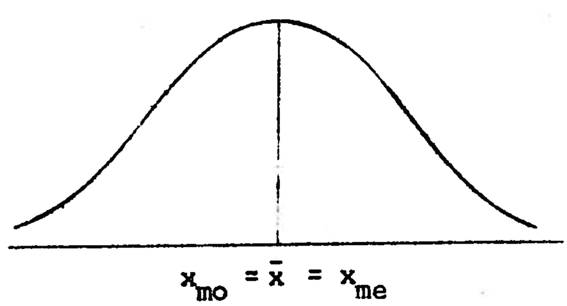
(b. Non-cumulative)



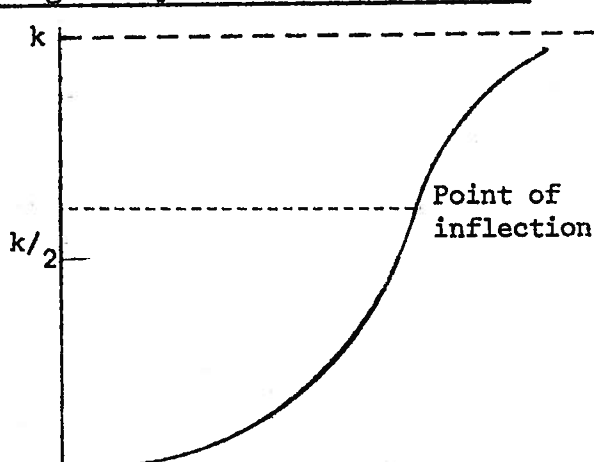
3.2 Symmetrical (a. Cumulative)



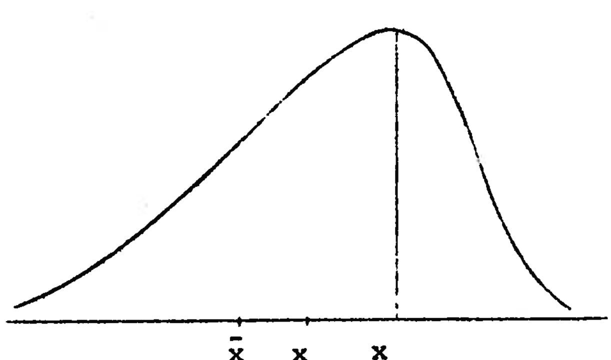
(b. Non-cumulative)



3.3 Negatively Skewed(a. Cumulative)



(b. Non-cumulative)



commonly portrayed cumulative case (a) and the less generally depicted non-cumulative case (b).

In a geometric sense, skewness is usually defined for the non-cumulative curve in terms of the extended or thinly spread 'tail'. A *positively* skewed function is represented with the 'tail' on the *right hand* side and a *negatively* skewed function has the tail on the *left hand* side.[7]

A quantitative classification of skewness with respect to the non-cumulative curve[8] depends on the relative values[9] of the mean ($\bar{x}$) mode (x_{mo}) and median (x_{me}) of the adopter distribution where

(1) For positively skewed functions, $x_{mo} < x_{me} < \bar{x}$

(2) For symmetrical functions, $x_{mo} = x_{me} = \bar{x}$ and,

(3) For negatively skewed functions $\bar{x} < x_{me} < x_{mo}$

The sensitivity of these three parameters will be exploited later in this thesis in an attempt to test empirically for the existence of a significant level of skewness in the observed copper-zinc adoption distribution. Details concerning the exact measures of skewness to be employed will also be presented with the relevant empirical information in Chapter 5.

Before entering a detailed consideration of the sources of skew, a clarification of the general concept of the diffusion process employed will be considered. Traditionally, studies in this area have failed to highlight the 'management' aspects of the adoption process. To focus on this aspect enables -

(1) diffusion models to incorporate explicitly the prospect that knowledge of an innovation need not be followed by *instantaneous* adoption.

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7 See Kane [1968, ch.5].

8 The key algebraic parameter of skewness for cumulative diffusion functions is the inflection point where
(a) Positively skewed functions exhibit an inflection point below 0.5 K(where K represents the ceiling or saturation level of adoption)
(b) Symmetrical functions exhibit an inflection point at 0.5K and
(c) Negatively skewed functions exhibit an inflection point above 0.5K.

9 See Kane [loc.cit.].

Empirical justification relating to the claim that the first knowledge and adoption stages of the diffusion process are usually not simultaneously determined, was offered by Ryan and Gross [1943, pp.17-18] in their seminal study of the diffusion of hybrid corn seed. Data presented in this study showed a lag of roughly five years between first knowledge and adoption, with almost all farm operators having heard of the new 'trait' before more than a handful had planted it, and

(2) the adoption process to be more readily incorporated into a management framework. Implicit in this statement is a recognition that the adoption (or rejection) of an innovation is simply another facet of the management decision making process, and involves a consideration of the basic principles common to all management decision-making. A fundamental principle of management decision-making is that such a process can be conceived as a series of sequential steps. Beal *et al* [1957, p.167] presented a five stage decision model relating to innovation adoption which consisted of

(1) Awareness: At this stage the individual is first exposed to the idea.

(2) Information: The individual is now collecting information specific to the new practice.

(3) Application: This stage is purely a 'mental trial' in which the individual is assessing the relative advantage of the new practice over other alternatives. A decision on whether or not to try the new practice is made.

(4) Trial: The new idea is now applied to the individual's own environment at an experimental level. 'Site specific' information is thus generated and evaluated.

(5) Adoption: At this stage the individual either accepts or rejects the new idea at a non-experimental or 'commercial' level.

Similar models are often found in the literature[10] concerning

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[10] See Johnson [1961].

management decision-making although the number and sequence of decision stages varies considerably. Data collected in Beal's study was not conclusive but seemed 'to support the validity of the stages concept.' [Beal *et al*, 1957, p.168]. These results highlight the fact that a potential adopter is not a *passive* participant in the adoption process, but that he is involved in an *active* decision-making role which requires him to engage in varying levels of information acquisition and evaluation before he actually adopts an innovation. Given Beal's evidence, it was considered useful to introduce explicitly the management component of the diffusion process into a discussion of the sources of skew. This was attempted by aggregating the various skew inducing factors into two groups,

(A) Non-Managerial Skew Factors - which consist of factors which are essentially outside the control of the decision maker, and

(B) Managerial Skew Factors - which consist of factors which are subject to the direct control of the decision-maker.

Despite the desirability of conceptualizing the skew inducing factors into two distinct groups in order to stress the management aspect of the diffusion process, it is possible to collapse them together when attempting an analytical investigation of skewness, thereby considerably simplifying the mathematical procedures involved.[11]

(A) *Non-Managerial Skew Factors*

(i) Structural Heterogeneity has been interpreted by Coleman [1964, p.493] to imply that there is a failure to achieve complete intermixing of the potential adopter group. For example, this requires that when diffusion begins with one member of a P.A.G., then the person(s) he influences will *not* be chosen at *random* - this means that there is a bias towards an adopter at a given point in time influencing people of

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[11] This point is also made by Hernes [1976, p.435] where he writes, 'An advantage of the [diffusion equations presented] is that the parameters are simple to estimate.' Another advantage is that the parameters so derived are more readily interpretable.

a similar nature who are more likely to have already adopted themselves than if they were chosen at random. As Hernes [1976, p.428] pointed out, this will result in 'different rates of spread in different subgroups'.

He considered structural heterogeneity to result 'when some *capacity is differentially distributed* in the population', an example of which could be a variation in the range of social contacts amongst group members. In general, structural heterogeneity occurs when there exists a restriction on the randomness of information transmission at a particular point in time. It is important to note that we are considering cross-sectional heterogeneity in the information transmission process, *not* cross-sectional heterogeneity in the interpretation or response to such information, which is a form of managerial heterogeneity.

The existence of structural heterogeneity in an adopter group explicitly introduces the possibility that information transmission may take place between adopter group members other than adopters and non-adopters. Such a possibility highlights the rather restrictive nature of Havens and Rogers' concept of the interactive effect presented above.

(ii) Dynamic Heterogeneity occurs '*when the population changes as the [diffusion] process goes on.*' Hernes [1976, p.428]. In a probabilistic sense this implies that the probability of a particular P.A.G. member (A) influencing another group member (B) is a function of time, such that the probability of (A) influencing (B) at time $t=1$ does not equal the probability of (A) influencing (B) at time $t=n$ where $n \neq 1$. Again it should be emphasized that we are not concerned with temporal variation in the interpretation or response of information transmission concerning an innovation, but more specifically with the temporal impediments to the flow of information itself. An example offered by Hernes [1976, p.428] which is relevant to this particular concept of dynamic heterogeneity, is the situation in which P.A.G. members reduce their social contacts over time.

(iii) Dynamic Stimulus Effect relates to the extent to which the degree of influence changes over time. As with the other two skew effects considered in the 'non-managerial' context above, this effect is concerned solely with the temporal change in the quality of information itself. Hernes [1976, p.428] states that,

> This either can be thought of as a declining or augmenting effect of the stimulus itself, as when the quality of a product changes over time...

Another example is when an adopter becomes either more or less enthusiastic when conveying information about an innovation to other P.A.G. members.

(iv) External Versus Internal Sources of Influences. As highlighted by Lekvall and Wahlbin [1973, p.367],

> ...The current view of the communication process in a social system is based on the so-called *two-step flow* of communication hypothesis, first formulated in a study by Lazarsfeld, Berelson and Gaudet [1948]. (my emphasis)

Early studies in applying the two-step flow hypothesis argued that information was initially acquired (often from mass media sources) by so-called 'opinion leaders' who subsequently influenced other members of their social system. Later work modified this approach somewhat by conceptualizing communication patterns as simultaneous rather than sequential information flows, in which each member of a social system was exposed to both mass media and interpersonal information sources.[12]

The latter methodology was adopted by Lekvall and Wahlbin in their development of a skewed diffusion function. They [1973, p.367] emphasized that

> ...a general distinction can be made between two major forms of influence on the individual adoption process, i.e., external and internal influence.

External influence relates to the influence that 'emanates from sources *outside* the set of prospective adopters', whilst internal influence 'is the influence that the members of a social system exert on one

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[12] See Rogers and Shoemaker [1971, pp.205-209] for a more detailed exposition of this approach.

another as a result of their social interaction.' [Lekvall and Wahlbin 1973, p.367].

Their investigations attempted to show that it was possible to generate positively skewed diffusion functions by explicitly incorporating external and internal influences into a diffusion model. The degree of skew was related to the degree of influence of the external sources, such that an increase in the level of influence of external sources relative to internal sources would be reflected in the diffusion function by an increase in the degree of positive skew.

(B) *Managerial Skew Factors*

(i) Managerial Heterogeneity embraces those skew factors which are directly attributable to the adopter decision maker and is therefore concerned solely with analyzing the skew which is introduced into a diffusion process as information acquisition is transformed into innovation adoption.

Both static and temporal aspects of heterogeneity are relevant here and correspond closely to the structural and dynamic forms of heterogeneity dealt with above. An example of this particular type of static heterogeneity would be a cross-sectional difference in the risk preferences of non-adopters. In fact any cross-sectional differences in the characteristics of decision makers which will result in varying responses to identical influences concerning an innovation may introduce skewness into a diffusion pattern. A variation over time in these same characteristics for a particular non-adopter exemplifies the temporal form of managerial heterogeneity.

3.3.3 Potential Adopter Group Constancy:

The assumption that the potential adopter group (P.A.G.) size (i.e. the *potential* number of adopters at the start of the adoption period) is constant over time has implicitly pervaded the literature on diffusion studies for the last two decades. In 1957, Griliches, using corn acreages as a proxy for adoption levels, calculated changes in the percentage of total corn acreage planted to hybrid corn over time using a constant (pre-hybrid)[13] corn acreage as the denominator in the percentage calculation. Mansfield [1961] taking the proportion of firms (within an industry) which had adopted a specific innovation as a measure of imitation or adoption levels, achieved the requirement for constant potential adopter numbers by either

(1) excluding firms which merged or went out of business before installing the innovation under study, or

(2) including only *large* firms which existed at a particular period in time to represent the highest attainable number of adopters.[14]

A more recent study by Romeo [1977] which attempted to detail the rates of imitation in ten U.S. industries paralleled Mansfield by arbitrarily holding constant (intra-industry) firm numbers to enable the fixed P.A.G. size assumption to be employed. Such constancy in the upper-bound to the (long-run) level of adoption has theoretical and analytical implications which perhaps deserve some attention.

The primary implication flowing from this constancy requirement[15] is that the P.A.G. size must be determined on an *a priori* basis in order that it be incorporated as a (fixed) denominator in the adoption percentage calculations *from the beginning of the adoption period.* At the conceptual level it therefore represents the potential maximum level of acceptance of the innovation under consideration *at any particular point in time.*

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[13] It is not explicitly stated that pre-hybrid total corn acreage was used in the calculation of hybrid corn percentages although such a figure was used in other estimations such as the size of market variable, (i.e. he used the average corn acreage in the area at about the time of the date of entry. [Griliches, 1957, p.509]).

[14] These arbitrary criteria excluded all firms which had not adopted the majority of innovations under consideration by the end of the study period. This meant that the final adoption levels reached 100 per cent for all but one innovation.

[15] It is required in the sense that an application of the simple logistic used by Griliches [1957] and Mansfield [1961] pre-supposes constancy with respect to the P.A.G. size.

This requires that it not only represents the potential number of adopters at the moment the innovation is introduced, but that it also takes into account changes in the P.A.G. size which occur as a *result* of the innovation.

In order to meet such a requirement it is necessary that changes in the potential maximum level of acceptance resulting solely from the introduction of the innovation at hand be isolated from all other factors whose change could influence this maximum adoption level. This implies a strict application of the *ceteris paribus* criteria to these 'secondary' factors.[16] Once this is done, it is recognized that any changes over time with respect to these 'secondary' factors would cause a *shift* in the logistic curve via a change in the P.A.G. size, whilst changes in those factors more directly related to the innovation under study would cause a movement *along* the curve.

In practice it is virtually impossible to find a situation in which the desired *ceteris paribus* assumptions are upheld, and observed diffusion curves are therefore measuring a hybridisation of shifts in and movements along the theoretical diffusion curve. That is, changes in the observed *absolute* level of adoption may be due to influences directly related to the innovation of interest or factors essentially exogenous to it, such as changes with respect to complementary or substitutable technologies. A re-examination of Griliches'hybrid corn analysis may serve to highlight this point.

As mentioned earlier, Griliches considered the change over time in the percentage of total corn acreage planted to hybrid corn as representative of the diffusion process solely with respect to hybrid corn technology. From the theoretical discussion above, it follows that total corn acreage must be taken as the potential maximum acreage which can be planted to hybrid corn *after* allowing for the effect which the new technology would have on corn acreages. Furthermore,

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[16] In some circumstances it is difficult to decide what constitutes a 'primary' versus 'secondary' factor as in the case where the adoption of one, from a group of closely complementary innovations is being considered.

differences in the total corn acreage before and after the hybrid technology are assumed to be independent of changes other than those directly related to the new corn technology. For example, movements in corn acreage resulting from the introduction of technologies complementary to hybrid corn (such as improved harvesting techniques), are in theory excluded from the analysis.

If such exogenous factors could indeed be held constant over time, then the observed changes in hybrid corn acreage relative to some *a priori* determined total corn acreage would be a true representation of the movement from non-hybrid to hybrid corn acreages resulting *solely* from the introduction of the new corn technology. But in the real world total corn acreage varies in response to many factors other than the innovations under consideration, and the observed diffusion curve is consequently the result of shifts in and movements along the theoretical diffusion curve.

Although this problem has not been explicitly confronted in the diffusion literature, it is difficult to ascertain its impact in quantitative terms. What can be said at this stage is that the choice of variable on which to focus a diffusion study may have important consequences in this respect. By choosing a numeraire of adoption which has exhibited proportionately small variations over time, it is likely that the assumption of a constant P.A.G. size may not be significantly at variance with the truth. However, if the numeraire has shown itself to be reasonably variable in the pre-innovation period, it is possible that the introduction of the innovation under study (amongst other factors) will influence it to an essentially unpredictable degree. This would make *a priori* estimation of the long-run P.A.G. size inaccurate as well as reducing the confidence that could be placed in the claim that observed changes in the absolute level of adoption were solely the result of the new innovation.

3.4 DIFFUSION MODELS

This section presents a brief introduction to the approaches taken by past diffusion studies to overcome some of the limiting assumptions of the logistic which were outlined in equation (3.4) above, when attempting to investigate the diffusion of innovations (or information) over time.

3.4.1 Rapoport and Diffusion

Rapoport's method of analysis consisted of tracing the movement of information by 'removes' (i.e. the number of hands each message has gone through) over 'ordinal' time. His initial analysis involved the conventional completely mixing population assumption which yielded an equation which 'predicts an ordinal time course of a spread which is much more rapid than the observed one.' [Rapoport, 1953, p.524].

Attempts to account for this result via 'psychological considerations'[17] met with little success. This led Rapoport [1953, p.526] to introduce 'some assumptions concerning the *structure* of the population, which places certain constraints on the possible contacts, so that they are no longer equi-probable.'

The first constraint was to allow the contacts of each individual to take place only within his 'acquaintance circle' where such acquaintances were randomly chosen from the population. This rather rigid assumption which involves segmenting the population into independent *finite* acquaintance circles was not considered entirely satisfactory, as it led to no substantially new results when compared with his earlier modelling attempts.

The 'acquaintance circle' assumption was eventually refined somewhat by introducing the concept of 'transitivity' such that

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[17] Rapoport [1953, p.525] attempted to incorporate a 'start effect' into his assumptions but concluded that this was not entirely compatible with the conditions which applied to the data he was attempting to model. The 'start effect' implied that the initial propensity to pass on knowledge was high.

> ...there is a *limited* mixing in the population in the sense that the 'acquaintance circle' does not stay fixed but changes with t [time]... The mixing is limited, however, in that there is a certain 'inertia', i.e. new knowers tend to talk almost exclusively to new knowers.

Rapoport's models are, however, of limited general applicability in that they are highly stylized formulations which emphasize structural skew inducing factors to the virtual exclusion of the other sources of skew detailed above.

3.4.2 Coleman and Diffusion

Coleman's attempts[18] to construct models of social diffusion processes evolved out of the mathematical and analytical work relating to medical epidemics.

He adapted the descriptive models of medical epidemics developed by Bailey [1957] to diffusion processes in a social context, where he considered

(1) Diffusion models with complete intermixing:

This approach encompasses a complete intermixing assumption which corresponds to a concept of structural and dynamic *homogeneity* in the population or P.A.G., or as Coleman [1964, p.494] writes,

> Implicitly this [the model] assumes that the item [or innovation] spreads through its users and that each user is in contact with all non-users.

Besides stressing the homogeneity of the adopter group, this statement also highlights Coleman's perception of a non-user as a *passive* participant in the adoption process, thereby largely divorcing such individuals from any managerial attributes.

The deterministic form of this 'person-to-person' model is the familiar[19]

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[18] See Coleman *et al* [1957] and Coleman [1964, Ch.17].

[19] Coleman [1964, p.494] submitted that it is possible to account for diffusion from some constant by adding another term to equation(3.5). In the deterministic equation this would be $+k_2n_2$ where k_2 is the co-efficient of conversion from the constant source.

$$\frac{dn_1}{dt} = kn_1 n_2 \quad .... \quad (3.5)$$

where n_1 is the number of 'haves', n_2 is the number of 'have-nots' and k is the coefficient of conversion (from the 'have' to the 'have-not' state). The explicit assumption of this model is that, 'the potential for diffusion is proportional to the number of pair relations between the haves and have-nots which is simply the product, n_1n_2.' [Coleman, 1964, p.494].

Such assumptions are compatible with Griliches' model of adoption over time and as such fail to account for the case in which the social structures are not homogeneous. Attempts to incorporate this aspect into a temporal model of diffusion led to a consideration of diffusion models with incomplete social structures.

(2) Diffusion models with incomplete social structures:

This approach specifies that a failure to support completely intermixing assumptions was due to the existence of 'a number of discrete groups, *within* which communication is complete, but *between* which it is absent or nearly so.' [Coleman, 1964, p.495]. His first step was to divide the study population into $\frac{n}{2}$ two-person groups[20] where n equals the population size. The groups may be in one of three states:

State 0: both members have-nots

State 1: one member have, one have-not, and

State 3: both members have

and after assigning transition rates[21] between each state Coleman

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[20] Further flexibility is introduced to the model when the possibility of 3, 4 or larger group sizes is admitted.

[21] In the two-person group model it is assumed [Coleman, 1964, p.495] that, (a) if one member of the pair is a 'have', the second has a transition rate of βdt of becoming a have in a small increment of time dt. (b) In addition, independently of the other member of the pair, each person has a transition rate αdt, due to outside communication from some constant source.

developed a stochastic model which yields the expected number of persons in state 1 as a function of the transition rates. In its simplest form, the model assumes that each group acts in isolation, however, a more sophisticated approach allows for 'partially inter-penetrating groups'. (i.e. some communication between persons in *different* groups is admitted.)

This attempt at formulating a formal diffusion model has successfully freed such models from the 'symmetry of diffusion' assumption by approximating some of the structural irregularities exhibited by actual social systems which,

> ...always slows the diffusion, [compared with completely inter-mixing populations] and in general slows it differentially at different stages of the process.
>
> [Coleman, 1964, p.494]

Although both Rapoport and Coleman have attempted to account for diffusion processes which do not reflect the completely intermixing assumption, their approaches, although structural in nature, have been substantially different. Coleman introduced the concept of 'partially interpenetrating groups' which allowed for communication between persons in different (finite) groups whilst Rapoport utilized the concept of 'transitivity' which allowed the acquaintance circle to change over time in a form 'rather analogous to an imperfect shuffling of cards, where after each shuffling, the cards that had been together tend to stay together for some time longer.' [Rapoport, 1953, p.546].

Despite these differences in approach Coleman's models have not found general usage in diffusion studies, possibly due once again to the exclusively structural emphasis of the skew inducing factors.

3.4.3 Mansfield and Diffusion

In his 1961 study of the spread of twelve innovations from enterprise to enterprise in four industries, (bituminous coal, iron and steel, brewing and railroads) Mansfield constructed a deterministic model to 'explain' the S-shaped growth in the percentage of major firms which introduced innovations over the period 1890-1958.

Initial calculations involved an estimation of $\lambda_{ij}(t)$ - which was defined as the proportion of 'hold-outs' (i.e. firms not using a particular innovation) at time t that introduced it by time t+1 - where,

$$\lambda_{ij}(t) = \frac{M_{ij}(t+1)-M_{ij}(t)}{N_{ij}-M_{ij}(t)} \quad \ldots\ldots\ldots\ldots\ldots (3.6)$$

and N_{ij} = total number of firms considered for the jth innovation in the ith industry, and

$M_{ij}(t)$ = the number of firms having introduced the innovation at time t.

He then hypothesized that $\lambda_{ij}(t)$ was a function of

(1) $\frac{M_{ij}(t)}{N_{ij}}$, the proportion of firms that already introduced the innovation by time t,

(2) π_{ij}, the profitability of installing this innovation relative to that of alternative investments,

(3) S_{ij}, the investment required to install this innovation as a per cent of the average total assets of the particular firm, and

(4) other unspecified variables such that,

$$\lambda_{ij}(t) = f_i\left(\frac{M_{ij}(t)}{N_{ij}}, \pi_{ij}, S_{ij} \ldots\right) \quad \ldots\ldots (3.7)$$

which collapses to

$$M_{ij}(t) = \frac{N_{ij}[e^{\ell_{ij}+(Q_{ij}+\phi_{ij})t}-(Q_{ij}/\phi_{ij})]}{1+e^{[\ell_{ij}+(Q_{ij}+\phi_{ij})t]}} \ldots (3.8)$$

by the application of a Taylor's expansion which ignores the third and higher order terms [Mansfield, 1961, p.747].

In this equation (3.8), ℓ_{ij} is a constant of integration, Q_{ij} is the sum of all terms in the Taylor expansion not containing $M_{ij}(t)/N_{ij}$ and $\phi_{ij} = a_{i_2} + a_{i_5} + a_{i_6} S_{ij} + \ldots$ (i.e. ϕ_{ij} is the sum of the co-efficients of $M_{ij}(t)/N_{ij}$ in the expansion).

Assuming that,

$\lim_{t\to-\infty} M_{ij}(t) = 0$ (i.e. the number of innovators as we go backwards in time equals zero) then,

$$M_{ij}(t) = \frac{N_{ij}}{1+e^{-(\ell_{ij}+\phi_{ij}t)}} \quad \ldots\ldots\ldots\ldots\ldots \quad (3.9)$$

is a (symmetric) S-shaped logistic growth curve in the Griliches tradition.

The rationale underpinning Mansfield's formulation with regard to the inter-firm diffusion of an innovation is sociological in emphasis. He [1961, pp.745-7] asserts, *inter alia*, that,

> As more information and experience accumulate, it becomes less risky to begin using it [the innovation]. Competitive pressures mount and *bandwagon* effects occur... The mere fact that a large proportion of its competitors have introduced it may prompt a firm to consider it more favourably.

The latter part of this statement alludes to the mode of diffusion which Mansfield has imputed in his model; namely that of the person-to-person or,more specifically, firm-to-firm diffusion mechanism. He upholds this assumption by reference to Schumpeter [1939] who noted that 'accumulating experience of other firms and vanishing obstacles' smoothed the way for imitators, with such a claim being supported by almost all the executives who were interviewed during the course of his study. Mansfield further highlighted the relationship between the innovation's profitability and investment requirements, and the risk associated with the introduction of the new technique. He stated that the greater an innovation's profitability (relative to others that are available) the higher will be the compensation to risk, and the larger the investment required, the more cautious will businessmen be.

A significant assumption implicit in the model is the constancy of potential adopters restriction (i.e. a constant N_{ij} value is used). As mentioned earlier, such a condition was met by omitting from the sample all the smaller[22] firms which were not considered potential users.

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[22] See Mansfield [1961, p.763ff.] for a statement of the arbitrary criteria used to categorize firms with respect to their size.

Mansfield [1961, p.742] achieved constancy by including only large firms in his analysis 'because of difficulties in obtaining information concerning smaller firms and because in some cases they could not use the innovation in any event'. Whilst data constraints impart some validity to the preclusion of smaller firms, the latter justification appears dubious. Variables such as profitability, the required level of investment and the durability of old equipment which 'explained' the variations in the rate of imitation amongst large firms would appear, *a priori*, to be capable of explaining the lack of imitation amongst smaller firms.

From a theoretical viewpoint this *ex post* approach of dividing an industry into small and large firms carries with it the assumption of a relatively static industry structure in that it precludes the possibility of

(1) new (large) firms entering the industry,

(2) extant (large) firms leaving the industry or declining over time into the small firm category, and

(3) extant (small) firms increasing in size over the study period such that they enter the large firm category. (P.A.G. size (i.e. the number of large firms) must be determined at the beginning of the analysis period as it represents the total number of *potential* adopters. Hence, firms which were relatively small at this point in time are deemed by Mansfield to be such at the end of the study).

Nevertheless, the work by Mansfield was the first to incorporate (economic) determinant variables into the model building stage of a diffusion study. However, his consideration of the actual mode of diffusion went no further than the rather vague statement concerning *bandwagon* effects. By omitting to pursue this aspect in detail, his investigations failed to confront the possibility of asymmetry in the observed pattern of temporal diffusion.

3.4.4 Lekvall, Wahlbin and Diffusion

An attempt by Lekvall and Wahlbin [1973] to introduce skew into a diffusion process was presented in section 3.3.2(iv) above. The prime assumption of their deterministic model was that both external and internal sources of influence are relevant to a study of the diffusion of an innovation within a potential adopter group. In contrast to the symmetrical diffusion curves presented earlier (equation 3.3) the differential form of Lekvall and Wahlbin's model is given by

$$\frac{dy}{dt} = \left[\frac{(N-y)}{N} \cdot (g+ky) \right], \quad 0 \le y \le N \quad .... \quad (3.10)$$

Where N is the prospective number of adopters of a given innovation,

g is the 'instantaneous' number of contacts of market individuals made by an external influence,

k is the 'instantaneous' number of influential contacts made by each adopter, and

y=y(t) denotes the current number of adopters in the market.

The model assumes that 'once a non-adopter receives an influential contact (external or internal) he immediately becomes an adopter' [Lekvall and Wahlbin, 1973, p.369] and therefore, in this form it does not explicitly take into account managerial heterogeneity. The authors also admit that

> Some examples of possibly relevant [skew] factors which are omitted from the analyses are the characteristics of the innovation, barriers to communication through social stratification and various environmental conditions.
>
> [Lekvall and Wahlbin, 1973, p.366]

Despite such omissions they [ibid.] conclude that,

> ...it seems reasonable to believe that the factors evaluated are some of the most important determinants of the shapes of innovation diffusion curves.

Solving equation (3.10) for the case $y(0) = 0$ yields,

$$y(t) = \frac{N(1-e^{(-gt/rN)})}{1+(\frac{1-r}{r})e^{(-gt/rN)}} \quad \text{.............. (3.11)}$$

where $$r = g|(g + kN) \quad \text{........................ (3.12)}$$

such that $0 \leq r \leq 1$ and $r = 0$ if $g = 0$ or alternatively $r = 1$ if $k = 0$.

The verbal interpretation of equation (3.11) is - if the predominant source of influence is internal then r will be close to zero, whilst if external sources dominate then r will be nearer to one. Consequently, for this particular temporal diffusion model changes in the relative strengths of internal versus external influences can be effected by changes in the value of r within the one to zero range.

Two significant limitations of this model are -

(1) It can only generate positively skewed diffusion functions and in this respect lacks functional generality, and

(2) Although introducing skewness into the diffusion process by explicitly distinguishing between different sources of influence it was (again) at the expense of other skew factors. In an attempt to accommodate such criticism, Lekvall and Wahlbin [1973] developed a simulation model which extended the analysis to include also a form of static managerial heterogeneity. This was achieved by associating each individual in the potential adopter group with an 'Influence Level' 'which designates his appreciation of - or attitude towards - the innovation at time t.' [Lekvall and Wahlbin, 1973, p.371]. It initially takes a value of zero and recursively builds up as influential contacts (both internal and external) are made. When the 'Influence Level' variable reaches a certain threshold value the P.A.G. member becomes an adopter. The threshold values are assumed to be normally distributed throughout the P.A.G. and are deemed to represent a cross-sectional variation in the resistance to innovation.

Lekvall and Wahlbin [1973, p.371] point out that this model allows for 'no decay of effects over time and no interaction between the two kinds of influence'. The absence of decay effects in the stochastic model, along with time independent influence parameters (k and g) in the deterministic approach, means that dynamic skew influences have not been formally considered in these modelling attempts.

3.4.5 Hernes and Diffusion

Having observed the structural emphasis of many diffusion models including Lekvall and Wahlbin's, Hernes [1976] proceeded to construct a model that contained skew potential as a result of temporal factors. The differential equation of Hernes' diffusion function is

$$\frac{dP}{dt} = q\,(1-P)\,P \qquad \text{.....................(3.13)}$$

where P is the proportion of adopters at a particular point in time and $q = q'N$ in which q' is a constant of conversion and N is 'the total number in the population reached by the process'. [Hernes, 1976, p.429]. N is introduced into the equation when converting from the absolute to the proportional form.

Temporal skew factors such as dynamic managerial and non-managerial heterogeneity and dynamic stimuli effects were then introduced by allowing q to be a function of time, t. This was achieved by assuming that the potential for diffusion was initially proportional to a quantity A, but that it declines or increases by a constant b for each unit of time such that

$$q = q(t) = Ab^t \qquad \text{.............................. (3.14)}$$

where b is a 'constant of deterioration if $b < 1$' or a 'constant of augmentation if $b > 1$'.

Inserting (3.14) into (3.13) and integrating gives

$$P_t = \frac{1}{1 + {}^{1}/_{k}a^{bt}} \qquad \text{.............................. (3.15)}$$

where $\log a = {}^{A}/\log b$ ....(3.16)

and $k = P_0/[a\,(1-P_0)\,]$ ....(3.17)

Equation (3.15) represents a significant improvement on the deterministic form of Lekvall and Wahlbin's diffusion function, equation (3.11), in that it can account for both negatively and positively skewed curves. For example, 'if $b < 1$ it is positively or right-hand skewed, if $b > 1$ it is negatively or left-hand skewed... [and when] ...$b = 1$, the function is the same as the [symmetrical] logistic.' [Hernes, 1976, p.431]. Indeed, the curve can be used to describe not only an S-shaped curve, but a J-shaped one as well! Such flexibility obviously makes this formulation more attractive than that presented by Lekvall and Wahlbin as a diffusion function of general applicability.

Although this model does not directly incorporate structural skew factors, Hernes [1976, pp.429-30] argues that there exists an interaction between dynamic and structural factors such that,

> ...even if the distribution [of P.A.G. characteristics] remains fixed, the nature of the interaction may change as members with different scores on the distributed characteristic[s] adopt the item.

This is an important observation and, if generally true, as Hernes claims, means that 'it should be fairly easy to find situations in which structural heterogeneity mediates effects which can be represented by equation [3.14].' [Hernes, 1976, p.430]. The inference which can be drawn from this statement is that fitting equation (3.15) to adoption data does not make it possible to determine the skew factors which are operating to produce the particular diffusion pattern which is observed. Neither can the direction and relative influence of each particular factor be discerned, as the observed diffusion represents the combined contribution of skew factors to the diffusion process.

Past studies have considered that the shape of a cumulative diffusion curve is indicative of the underlying diffusion process. This methodology was reflected in Lekvall and Wahlbin's [1973, p.375] statement that,

> Generally speaking, if the communication network is dominated by external sources of influence, the diffusion curve will approach the modified exponential function [J-shaped]. If, on the other hand, internal communication is the most important influential factor, the curve will tend more towards the logistic type [S-shaped].

However, Hernes fitted a modified exponential (Gompertz) function which incorporated dynamic skew effects along with 'constant source' assumptions to *both* S and J shaped diffusion data. He concluded that 'we can no longer infer from the shape of the curve (S-shaped or J-shaped) what the underlying process is.' [Hernes, 1976, p.434].

In summary, it is evident that fitting a particular mathematical formula to an observed diffusion process is no test for the underlying process of diffusion, when it is remembered that a modified exponential function which contains constant source assumptions and a logistic function which embraces person-to-person assumptions can both be fitted to the same S-shaped data.

3.5 SUMMARY

The methodological conclusion which can be drawn from this chapter is that the use of the logistic in attempts to quantify the diffusion process imposes constraints on the aspects of diffusion which can be investigated. In this regard, Hernes' study concluded that fitting a particular mathematical formula (e.g. any particular form of the logistic function) to an observed diffusion process was *no* test of the underlying process of diffusion. His study therefore invalidates the earlier attempts by Coleman, Lekvall and Wahlbin and others to impute modes of diffusion based on the shape of the observed temporal diffusion pattern.

Having accepted this proposition, it is felt that the summarizing aspect of a Griliches-type logistic (whereby a large body of data can be reduced to several interpretable parameters) makes it an appealing formulation for the purposes of this study, as long as no conclusions concerning the actual mode of diffusion are to be drawn. However, this does not deny the necessity for entering a consideration of the assumptions encompassed in this form of the logistic.

Given the relatively widespread recognition of asymmetry in diffusion processes, an investigation of the observed diffusion pattern in order to ascertain how closely it conforms to the symmetry constraints of the Griliches-type logistic seems desirable. This is especially important in view of the observation made earlier that *significant* real world departure from these assumptions may ultimately be reflected in the estimated parameters which are deemed to represent the diffusion process itself.

If asymmetry appears significant it would then be necessary to summarize the relevant diffusion data using a (logistic) function which has the ability to accommodate such asymmetry. These functions however, usually increase the difficulty of realistically interpreting any parameters which they generate, and in this respect are less appealing when employed as a summary device. Before attempting to test statistically the symmetry property of the observed patterns of copper-zinc adoption, chapter 4 will detail the methods by which these adoption patterns were constructed.

CHAPTER 4

DATA COLLECTION AND PROCESSING

4.1 INTRODUCTION

One of the principal aims of this study is to undertake an investigation of any observed inter-regional variation in the adoption pattern of trace elements. To meet this end, the generation of a temporal series of data within chosen regions of the State (of South Australia) which are representative of the diffusion process under consideration was required. This chapter will trace the development of the raw data into a form suitable for analysis.

4.2 DATA DESCRIPTION

The raw data set consists of unpublished listings of trace element deliveries that were compiled yearly by Fertilizer Sales Limited (F.S.L.). This firm was jointly owned by Cresco Fertilizers, The Adelaide Chemical and Fertilizer Company and Wallaroo-Mount Lyell Fertilisers, the three local manufacturers who between them accounted for 100 per cent of the local production of all artificial fertilizers.[1] F.S.L. was established in 1936 and its primary function was to act as a marketing agency for the three manufacturers.[2]

The F.S.L. listings were compiled from the first year of commercial availability of trace elements in this State, 1939/40 through to 1951/52. Given that F.S.L. co-ordinated the fertilizer sales of all local producers, these listings detailed virtually all the deliveries made to trace element users within South Australia. The only deliveries

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1 In 1965 Adelaide Chemical and Wallaroo-Mount Lyell merged to form Adelaide and Wallaroo Fertilizers Ltd. This company subsequently purchased the assets of Cresco in 1971.

2 Pers. com. with Adelaide and Wallaroo Fertilizers Ltd.; March, 1977.

not recorded would have been those made by fertilizer manufacturers outside the State or local primary producers who purchased trace elements from alternative sources and engaged in their own on-farm mixing.[3] Given the relatively high freight costs associated with the delivery of trace elements in mixture form, the prime interstate competitors with the local producers are the manufacturers in Victoria, a neighbouring State of South Australia. However, enquiries[4] made to the largest Victorian producer, The Phosphate Co-operative Company of Australia, revealed that during the 1940s and 50s this company sold only a very reduced total tonnage into South Australia and the trace element content was not very significant. They claim that the upsurge in usage which occurred with the development of the Ninety Mile Desert[5] was almost wholly supplied by South Australian based companies, and it was not until the Cresco factory opened in 1968-9 that the Victorian Companies achieved a significant increase in sales and, in particular, trace elements.

With the observation that nearly all the trace elements purchased from F.S.L. were in mixture form[6] from 1939 to 1952, it was assumed that the incidence of on-farm mixing of trace elements purchased from alternative outlets was *relatively* insignificant.[7] It is therefore asserted that the F.S.L. listings do in fact closely reflect the total State purchasing pattern of trace elements for the period under study.

Turning to the details of the listings, the first point worth

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3 Due to the small quantities of trace element required per acre, the usual method of broad acre application was to apply the trace element in mixture form (e.g. 7 lbs of copper and/or zinc per bag (180 lbs) of superphosphate was a common mixture).

4 Pers. com. with The Phosphate Company of Australia; March, 1977.

5 A large area in the South East of South Australia in an area adjacent to Victoria.

6 In fact in 1951/52, the last year for which disaggregated data was available, there were no unmixed deliveries of copper-zinc (super) fertilizers made.

7 This conclusion was supported by representatives from the local fertilizer manufacturer.

noting is the sheer magnitude of the data set. In total, approximately 24,000 transactions are recorded. Each transaction lists the name and address of the purchaser of the various trace elements - copper, zinc, cobalt, molybdenum and manganese. The tonnages and concentration of trace element per bag of superphosphate for each delivery are also recorded. Although most of the sales are listed with respect to individual trace element users, a small proportion of deliveries was made to developmental authorities such as the Australian Mutual Provident Society[8] or re-sale (stock and station) agents such as Dalgety and Co. Ltd. The number and tonnage of such sales relative to the total number of transactions per season[9] was small enough to engender confidence in accepting the proposition that these *sales* data do in fact proxy the (on-farm) *usage* pattern of trace elements in South Australia.

4.3 WHY COPPER-ZINC?

In the overview of the initial trace element research which was presented in Chapter 3, it was revealed that experimental work into the effect of copper applications on cereal and pasture growth was begun in 1935 whilst investigations into the role of zinc were not undertaken in South Australia until 1939. Despite the lag in initiating research into the role of zinc, it was realized by 1940 that the problem of cereal and pasture production on the calcareous aeolian sands of the South East was essentially the result of a *dual* deficiency of both copper and zinc. In broad terms cereals responded primarily to zinc, lucerne to copper, and subterranean clover (particularly with respect to seed

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8 This company was involved in a large development project in The Ninety Mile Desert area. Development companies (and government agencies) only accounted for approximately 15 per cent of the total copper-zinc tonnage during 1951/52 - the last year for which data was available and certainly a peak year with respect to the post war development in which such companies were involved.

9 Each season corresponds to the financial year.

production) to both.[10] Experimental evidence had therefore suggested that copper and zinc could often be considered complementary trace elements (especially with respect to pasture growth) or at least that zinc applications were at times required in order to supplement the copper response.[11]

In the light of these observations, it was likely that farmers would not have perceived the application of copper and zinc to pastures and cereals as significantly different forms of technology, and therefore the use of either copper, zinc or a combination of both of these trace elements could be considered an adoption of the same innovation. This conclusion is further supported by the fact that as early as April 1941 commercial sales of copper-zinc-superphosphate mixtures were recorded, even though research work on the interaction between copper and zinc had only been initiated during 1939 and 1940.

4.4 THE NUMERAIRE OF ADOPTION

The relative importance of land as an input into agricultural production processes makes it an appropriate variable by which to investigate the diffusion of innovations within the agricultural sector. In the case of Griliches' [1957] study of the adoption of hybrid corn seed by United States farmers, it was observed that a further justification for the use of land as the focus variable was that hybrid corn technology aimed directly at increasing land productivity.

The use of trace elements by South Australian farmers obviously satisfies a criterion similar to hybrid corn usage in that its primary effect was to increase land productivity.[12] This would appear to lend support to the use of land as the variable on which to focus attention

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[10] See C.S.I.R.O. [1976, p.32].

[11] Given that pastures were generally sown in rotation with cereals, farmers predominantly orientated towards cereal production were also potential copper users.

[12] It also had a qualitative effect, with the application of copper to pastures having the ability to rectify the copper deficiency symptom of steely wool in sheep. See Section 7.2.2 .

in order to analyse the adoption of trace elements. However, there exists one significant difference between the two technologies which limits the usefulness of a land numeraire in the case of trace elements.

Corn production using hybrid seed[13] requires that *new* hybrid material must be utilized at every successive planting. However, trace elements, although applied in relatively small concentrations (usually in the order of 3½-7 lbs per acre for copper and zinc), have a marked *residual* effect in that further applications of the particular trace element which was initially applied are not required for several years hence. The rule of thumb often followed was that the number of lbs. per acre is directly related to the number of years before re-application is required - i.e. 7 lbs. of copper per acre will preclude the necessity for further applications of copper for a period of seven years.[14]

It is evident therefore that in years following the first commercial use of copper and zinc, some acreages will be receiving trace elements for the first time, whilst others will be receiving repeat applications. Furthermore, in any chosen year, some acreages will *not* be receiving any trace elements as they are still responding to previous applications. Using the number of acreages receiving trace elements (either cumulative or non-cumulative) as a measure of the level of trace element adoption in any particular year could obviously yield misleading results.

The numeraire of adoption employed in this study is the actual number of individuals who used either copper, zinc or any combination of the two trace elements. The ability to identify copper-zinc users by *name* in the F.S.L. listings made this measure possible. Such a measure of adoption not only abstracts from the difficulties outlined above

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13 Griliches [1957, p.502] offers a brief explanation of hybrid corn technology.

14 Obviously many factors (including rainfall, land usage, etc.) other than the application rate will influence the length of the residual effect.

with respect to a land numeraire, but also orientates the investigation to a study of the inter-firm (farm) adoption pattern of copper and zinc. Griliches, for example, was unable to distinguish between inter and intra-firm adoption levels by the use of a (hybrid corn) acreage measure, as both aspects of adoption are encompassed within this variable. By choosing another measure such as firm numbers to represent the diffusion level, the inter-firm diffusion process can be segregated from the degree of acceptance of an innovation *within* an adopter unit.

4.5 THE GEOGRAPHIC UNIT OF ANALYSIS[15]

In this study the geographic unit of analysis is similar to the unit which Griliches employed in his 1957 study of hybrid corn adoption. The basic geographic units consisted of two arbitrarily determined (political) regions, namely Counties and Hundreds; the latter area being a sub-division of the former.[16]

The most desirable unit of analysis for the purposes of this study would be achieved if areas that are homogeneous with respect to the technical conditions pertaining to trace element (or in this case copper-zinc) responses could be aggregated. In the case of trace elements this would primarily require defining regions of homogeneous geo-climatic characteristics. Unfortunately, data availability in conjunction with the resource constraints imposed on this study precluded the possibility of constructing a data set compatible with this 'ideal' unit.

Having settled on the County and Hundred regions for use in this investigation, a method of allocating the trace element adopters detailed on the F.S.L. listings to each region was required. As the (postal)[17] address of each user was recorded on the F.S.L. listings, it

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[15] See Griliches [1957, pp.512-515] for his approach to the problem of deciding what is the 'correct' geographic unit of analysis.

[16] There are 49 Counties and 544 Hundreds in the settled region of South Australia.

[17] In general, it was the address to which the account rather than the fertilizer was delivered. See Appendix A for a discussion of this aspect in relation to the units of analysis employed in this study.

was a relatively simple although laborious process to allocate users to a particular County and Hundred by referring to their nominated addresses. In order to complete this task, it was required that the location of approximately 700 rural towns and outer Adelaide suburbs be determined. Maps supplied by the State Lands Department and information made available by the Geography Department of the University of Adelaide were of assistance in this matter.

4.6 FROM ABSOLUTE TO PERCENTAGE LEVELS OF ADOPTION

The level of adoption in absolute terms is defined simply as the number of individuals (identified by name from the F.S.L. listings) who have received at least one delivery of either copper, zinc or any combination of the two. The individual is recorded *only* in the year of *first* delivery in a particular region. The data set so generated therefore attempts to measure only inter-firm or farm adoption levels in a manner somewhat similar to the measures of adoption which were used in the studies by Mansfield [1961] and Romeo [1977].

In order to make meaningful inter-regional comparisons, absolute adopter numbers need to be weighted by the potential number of copper-zinc adopters in each region. The potential number of adopters for a particular year within a given region should ideally reflect the number of individuals who are ultimately responsible for making the decision concerning the adoption (or non-adoption) of the trace elements under study.

As no direct measure of this variable was available, two alternative proxies were considered; the first being the number of holdings per County and Hundred. The accuracy of this proxy is limited by the extent that principal decision makers have control over more than one holding. To the degree that this situation prevails, the holding figure will over-estimate the number of potential adopters within each region. In a study by Anderson [1976] of (sheep) flock-size distribution around Longreach (Queensland), it was shown by detailed survey methods that 145 'holdings' were *independently* owned and managed. This compared with the figure of 179 holdings which was obtained under the holding definition employed by the C.B.C.S.[18] The difference between these two figures can be taken as an indication of the level of multi-holding (using the C.B.C.S. definition) ownership that exists in the Longreach region.

Unfortunately no compatible measures of the degree of multiple ownership which exist within the regions used in this study are available, and extrapolating the Anderson analysis to South Australian (holding) figures is fraught with possible dangers.[19] All that can be said is that the C.B.C.S. figures in Anderson's study over-estimate the level of independently owned and managed holdings by around 19 per cent. If similar orders of magnitude exist for the South Australian data, the problem is perhaps not too critical. In fact, all that is really required for the purposes of this study is that the proportion of multiple ownership is essentially constant between regions over time.

An alternative measure of potential adopters which, like the holding figure, is available from the yearly statistical registers of South Australia, is the number of owners, lessees or share farmers working permanently full-time on holdings. Again it must be recognised that this proxy will over-estimate the potential number of adopters if

(1) there exists a degree of multiple ownership by resident working owners, or

(2) a particular holding is worked by both a resident owner and a share farmer, in which case one of the individuals (most likely the share farmer) is not responsible for the ultimate decision concerning the adoption or otherwise of the copper-zinc technology.

On the other hand, this proxy will under-estimate the potential number of adopters if a situation exists whereby a property which is owned by

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[18] C.B.C.S. is the Commonwealth Bureau of Census and Statistics. Now called the Australian Bureau of Statistics.

[19] Many factors, both sociological and economic (and some site specific), influence ownership patterns.

an absentee owner is worked part-time by (say) a neighbouring farmer or is under the control of a manager. In such a case neither the absentee owner, part-time worker or manager would be recorded, although one of these individuals was obviously responsible for adopting or rejecting the innovation. Given these possibilities, it was decided to employ the holding figure as an estimate of the potential adopter level on the assumption that it would incur the smaller error of the two alternative proxies.

Recalling the discussion presented in Chapter 3, it will be remembered that the use of a static estimate of potential adopter numbers tends to ignore the dynamic influences of new innovations on this variable. It is also implicitly evident that in this study, the number of holdings per year per region is a function of a multiplicity of factors[20] apart from the introduction of trace element technology. This would suggest that the percentage level of adoption in each region (j) for each year (i) should be given by,

$$P_{ij} = \frac{A_{ij}}{H_{ij}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

where P_{ij} = the percentage level of adoption,

A_{ij} = the number of adopters (or more specifically first users) of copper-zinc (as identified from the F.S.L. listings),and

H_{ij} = the number of holdings.

Although this calculation yields a measure of the percentage level of adoption which embodies the dynamic influences of the new technology on potential adopter numbers, it is inappropriate to the extent that,

(1) H_{ij} values vary as a result of many influences other than copper-zinc technology which are not the direct concern of this particular study, and

(2) the use of a variable denominator in the P_{ij} formula precludes

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[20] For example, the introduction of trace element fertilizers was followed by the introduction of new large scale land clearing methods which were used extensively in areas such as the South East of the State.

the use of the Griliches-type logistic as a means of summarizing the intra-regional temporal diffusion pattern. The use of such a logistic is appealing in that its parameters can not only be readily estimated but, perhaps more importantly, can be readily *interpreted*.

These two factors alone are possibly insufficient grounds on which to reject the formulation presented in equation (4.1) for the purposes of this analysis. What must also be remembered is that the holding figure is itself merely an *estimate* of the potential number of adopters per region, and it is therefore doubtful whether such a rejection would further seriously bias the results. Indeed, Griliches [1957, p.520] also recognized a problem with respect to changing total corn acreages[21] over time but stated that 'as a first approximation I shall ignore this problem'. A constant denominator was therefore incorporated into the percentage calculation by substituting $\bar{H}_j$ for H_{ij} where $\bar{H}_j$ represents the average number of holdings for the j^{th} region over the period 1939-40 to 1964-65.

One further adjustment to the potential adopter estimate is required before the percentage level of adoption series can be generated. It will be recalled that the absolute number of adopters was determined by recording the year in which the first copper-zinc delivery to a particular region was made. Identification was based on the *name* of the individual receiving the trace elements. This method of recording may therefore attribute two or more adopters to the one holding if the individual responsible for trace element purchases for that particular holding changes over the data period.[22]

Such changes can primarily be attributed to

(1) a change in holding ownership, or

(2) a change in the holding decision maker without a change in ownership (e.g. transfer of decision making responsibility from a father

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21 ~~He~~ was actually discussing the relationship between changing total corn acreages and changes in his ceiling estimates (K).

22 This obviously further assumes that the new decision-maker(s) also purchases some copper-zinc fertilizer.

to a son or from an owner to a manager).

Unfortunately, neither of these factors is quantified directly in the published statistics at the level of disaggregation required for this study. A method of estimating the number of adopters within each region who were *not* resident farmers (or graziers) at the conclusion of the data period (1951-52) was pursued by reference to the Commonwealth Electoral Roll of 1952. The electoral roll for the State House of Assembly consists of a list of all eligible[23] adults of voting age[24] who have enrolled. Given that enrolment is compulsory for all eligible adults, the number of omissions from the list is considered to be quite small.[25] Individuals are allocated to a particular electorate by reference to the address which is shown on their enrolment form. The address entered on the enrolment form is left to the discretion of the individual who is enrolling, but rural voters are instructed to declare their address as the town nearest their property.[26] This implies that for all resident farm operators the addresses recorded on the electoral roll will closely correspond to that shown on the F.S.L. listing.

By comparing the names, addresses and occupations on the 1952 electoral roll for a particular electoral district, with the names and addresses for the corresponding regions derived from the F.S.L. listings, it was possible to determine the number of copper-zinc adopters who were still *resident farm operators* at the end of the data period. The difference between this figure and the *total* number of adopters for the period 1939-40 to 1951-52 is largely the result of factors (1) and (2) above, which detail the bias introduced into the analysis by using the number of holdings as a proxy for the potential number of adopters.

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23 Convicted criminals serving their sentences and such like are excluded from the roll.

24 At the time of this study, it was persons 21 years and over.

25 Pers. com. with Electoral Office; August 1978.

26 Pers. com. with Electoral Office; August, 1978. In fact, rural voters were asked to list the Hundred in which they resided.

Quantification of this bias allowed the average holding figure to be adjusted such that,

$$\text{Potential number of adopters } (A\bar{H}_j) = \bar{H}_j \cdot \left[1 + \frac{\Delta \text{ Adopters}_j}{\sum_i \text{Adopters}_{ij}}\right] \quad \ldots (4{:}2)$$

where $\bar{H}_{ij}$ = the average holding number for the j^{th} region over the period 1939-40 to 1964-65,

Δ Adopters$_j$ = the difference between the total number of copper-zinc adopters and the number of adopters who were still resident farm operators at the end of the data period (1951-52) for the j^{th} region, and

$\sum_i$Adopters$_{ij}$ = total number of copper-zinc adopters from i = 1939-40 to 1951-52 for the j^{th} region.

Although this modified $\bar{H}_j$ is an attempt to allow for changes in *resident* farm operators, it was recognized that the recording procedures for the House of Assembly roll would have omitted to account for any changes with respect to *absentee* owners. To obtain an estimate of the error which may have been introduced by this omission, compatible[27] House of Assembly and Legislative Council rolls were compared with the F.S.L. listings. The House of Assembly roll embodies a residency regulation, whilst the Legislative Council roll was based on a land ownership franchise.[28] This means that any differences in the number of copper-zinc adopters which appeared on either roll (for a particular area) can largely[29] be interpreted as a measure of the level of absentee ownership.

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27 On geo-temporal grounds.

28 The roll changed to an adult franchise in 1973.

29 Some names which did appear on the House of Assembly roll may not appear on the Legislative Council roll due to the non-compulsory voting requirement which existed for the L.C. roll. The Assembly roll, on the other hand, had a compulsory voting requirement.

Selected comparisons indicated that the degree of absentee ownership amongst copper-zinc adopters for the period 1939-40 to 1951-52 was not significant enough to bias seriously the results. For County Carnarvon (i.e. all of Kangaroo Island) only 2 or .008 per cent of the copper-zinc adopters appeared on the Legislative Council but not the House of Assembly roll, whilst for the Hundred of Penola in the South East of the State both rolls were compatible with respect to trace element adopters.

4.7 SUMMARY

Although $\bar{AH}_j$ is to some degree an imperfect measure of P.A.G. size, it is felt that it represents a reasonably accurate estimate, given the available data sources with which it was estimated. It was subsequently employed to generate the observed regional adoption percentages which are presented in graphical form in Appendix C. The following chapter will empirically investigate the symmetry properties of these adoption patterns.

CHAPTER 5

TESTING FOR SYMMETRY

5.1 INTRODUCTION

As mentioned in section 3.3.2, the degree of skewness of a distribution can be quantified by reference to the three common measures of central tendency namely, the mean ($\bar{X}$), mode (X_o) and median (X_{me}). The most widely used measure of skewness which employs these parameters is the Pearsonian skew co-efficient, which is a dimensionless measure of relative skewness. The initial formulation of this skew co-efficient combined the mean and mode such that

$$\text{Skewness} = Sk_1 = \frac{\bar{X} - X_o}{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.1)$$

where S = the standard deviation of the relevant frequency distribution.

Two points can be made concerning this measure. Firstly, larger degrees of skewness are characterised by larger absolute values of Sk_1. This result is derived from the fact that measures of the mode are not influenced by the presence of extreme values in a frequency distribution whilst the mean is sensitive to the size of extreme observations. Secondly, the sign on Sk_1 is indicative of the direction of skewness - having a positive sign when skewness is to the right and a negative sign when skewness is to the left. Such a result is attributable to the fact that the change in the value of the mean resulting from the introduction of skewness into a distribution is in the direction of the skew, i.e. positive skewness or skewness to the right increases the value of the mean.

Empirical studies by Pearson[1] showed that in moderately skewed distributions of continuous variables the median tended to fall around

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[1] Quoted in Croxton [1967, p.202, n.7].

two thirds of the distance from the mode toward the mean. This finding enabled the mode to be expressed in terms of the mean and median such that,

$$X_o = \bar{X} - 3(\bar{X} - X_{me}) \quad \ldots\ldots\ldots\ldots\ldots \quad (5.2)$$

and substituting for X_o in (5.1) above we get,

$$Sk_2 = \frac{\bar{X} - [\bar{X} - 3(\bar{X} - X_{me})]}{S}$$

$$= \frac{3(\bar{X} - X_{me})}{S} \quad \ldots\ldots\ldots\ldots\ldots \quad (5.3)$$

This is the more popular form of the Pearsonian skew co-efficient due to the greater accuracy which is normally associated with estimating the median relative to the mode. The interpretation which was placed on the sign and value of the Sk_1 co-efficient above also applies to the Sk_2 measure of skewness.

An alternative measure[2] of skewness can be derived by making use of the third moment about the mean which is given by

$$M_3 = \frac{\Sigma f_i(X_i - \bar{X})^3}{n} \quad \ldots\ldots\ldots\ldots\ldots \quad (5.4)$$

for a frequency distribution[3] where f_i is the absolute frequency of occurrence in the X_i^{th} time interval and $n = \Sigma f_i$. Dividing (5.4) by the cube of the standard deviation yields a *relative* measure of skewness, a_3, as presented in equation (5.5).

$$a_3 = \frac{M_3}{S^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.5)$$

As with the two co-efficients presented above, the sign and absolute value of the adjusted moment a_3 are considered representative of the direction and magnitude of skewness, where again a positive sign implies skewness to the right and a negative sign implies skewness to the left.

[2] There exist other measures based on quartiles and percentiles but they suffer from estimation problems and have therefore not been considered here - see Croxton *et al* [1967, p.205].

[3] See Hamburg [1970, p.220].

Having generated these co-efficients, a problem arises in placing some level of significance on any values for Sk_1, Sk_2 and a_3 which differ from zero. It was pointed out previously that the Sk_2 co-efficient is generally considered a more satisfactory measure of skewness than Sk_1 due to the superior accuracy of X_{me} compared with X_{mo} estimations. Another factor in its favour is that the Sk_2 distribution has a well-defined range of ±3.[4] By convention[5] values of Sk_2 between ±1 are taken to indicate only 'moderate' skewness. In order to apply objective significance level criteria to the acceptance or rejection of the hypothesis that a_3 equals zero, Pearson[6] prepared tables of the 0.10 and 0.02 critical values for a statistic similar[7] to a_3. The one major limitation of these critical levels, with respect to this study, is that they were based on samples drawn from a normal population. In this analysis, we are constructing frequency distributions based on the number of adopters within yearly time intervals, which is obviously a time series which at best could be considered a quasi-frequency distribution.

To treat such a discrete distribution as an approximation of the normal distribution, for the purpose of significance testing, could yield misleading conclusions. A more satisfactory approach is to apply less formal criteria to test for significant skewness. One such test which is conventionally used is to regard a distribution as 'noticeably' skewed whenever a_3 is greater than one-half in absolute terms.[8]

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4 For a proof that this is the appropriate range for Sk_2 values see Hotelling and Solomons [1932, pp.141-142].

5 See Kane [1968, p.85].

6 See Croxton *et al* [1967, p.620].

7 In this case M_3 was squared whilst in this study M_3 enters the a_3 estimation equation directly (re equation (5.5) above).

8 See Kane [1968, p.84].

5.2 THE MAGNITUDE OF SKEW

The values and sign of Sk_2 and a_3 for both Counties and Hundreds are presented in Tables 1 and 2 in Appendix B and summarized in Tables 5.1 and 5.2 below. Table 5.1 shows that the non-cumulative diffusion functions for all the Counties and Hundreds which were analysed failed to register simultaneously a_3 and Sk_2 values which were indicative of 'moderate' or 'noticeable' skewness when employing the conventionally adopted significance criteria. Of the twenty Hundreds studied, one half (10) revealed a lack of 'noticeable' skew with both a_3 and Sk_2 being non-significant. Of the remaining ten Hundreds, only one of the two measures pointed to the existence of 'significant' levels of skewness. Similarly, for the three Counties which were tested, the a_3 but not the Sk_2 measure indicated 'moderate' skewness. A discrepancy between these two measures is to be expected for, as Kane [1968, p.85] observed, 'since the numerators of Sk_1 and Sk_2 do not weight observations in the tails as heavily as M_3, the three co-efficients almost always differ somewhat.'[9]

It can therefore be concluded that in general[10] there is no clear-cut evidence that the pattern of diffusion of trace elements over time is 'significantly' skewed. On the basis of these results a more definitive statement concerning the symmetry property of the copper-zinc data would perhaps be tenuous. A sensitivity analysis will be undertaken in Section 5.4 below in order to investigate this matter more closely.

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9 Note that in the 14 County and Hundred regions for which only one of the skew measures was significant, it was primarily the a_3 and not the Sk_2 coefficient which was significant.

10 That is at either lower (e.g. Hundreds) or higher (e.g.County) levels of spatial aggregation.

TABLE 5.1

Significance of Skewness Measures (a_3 and Sk_2) at both the Hundred and County Level.

	a_3 and Sk_2 both sig.	a_3 and Sk_2 both not sig.	a_3 sig. Sk_2 not sig.	a_3 not sig. Sk_2 sig.
No. of Counties N = 3	-	-	3	-
No. of Hundreds N = 20	-	10	9	1

TABLE 5.2

Sign of Skewness Measures (a_3 and Sk_2) at both the Hundred and County Level

	a_3 positive Sk_2 positive	a_3 negative Sk_2 negative	a_3 positive Sk_2 negative	a_3 negative Sk_2 positive
No. of Counties N = 3	-	3	-	-
No. of Hundreds N = 20	4	12	-	4

5.3 THE DIRECTION OF SKEW

An inspection of the data summarized in Table 5.2 is useful in deciding whether the observed skewness was consistent in terms of its direction. Approximately sixty-five per cent (i.e. 15) of the regions studied (i.e. Hundreds plus Counties) simultaneously gave negative a_3 and Sk_2 estimates, which thereby suggests that the distribution is skewed to the left. However, this conclusion must be tempered by the fact that one half of the remaining Hundreds had positive a_3 and Sk_2 estimates, an indication of skewness to the right. The residual Hundreds presented largely conflicting evidence in that the weighted third moment about the mean bore a negative sign whilst the Pearsonian co-efficient of skewness (Sk_2) was positive.

5.4 A SENSITIVITY ANALYSIS

The data on which the a_3 and Sk_2 estimates are based is limited to the period 1939-40 to 1951-52. This has the effect of truncating many of the temporal (non-cumulative) frequency distributions such that the right hand (R.H.) tail of the distributions is not fully developed. Given that skewness measures by their very nature are orientated towards emphasizing the polar frequencies, it was not clear how this uneven truncation would influence the estimates of skewness, although the choice of distributions on which to calculate these estimates used criteria aimed at minimizing the degree of truncation.[11]

As an approximate measure of the influence that such 'uncompensated' truncation exerted on the a_3 and Sk_2 calculations, the *left hand (L.H.) tail* of the distributions was itself truncated by successive years from t = 1 to t = 4 and a figure for a_3 and Sk_2 was re-calculated for each remaining set of adoption frequencies. The rationale for undertaking this form of sensitivity analysis is that the removal of

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[11] See Footnotes of Tables 1 and 2, Appendix B.

successive yearly intervals from the left hand tail of the distribution will tend to increase the values of the mean and median whilst leaving the modal value unaltered. Such a result parallels the effect that the *addition* of extreme frequencies to the R.H. tail would induce on the mean, mode and median calculations. Given that the sign and, to a large degree, the absolute value of the Pearsonian coefficients are directly influenced by the relative magnitude of these three measures of central tendency, it is evident that this L.H. truncation procedure will provide a rough insight into the influence of additional extreme frequencies to the right hand tail of the distribution on the Sk_2 estimates. This truncation also tends to mimic the influence of extending the right hand extremity of the distribution on the a_3 estimate of relative skewness.

Although L.H. truncation parallels the effect of augmenting the R.H. tail of the distribution for the numerator calculations of Sk_2 and a_3, the effect of truncation on the denominator of both measures of skewness is opposite to the effect which would be achieved by augmentation. Truncating tends to *decrease* the standard deviation whilst augmentation acts to increase it. Hence, for the denominator of the skew measure, L.H. truncation is operating to *increase* the a_3 and Sk_2 estimates whereas R.H. augmentation would be tending to *decrease* both measures.[12] It can therefore be concluded that any *decrease* in either the a_3 or Sk_2 values resulting from truncation would need to be amplified to some extent to represent more accurately the influence of augmentation on these skew estimates.

The evidence presented in Table 5.3 lends support to the implied hypothesis that the right hand truncation of the adoption distribution (due to data constraints) resulted in more distributions exhibiting 'significant' levels of skewness than would otherwise have

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[12] Its effect would be greater on a_3 than Sk_2, for in a_3 it is the standard deviation cubed, not just the standard deviation, which is entered as a denominator in the calculation.

been the case. All of the County a_3 and Sk_2 estimates became non-significant, whilst the number of Hundreds which simultaneously exhibited a_3 and Sk_2 values which lacked significance, increased from ten (see Table 5.1) to thirteen. Only one Hundred moved into a situation where both a_3 and Sk_2 indicated significant skew as successive yearly time intervals were truncated from the left hand tail of the observed frequency distribution. If allowance for the fact that the L.H. truncation procedure employed in this sensitivity analysis tends to under-estimate the denominator in both skewness measures, (with respect to the addition of extreme frequencies to the R.H. tail - the process we are attempting to mimic), then the possibility of even more non-significant skew values being achieved cannot be ruled out.

The data in Table 5.4 indicates that the sign on the a_3 and Sk_2 estimates is even more sensitive to the lack of frequencies in the extremity of the right hand tail than were their absolute values. Simultaneously positive values of a_3 and Sk_2, indicative of positive skewness, increased from a total (i.e. Counties plus Hundreds) of four in Table 5.2 to sixteen in Table 5.4, whilst the number exhibiting negative values for both the skew estimates dropped from fifteen to two. This result makes it unwise to draw any firm conclusions with regard to the general direction of skewness. However, the lack of overall significance in the magnitude of skewness indicated by the results in Table 5.3 precludes the necessity of any such conclusions being drawn for the purposes of this study.

5.5 CONCLUSIONS

Given the conventional rule of thumb method which was used to determine significance, along with the truncated (quasi) distributions on which the calculations were performed, these tests of skewness must be interpreted with a degree of caution. Despite these reservations, it has been argued above that the data presented lends support to the

TABLE 5.3

Significance Sensitivity of Skewness Measures (a_3 and Sk_2)at both the Hundred and County Level following L.H. Truncation.

	No.of Counties N = 3	No.of Hundreds N = 20
Both a_3 and Sk_2 remained or became non-significant	3	13
Either a_3 or Sk_2 remained or became non-significant	-	6
Both a_3 and Sk_2 remained or became significant	-	1

TABLE 5.4

Sign Sensitivity of Skewness Measures (a_3 and Sk_2) at both the Hundred and County Level following L.H. Truncation.

	No.of Counties N = 3	No.of Hundreds N = 20
Both a_3 and Sk_2 remained or became positive	2	14
Both a_3 and Sk_2 remained or became negative	-	2
a_3 and Sk_2 remained or became opposite in sign	1	4

hypothesis that in general, the cumulative diffusion curves for trace elements are *not* noticeably skewed. This conclusion engenders confidence in our ability to utilize symmetric logistic formulations whose parameters will not be significantly biased due to the symmetry constraints of the fitted functions.

CHAPTER 6

INTER-REGIONAL PARAMETERS OF ADOPTION: THEIR DERIVATION

6.1 INTRODUCTION

The evidence presented in the previous chapter on the degree of skewness in the observed intra-regional adoption patterns, lends credibility to the use of symmetric (temporal) diffusion curves in an attempt to quantify the adoption of copper-zinc technology. The precise technique of analysis will initially involve fitting a symmetric logistic to the temporal adoption patterns within each geographic region of analysis, the parameters of which will be taken to summarize particular aspects of the diffusion process. Multiple regression analysis will then be employed with the aim of elucidating the prime factors associated with cross sectional variation in the diffusion of trace element technology.

Although this approach obviously has its roots in the 1957 study by Griliches on the diffusion of hybrid corn technology, a critique[1] of several aspects of his work will be incorporated into the analysis below.

6.2 FITTING THE LOGISTIC

The specific form of the logistic applied in this study is given by

$$P_{tj} = \frac{K_j}{1+e^{-(a_j+b_jt)}} \qquad \text{..........} \qquad (6.1)$$

where P_{tj} is the percentage of copper-zinc adopters in region j for year t (see chapter 4 for details concerning this variable),

K_j is the ceiling or equilibrium value for the j^{th} region,

a_j is the y intercept,

b_j is the overall slope or rate of growth co-efficient, and

[1] The critique will centre on aspects of a general methodological nature as well as those peculiarities of Griliches' study which are not wholly applicable to the present analysis.

t is the time variable measuredin years from 1939/40.

The initial step in fitting equation (6.1) to the observed data involves estimating the ceiling value K. Griliches [1957, p.504] 'crudely' estimated K by plotting the percentage planted to hybrid seed on logistic graph paper and varying K until the resulting graph approximated a straight line. Unfortunately this statement is to some extent misleading. Earlier in his study, Griliches [1957, p.504] had defined P_t as 'the percentage [of land] planted with hybrid seed', which is assumed to be the ratio of hybrid corn acreage in year t to total corn acreage. K on the other hand was defined[2] as the 'maximum' hybrid corn acreage over total corn acreage where total corn acreages were taken to be constant.

Clearly, the observed value of P_t is unaffected by variations in the value of K (achieved by varying the 'maximum' hybrid corn acreage). It appears therefore that Griliches estimated K by plotting P_t/K rather than P_t against time on'logistic' graph paper,[3] which it is assumed gives a linear transform[4] of $\frac{1}{1+e^{-(a_j+b_jt)}}$.

Given the sensitivity of all subsequent parameter estimations to the calculated value of K, it was felt that the Pearl-Reed method[5] of estimating K offered a lower degree of subjectivity[6] than Griliches

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2 See Griliches [1957, pp.519-520].

3 Although we were unable to secure any 'logistic' graph paper, it was observed that arithmetic probability paper has been used for the same purpose. See Croxton and Cowden [1946, pp.458-460].

4 He did not explicitly state that this was the precise mathematical form of the transformation achieved by plotting P_t/K on 'logistic' graph paper. However, a close reading of his article implies that this is the transformation so achieved.
By dividing both sides of equation (6.1) by K_j we obtain

$$P_{tj}/K_j = \frac{\text{Hybrid corn acreage in year t}}{\text{total corn acreage}} \Big/ \frac{\text{Maximum hybrid corn acreage}}{\text{total corn acreage}}$$

$$= \frac{\text{Hybrid corn acreage in year t}}{\text{Maximum hybrid corn acreage}} = \frac{1}{1+e^{-(a_j+b_jt)}}$$

5 For a detailed summary of this method see Pearl [1924, pp.576-581] or Davis [1941, pp.216-218].

6 Care must still be taken when choosing the points P_0 P_1 and P_2 (below) to ensure that they are characteristic of the data to which the logistic curve is to be fitted.

essentially 'trial and error' method.[7] The technique involves selecting three equally spaced points in time which are deemed to be characteristic of the data to which the function is to be fitted. By substituting these three points, $(0,P_0)$, (t_1,P_1), $(2t_1, P_2)$, into the (natural) logarithmic transform of equation (6.1), given by

$$\log_e \left(\frac{P_{tj}}{K_j - P_{tj}}\right) = a_j + b_j t \qquad \text{..........} \qquad (6.2)$$

and solving the three simultaneous equations thereby generated, we can express K in terms of P_0, P_1 and P_2 such that,

$$K_j = \frac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2} \qquad \text{..........} \qquad (6.3)$$

Having derived K_j there now exist several[8] methods of estimating the parameters a_j and b_j. Because of its computational ease and relative[9] degree of accuracy, the method employed requires substituting K_j values into (6.2) above and solving by least squares analysis for a_j and b_j. The estimated values of K_j, b_j and R^2 are presented for Hundreds in Table 6.1, and Counties in Table 6.2 below. Only 11 out of a possible 49 Counties gave adoption patterns from which it was considered possible to estimate these adoption parameters with any degree of accuracy.[10] Likewise, estimatable adoption parameters are restricted to 34 Hundreds or Hundred aggregates.[11]

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7 This is how Kennedy and Thirlwall [1972, p.60, n.1] describe Griliches' method.

8 See Croxton *et al.* [1967, p.275].

9 This technique (which was also employed by Griliches [1957], Mansfield [1961] and Powell and Roseman [1972]) uses all the observed P_{ij} values for each region whilst the technique presented in Croxton uses only 2 of the P_{ij} values.

10 See Appendix A for a description of the criteria on which these choices were made.

11 See Appendix A for an outline of the reasons underlying the decision to aggregate some Hundreds.

Table 6.1

Diffusion Parameters by Hundred

Hundred	Origin[i] (or lag in acceptance) in years	Rate of Adoption, b_j	Ceiling, K_j	R^2
Willunga[ii]	2	.74	.26	.98
Price	6	.97	.52	.97
Stirling	3	.48	.78	.97
Tatiara	2	.56	.72	.96
Wirrega	7	1.25	.28	.95
Coombe	2	.65	.88	.97
Dudley	2	.29	.96	.94
Menzies	1	.51	.99	.90
Bews	6	1.0	.26	.83
Pinnaroo	8	2.0	.28	.97
Cummins	3	.78	.55	.92
Lincoln	2	.55	.58	.96
Blanche	2	.66	.43	.97
Gambier	3	.79	.14	.95
Grey	6	.61	.45	.97
Hindmarsh	3	1.0	.38	.99
Kongorong	5	1.10	.47	.95
Macdonnell	2	.67	.43	.95
Mt. Muirhead	1	.75	.56	.99
Penola	2	.64	.55	.97
Rivoli Bay	3	.69	.45	.98
Young	7	1.10	.22	.89
Encounter Bay	2	.61	.37	.99
Goolwa	3	.61	.26	.98
Myponga	6	.76	.15	.99
Nangkita	2	.66	.34	.95
Strathalbyn	6	.57	.27	.98
Binnum	6	.84	.40	.99
Shannon	8	.51	.66	.99
Comaum	2	.73	.52	.95
Joyce	6	1.10	.47	.97
Naracoorte	2	.79	.54	.96
Waterhouse	2	.49	.71	.95
Seymour	2	.44	.19	.96

(i) Origin = years to first usage as measured from 1939/40.

(ii) Due to data constraints, Willunga is actually a Council District and not a Hundred. Both areas are of compatible size and geographic location.

Table 6.2

Diffusion Parameters by County

County	Origin (or lag in acceptance) in Years	Rate of Adoption, b_j	Ceiling, K_j	R^2
Buccleuch	2	.45	.75	.97
Buckingham	2	.62	.81	.97
Cardwell	2	.63	.60	.99
Carnarvon	1	.44	.72	.90
Chandos	6	1.36	.16	.93
Flinders	2	.65	.34	.96
Grey	1	.81	.43	.99
Hindmarsh	2	.63	.24	.99
Musgrave	2	.60	.33	.94
Robe	1	.56	.79	.96
Russell	2	.40	.30	.96

See footnotes to Table 6.1

The R^2 presented in tables 6.1 and 6.2 compare favourably with those obtained by Griliches [1957, p.506 and pp.508-9] and Romeo [1977, p.66]. However, such uniformly high R^2s, as Griliches [1957, p.505, n.13] warns, 'should be taken with a grain of salt' as they 'are the R^2s of the transform rather than of the original function and give less weight to the deviations in the centre.' Despite this qualification, he [1957, p.505, n.13] also suggested that 'an examination of the original data indicates that they are not a figment of the fitting procedure.' Similar assertions appear appropriate for the diffusion patterns presented for this study in Appendix C.[12]

6.3 PARAMETERS OF ADOPTION

The next stage in the analysis requires that the appropriate parameters which are considered representative of the (intra) regional adoption patterns be determined. Griliches' pioneering 1957 study set many of the guidelines in this area, and his choice and interpretation of representative parameters have been incorporated into many diffusion studies more or less unaltered for the past 20 years.[13] The three parameters around which Griliches' study centered were,

(1) the *origin* which represented the date at which an area began to plant 10 per cent of its ceiling acreage with hybrid corn and was given by $\frac{-2.2-a_j}{b_j}$ when measured from 1940,

(2) the *rate of acceptance* (or *slope*) co-efficient which was self-evidently considered a measure of the average rate of adoption of hybrid corn and is equal to b_j and,

(3) the *ceiling* estimate (K) which was interpreted as the long-run equilibrium percentage of corn acreage which was planted to hybrid seed.

Additions to these measures of adoption were undertaken by Powell and Roseman in 1972, their stated reason being that,

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[12] The same visual appraisal seems less convincing in Mansfield's [1961, p.743] case.

[13] For a recent example see Romeo [1977].

> Rather than using vague temporal 'stages' we derived several specific parameters of the curve and analyzed them statistically.[14]
>
> [Powell and Roseman, 1972, p.222]

The six parameters which they calculated in order to characterize the diffusion of soybean production across the State of Illinois included the (1) origin value (production level at origin date 1929); (2) take-off point (date when 10 per cent of ceiling production was reached); (3) overall slope (b value of best fit logistic equation); (4) date of maximum slope (value of t when second derivative of the logistic equals zero); (5) maximum slope (slope of best fit curve at the inflection point); (6) ceiling level (highest production value between 1944 and 1954 - entered as K in their logistic equation).

The important contribution of their paper lay in their appreciation and investigation of the degree of *inter-dependency* of these six representative parameters. By the use of factor analysis they observed that the maximum slope and ceiling parameters showed a close association to the latter stages of the adoption curve, whilst the remaining four parameters (which included their origin and average rate of acceptance measures) indicated a mutual orientation towards the earlier portions of the curve.

The implication which their results suggest is that the ceiling can be taken as representative of one dimension of the adoption process, whilst the origin and (average) rate of acceptance parameters are both essentially representative of an alternative dimension of the process. Such a conclusion can possibly be attributed (in part) to the measures of the ceiling, slope and origin which they employed. Nevertheless, it does draw attention to the issue of whether or not it is justifiable to assume that these three parameters are in fact independent.

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[14] It seems that the reference to vague temporal stages related to the origin, rate of acceptance and ceiling parameters of Griliches. If such was the case, it is evident from the six parameters they employed (and which are described above) that they are guilty of the same 'sin'.

When confronting this issue Griliches [1957, p.505] stated that,

> The values of the different parameters are not necessarily independent of each other, but for simplicity will be considered separately.

It is doubtful if an appeal to simplicity is adequate justification for adopting this approach. Indeed, it is obvious from an inspection of equation (6.2) that in a mathematical sense the estimated value of b_j, the rate of acceptance measure, (and a_j) is directly dependent on the pre-determined value of K_j which is employed in the estimation procedure. Given that the formula offered above for Griliches' origin estimate is a function of both a_j and b_j, it can be concluded that his origin estimates are also dependent (although in a less direct sense) on the estimate of K_j which is used.[15]

Having also derived a_j and b_j estimates in this study by subjecting equation (6.2) to least squares analysis, it was concluded that it was not possible to proceed satisfactorily using the assumption of independence for the three Griliches-style adoption parameters. A satisfactory solution to this problem was attempted in two ways. Firstly, with the evident strong mathematical relationship between b_j and K_j it was decided to collapse these two parameters together such that mb_j(modified b_j) = b_jK_j.

Such action is tantamount to weighting the rate of acceptance coefficient, b_j, by variations in ceiling (K_j) levels, which has the advantage of making the rates of adoption more satisfactorily comparable between regions by translating the b_js back into actual percentage units from percentage of ceiling units. In fact, Griliches [1957, p.517] recognized this point and on that basis used mb_j rather than b_j as a dependent variable in his subsequent investigations of inter-regional variations in the rate of acceptance.

In contrast to Griliches, we will not pursue an enquiry into the inter-regional variations in K_j, having already incorporated it in

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[15] In an unpublished paper (received at the conclusion of this study), Dixon [1977] reaches a similar conclusion.

the mb_j measure. Such an omission would not appear to restrict significantly the analysis, as the mathematical relationship between b_j and K_j manifests itself in Griliches' study with the observation that,

> ...it is possible to explain a respectable proportion of their [ceilings] variation with the *same* "profitability" variables that were used in the analysis of *slopes*.
>
> [Griliches, 1957, p.520].

The second solution to the problem of parameter interrelationships required that an origin measure be derived which was independent of the fitted logistic curve. Fortunately in this study such a requirement was not only possible but also compatible with respect to *a priori* reasoning as to the interpretation which should be placed on an origin measure.

It seems appropriate to consider the origin measure as an attempt to characterize the activity of a regional *innovator* whilst the rate of acceptance co-efficient is a summary measure of the actions of regional *imitators*. The conceptualization of the process of technical change as a series of stages involving invention, innovation and imitation, found its genesis in the seminal work by Schumpeter.[16] This approach has been subject to criticism, generally on the grounds that it fails 'to emphasize the interdependent nature of all the steps of a time sequence.' [Johnston, 1966, p.160].

Despite this criticism, it has been observed that, whilst technological change may in reality consist of a continuum of interrelated events it,

> ...may best be analysed by breaking down the process into a number of component steps which might generally be regarded as ordered in the sense that a strong likelihood exists that these events will follow one after the other.
>
> [Hastings, 1974, p.10].

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16 See Schumpeter [1934, ch.2].

Following Mansfield's [1969, pp.99-100] approach, a quite narrow concept of regional innovator will be employed which requires that an innovator be the firm (or farm) 'that is *first* to apply the invention' (my emphasis). Here, this is taken to be the first purchaser of either copper, zinc (or a combination of both) in each geographic unit of analysis. By default, all other purchasers are classified as imitators. The origin is therefore measured by the lag (in years) between the year of first commercial availability (1939/40) and the year of first usage within each region.

This definition is desirable for two important reasons -

(1) It meets the objective of an origin measure which is independent of the fitted logistic, and

(2) it avoids the degree of arbitrariness which Griliches [1957, p.507] introduced into his origin measure which was defined as 'the date at which an area began to plant 10 per cent of its ceiling acreage with hybrid seed.'

He [1957, p.507] argued that the '10 per cent date was chosen as an indicator that the development had passed the experimental stage and that superior hybrids were available to farmers in commercial quantities.' Such an approach was considered necessary, in that hybrid corn was not a single development to the extent that varieties exhibited varying degrees of location specificity and therefore different varieties needed to be developed for different localities.[17]

However, in the case of copper-zinc technology, following the initial breaks-through by Riceman and Anderson around the late 1930s and early 1940s, the provision of a high level of locality specific research was not an *essential* precursor to the adoption of the innovation. This is not to deny the need for a certain level of local experimentation. Indeed, although the bulk of the experimental work was undertaken by publicly funded research organizations,[18] there was still a requirement

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[17] See Griliches [1957, p.502].

[18] In particular, C.S.I.R. and the Waite Agricultural Research Institute were responsible for much of the basic and some of the applied level research.

for adopters to determine (often by small on-farm trials)[19] both the trace element mixture and concentration which was best suited to their particular circumstances.

The information gathering and evaluation by trace element adopters which this requirement implies, highlights the management aspect of adoption which was incorporated into the discussions presented in chapter 3. It is also interesting to note that Ryan and Gross [1943, pp.18-19] observed that on-farm experimentation with respect to hybrid corn adoption was commonplace (relatively more so amongst innovators and early adopters than later users) with the statement that,

> The acceptance of hybrid [corn] was far from a conversion; individual and time consuming self-demonstration was required even after visible evidence and objective comparisons were readily available to all.

These summary measurements of regional origins and rates of acceptance are the two dependent variables around which the following multiple regression analysis will centre.

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19 Such local, small scale experimentation appears common with innovations which are in some sense 'divisible'. See Norris and Vaizey [1973, p.99].

CHAPTER 7

AN 'EXPLANATION' OF INTER-REGIONAL VARIATIONS IN ADOPTION PARAMETERS

7.1 INTRODUCTION

Having now quantified the observed adoption pattern of copper-zinc technology, this chapter will focus on those factors which are deemed to 'explain' inter-regional differences in both the origin and rate of adoption measures.

Attention will initially be given to the supply-demand aspects of trace element usage, followed by a consideration at the conceptual level, of the principal 'explanatory' variables. Finally, the attempts made by this study to transform these conceptual variables into quantified entities and incorporate them into a multiple regression analysis will be detailed.

7.2 'EXPLANATORS' OF INTER-REGIONAL DIFFERENCES IN ADOPTION PATTERNS: THE THEORY

7.2.1 Supply vs. Demand: The Identification Problem

From the discussion in the previous chapter, it follows that on-farm trials can be viewed as part of the cost of adopting copper-zinc technology. It is therefore appropriate that the reference point for origin calculations be the date of first commercial availability (i.e. 1939/40). Implicitly, this presumes that from this date, copper-zinc fertilizers were *potentially* available to all areas of the State *simultaneously* and that any lags in usage with respect to this date, reflect a lag in 'acceptance' rather than a lag in 'availability'.[1]

In other words, it is the demand rather than the supply of copper-zinc fertilizers which places the primary restrictions on the observed pattern of inter-regional variations in the origin measures.[2] An

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1 These terms were first used by Griliches [1957, p.507].

2 This can be interpreted as implying that the long run supply curve for copper-zinc fertilizers is highly elastic.

investigation of the supply conditions pertaining to copper-zinc fertilizers at the time of this study confirms this assertion. Although superphosphate fertilizers were in restricted supply due to the outbreak of World War II, it was the tonnage per user, rather than the total number of users which was the immediate subject of restraint.[3] Given that the relevant numeraire of adoption is the number of copper-zinc adopters per year per region, it is therefore felt that the war restrictions did not significantly influence the observed diffusion of copper-zinc technology.

A resolution of the identification problem in Griliches' hybrid corn study was not as forthcoming. The necessity of having to breed adaptable hybrids for each particular area meant that he [1957, p.502] was required to explain 'differences in the rate of adoption of hybrids by farmers - the "acceptance" problem - ...[*and* lags] ... in the development of adaptable hybrids for specific areas - the "availability" problem.' This meant that Griliches' study could not limit itself as readily as the present investigation to a consideration of the demand or "acceptance" aspects, but was required to examine the supply or "availability" factors also.

This requirement introduced a level of arbitrariness into Griliches' analysis, where variations in the origin were identified with supply factors and variation in slopes with demand factors. Following the development of a suitable hybrid for a given region, he supported his demand orientated analysis of acceptance rates by quoting Ryan [1948, p.273], who observed that any constraints on supply which did exist 'operated more as a potential than an actual limitation upon the will of the operator, and that [the] rapidity of adoption approximated the rate at which farmers decided favourably upon the new technique.' However, the site specificity of the hybrid technology meant that supply factors were also operating to determine adoption patterns, at least in the early stages of adoption within a particular region.

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[3] Pers. com. with manufacturer representatives; March 1977.

In the view of people associated with the marketing of fertilizers in South Australia, few farmers were denied the opportunity to use trace elements due to a lack of availability. The demand orientation of the variables used to 'explain' inter-regional variations in *both* the origin and rate of acceptance measures therefore seems reasonable.

7.2.2 The Determinants of Adoption

Debate[4] over the relative importance and veracity of economic versus sociological factors as 'explanatory' variables of the diffusion process, was initiated following the publication of Griliches' 1957 hybrid corn study. Griliches' stance on the matter was modified from his original [1957, p.522, n.45] statement that,

> It is my belief that in the long run, and cross-sectionally these [i.e. the sociological] variables tend to cancel themselves out, leaving the economic variables as the major determinants of the pattern of technological change.

to his concluding remarks on the debate several years later that,

> If one broadens my 'profitability' approach to allow for differences in the amount of information available to different individuals, differences in risk preferences, and similar variables, one can bring it as close to the 'sociological' approach as one would want to.
>
> [Griliches 1962, p.330].

The present study will employ this rather broad concept of profitability and recognizes that by so doing largely reduces the economic versus sociological debate to one of semantics rather than substance. The fact that adoption is also viewed as one aspect of the management process further supports this approach, as management students have traditionally married the domain of the economist and the sociologist in an attempt to promote further understanding within their field of interest.

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[4] The participants in this debate were given in footnote 1, Chapter 3.

Quite a large array of variables has been used in empirical analyses of the diffusion process in an attempt to explain either inter-regional or inter-industry differences in adoption levels. Whilst many investigations, including Mansfield [1961], Hsia [1973], Nabseth [1973] and Romeo [1975, 1977], have concentrated on comparative inter-industry studies in the non-farm sector, the number of inter-regional studies in the farm sector is less voluminous. Geographers such as Hagerstrand [1966], have attempted to model the spatial diffusion of innovations, but Griliches' [1957] study stands alone as the major published investigation into the determinants of observed differences in *temporal* adoption patterns *between* regions.

With the choice of relevant 'explanatory' variables already limited to those concerned with the demand aspects of copper-zinc usage, it is obvious that by deciding to undertake this analysis in the Griliches' tradition, the choice is further constrained to consider only those factors which exhibit a degree of inter-regional variation.

In conceptual terms, the demand for copper-zinc fertilizers by both *innovators* and *imitators*, as reflected in our origin and rate of acceptance estimates respectively, can be considered a function of three principal factors, namely; profitability, risk and information acquisition and assessment. A discussion of these three factors as they relate to the use of copper-zinc technology will be detailed below.

1. Profitability

In sympathy with Griliches' approach, it is hypothesised that the demand for copper-zinc fertilizers is a function of the (absolute) increase in profitability which the use of these fertilizers entails. As Griliches [1957, p.516] observed,

> This hypothesis is based on the general idea
> that the larger the stimulus the faster is the
> rate of adjustment to it.

It is perhaps important to emphasize that this hypothesis does not attempt to 'explain' the mechanism by which this stimulus induces a farmer to adopt. To do so would be to attempt an 'explanation' of the actual ~~diffusion~~ adoption process, a task which is considered beyond the ambit of this study.[5]

The specific relationship between profitability and the two measures of adoption employed in this study is that increased profitability will be inversely related to the origin or lag in acceptance measure, and directly related to the rate of acceptance estimate. The empirical variables which, in the case of trace element technology, have been used by this study to quantify this increased profitability, will now be considered.

(a) Soil Index:

It has been wide practice amongst economists to perceive the role of biological and chemical innovations as one of augmenting the contribution of land as a factor in agricultural production.[6] Trace element fertilizers are a significant form of chemical technology, and in this respect can therefore profitably be viewed in terms of the increase in land productivity which their usage promotes. This increase in land productivity and hence (per acre) profitability is directly dependent on various soil characteristics. These include such factors as soil type, acidity and depth.

Only data on soil type was available with the scope of geographical coverage required for this study. The response of various soils to the addition of copper-zinc fertilizers based only on soil type characteristics, is therefore best considered as a first approximation to the actual response which would be observed for a particular soil in any given area. The details concerning the construction of this soil index are given in Appendix D. In broad terms, the index is an attempt to rank soil types

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5 To attempt such an 'explanation' would require farm level data.

6 Extensive use of this perception of the impact of biological and chemical innovations was made by Hayami and Ruttan [1971].

on the absolute increase in either cereal or pasture production which the addition of copper-zinc fertilizers would induce. Soil types were therefore placed in one of five categories, namely, high, high-medium, medium, medium-low or low.

This approach implies that the higher the level of response (in absolute terms), the greater is the stimulus to adopt. However, the ranking alone was not sufficient to allow for comparisons between different geographic regions. To meet such a requirement, the proportion of each geographic unit which was covered by soil in each of the five response categories was determined (see Appendix D). This percentage figure subsequently entered the regression analysis as the independent variable which proxied the effect of inter-regional variations in soil type on the increased profitability associated with copper-zinc adoption.

The implicit hypothesis is that higher proportionate areas of higher response soils will be inversely related to the lag in acceptance and directly related to the rate of adoption. Conversely, higher proportionate areas of lower response soils will be directly related to the lag in acceptance and inversely related to the rate of adoption.

(b) Average Rainfall:

Another environmental factor that, along with soil type, may exhibit a cross-sectional influence on the degree of profitability increase associated with trace element adoption, is climate. Of the numerous climatic influences which are undoubtedly relevant, rainfall has been used as a representative measure due to its obvious importance[7] and the relative ease of data availability.[8] Climatic influences have been proxied by rainfall measures in the past, by studies such as Young's [1971] analysis of productivity growth in Australian rural industries. Here a rainfall

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7 Especially in South Australia, which on an international scale has the 'distinction' of being the driest state (on average) in the driest continent.

8 See Appendix D for a discussion of the source of rainfall data.

index was used in an attempt to explain some of the temporal fluctuations in an estimated productivity index. The present study is similarly concerned with fluctuations in (trace element) productivity but in a cross-sectional, rather than temporal sense.

It is hypothesized that within the range of yearly rainfall levels observed for this study, the growth (and ultimately the profitability) response from copper-zinc usage is directly related to the absolute level of rainfall. The cross-sectional nature of this analysis restricts the choice of variable to a single measure per region. The mean level of yearly rainfall totals[9] was chosen as the variable which represents the mean (or long-run) expected profitability increase, which is a result of the influence of rainfall on the observed inter-regional differences in copper-zinc response.

The average rainfall and soil index variables in fact proxy the *potential* profitability increases resulting from the use of copper-zinc fertilizers as opposed to measures of profitability increases based on observed output changes. Such measures are encumbered to the extent that they are estimates of profitability responses which are influenced not only by technological factors (the direct concern of this measure), but by management factors as well.[10]

(c) <u>Steely Wool:</u>[11]

Copper-zinc fertilizers not only increased the output of cereal and pasture acreages, (which was directly reflected in carrying capacities) but had a marked qualitative effect in its control of a widespread problem known as steely wool. Steely wool was the name given to wool fleeces which exhibited a poor level of crimp development or, in extreme cases, the

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9 A yearly figure captures the total effect of rainfall on both cereal *and* pasture growth.

10 For example, farmers may not be pursuing profit maximizing goals which may therefore result in sub-optimal stocking rates.

11 See C.S.I.R.O. [1976, pp.11-12] for a pictorial example of steely wool.

development of waves rather than crimps. This had a significant influence on profitability in that fleeces exhibiting such poor crimp development could only be sold at heavily discounted prices.[12]

A measure of the inter-regional variation in the incidence of steely wool was constructed by referring to data collected in 1948 by Lee.[13] The hypothesis subsequently tested was that the percentage area of each geographic region of analysis for which evidence of steely wool occurrence was recorded, would be directly related to the lag in acceptance and inversely related to the rate of adoption.

2. Risk.

A consideration of risk is central to much of the current work being undertaken with respect to agricultural decision analysis.[14] Agricultural decision-making is characterised by uncertainties in relation to the level of output, product prices and consequently, farm income. The statement made earlier in this study[15] that the adoption of an innovation is simply another facet of the management decision-making process, allows for explicit recognition of these uncertainties as they relate to decisions concerning the introduction of a new farm technology such as copper-zinc fertilizers.

The risk associated with the increased level of farm output (and ultimately profitability) resulting from the adoption of copper-zinc technology[16] is thought to be primarily a function of climatic variability.[17] The principal climatic variable which will be used to

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[12] See C.S.I.R.O. [1976, p.14].

[13] See Appendix D for details concerning the construction of this index.

[14] See Anderson *et al.* [1977].

[15] See Section 3.3.

[16] In fact, the output change is only one dimension of the risk associated with adopting the new technology. Uncertainty may also exist with respect to the per unit price that will be obtained for the post-adoption output.

[17] See Anderson [1972, p.1] where he states that, 'Risk is important in Australian agriculture because of the generally high climatic variability.'

estimate the level of risk in respect to the realization of such profitability gains, will be the variability of rainfall. Again, this variable has appeal in terms of the ready availability of State-wide rainfall statistics along with the fact that rainfall, especially in the South Australian agricultural scene, constitutes one of the prime limiting (environmental) factors in terms of pasture and cereal growth. Therefore it is likely that rainfall variability would figure predominantly in most farmers' notions of risk.

It has been recognized[18] that perhaps the most appropriate measure of risk would be based on farmers' own perception of the degree of risk associated with the adoption of trace element fertilizers. Given the unavailability of such data, an estimate of the level of risk associated with the attainment of a mean or expected profitability response for each region of analysis, following the use of copper-zinc fertilizers, was required. Despite its limitations,[19] the variance of yearly rainfall totals per region was chosen as the representative risk estimate where increases in the variance measure are taken to indicate increases in the level of risk associated with adoption.

The discussion to date has dealt only with the *degree* of risk associated with the new technology. In order to give a consideration of risk any operational content, the *attitude* which decision-makers display towards risk needs to be made explicit. Aggregate level studies such as this have much difficulty when confronted by this aspect, as most of the theoretical discussion of risk propensities is at the level of the firm or individual adopter unit. The absence of any information concerning farmers' risk propensities which are of relevance for this study requires that these attitudes to risk be established by assumption. Such an approach has many antecedents in aggregate studies which have attempted

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[18] See Anderson [1972], Roumasset [1974] and Menz [1975].

[19] See Anderson [1972, p.5].

to endogenise the notion of risk. By far the most widely employed assumption is that *all* farmers are risk averse.[20] Applying this assumption to the present study, it is hypothesized that higher levels of rainfall variability (and therefore higher levels of risk) act to inhibit the adoption of the new fertilizer technology. As the levels of risk are being compared cross-sectionally, it is subsequently hypothesized that those regions in which the risk is highest will be associated with *greater* lags in acceptance and *lower* rates of adoption.

However, such conclusions, based as they are on a risk aversity assumption, must be tempered by the evidence of 27 studies cited by Rogers and Shoemaker [1971, p.366] of which 73 per cent support the hypothesis that 'earlier adopters have a more favourable attitude toward risk than later adopters.' Applying these observations to this study, it may be asserted that innovative behaviour is characterised by risk preferring farmers, whilst imitative behaviour is characterized by risk averse farmers. If such were the case, the above hypothesis may then be modified to read that those regions in which the risk is highest will be associated with *shorter* lags in acceptance and *lower* rates of adoption.

Finally, it is necessary that a peculiarity of cross-sectional investigations of risk be discussed. It may be possible that in the long run those farmers who are risk averse would settle in the areas with more reliable rainfall, leaving the more marginal areas to those farmers who in a *relative sense* are risk preferrers. It is therefore possible that *both* innovators and imitators within a region of high rainfall variability are risk preferrers when compared with the potential adopters in an area of lower rainfall variability. Restating our hypothesis in the light of this possibility would require that those regions in which the risk is highest be associated with *shorter* lags in acceptance and *higher* rates of adoption.

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20 Dillon and Anderson [1971, p.31] state that the conventional wisdom in this area is that new techniques and inputs are viewed by farmers as risky, *and* furthermore that farmers are risk averse. For example, Dalton and Lee [1975, p.231] hypothesize that *all* woolgrowers are risk averse producers.

It is clear from the above discussion that no conclusive expectation concerning the relationship between risk and the two adoption measures employed in this study can be made on *a priori* grounds. However, the alternatives have been canvassed and the best that can be hoped is that the multiple regression analysis to follow will *suggest* a more conclusive resolution of the problem.

In conclusion it deserves mention that, although this represents a first approximation of the cross-sectional influence of risk, it moves the study away from the rather naive profit maximization approach which Griliches employed, to a utility maximization approach. Here utility is a function of both the mean or expected level of regional profitability discussed earlier, plus the risk associated with attaining such a profitability level.

3. Information Acquisition and Assessment.

A study of the diffusion of technology in a management framework entails a rejection of the traditional assumption of perfect knowledge. Here the acquisition and assessment of knowledge concerning the new trace element technology is viewed as neither a timeless nor costless process. Indeed, it is explicitly recognized that reductions in the per unit cost of information assimilation will act to stimulate the adoption of new technology. The attempts made by this study to quantify the information aspect of copper-zinc adoption are discussed below.

(a) Farm Size:[21]

Farm (or firm) size has had wide use as an 'explanatory' variable of observed differences in adoption patterns. As a demand variable, Griliches [1957, p.517] used average corn acres per farm in order to 'add the impact of total profits per farm' to the per acre profitability

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[21] It should be emphasized that the influence of firm size on innovation adoption is generally considered in a profitability context. The farm size variable is considered here in an attempt to stress the aspects of information acquisition and assessment which it (in part) is thought to represent.

variables which were also included in his analysis.

In a discussion of the characteristics of firms likely to affect their speed of response (i.e. their lag in acceptance) to a new technique, Mansfield [1969, p.123] considered firm size a relevant factor with his statement that, 'one would expect them (larger firms) to be quicker, on the average, to begin using new techniques than smaller firms.' He supported this proposition with the observation that large firms had obvious advantages such as greater financial resources, bigger engineering departments, better experimental facilities, closer ties with equipment manufacturers and so forth. Clearly these factors pertain largely to the manufacturing sector.

Studies on the relationship between adoption and size in the rural sector have confirmed the 'explanatory' significance of this variable.[22] In an early Australian study of innovation amongst wheat farmers in northern New South Wales, Parish [1954, p.191] observed that the scale of farm operations (size of farm) was of 'overriding importance' in determining the pattern of adoption of mechanical innovations. In general terms, however, he found that non-mechanical innovations were being adopted as freely on the small as on the large farms. He tempered this generality to some degree by observing that

> ...inspection of individual cases suggests that inadequate size may be a factor preventing the adoption of non-mechanical innovations on some of the very small farms.
>
> [Parish, 1954, p.204].

Despite such a statement, no specific rationale for the existence of such size effects was offered.

In a more recent study by Perrin and Winkelmann [1976], farm size was found to exert an influence on adoption decisions, particularly in respect to fertilizer usage. The rationale for such an observed size effect, offered whilst discussing the adoption of new grain varieties, was that,

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22 See Rogers and Shoemaker [1971, p.361]. Of the 152 studies surveyed, 67 per cent supported the hypothesis that earlier adopters have larger sized units (farms) than do later adopters.

> ...small farms can be expected to lag behind larger farmers because of economies of size in transaction costs in evaluating and acquiring the new varieties.
>
> [Perrin and Winkelmann, 1976, p.893].

It is felt that similar size economies were relevant with respect to trace element adoption, given the level of on-farm trials which accompanies readily divisible innovations such as copper-zinc fertilizers. By presenting the adoption process within a management framework, the evaluation of a new innovation is seen as an integral part of this process.

It is worth emphasizing a point of theory at this stage. Economies of scale[23] are traditionally represented by a decline in long run (per unit) average cost (L.R.A.C.) as firm size[24] increases. This observed decline in L.R.A.C. may be presumed to occur solely due to scale effects, abstracting from all other influences. In particular, the theory assumes (in its purest form at least) that firms at all stages along the L.R.A.C. curve embody 'best practice' technology.[25] Given this assumption, the scale economies pertaining to the adoption of a new technology (in this case copper-zinc), relate to differences in the per unit *cost saving* as a firm moves from one form of technology to another. These cost savings are therefore represented by a *shift* from one L.R.A.C. curve to another, rather than a movement *along* a given cost curve.

Figure 7.1 summarizes this pos..ion where C_1 represents the L.R.A.C. of firms using pre-copper-zinc technology, C_2 the L.R.A.C. using

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[23] Economies of size relate to plant economies, whilst economies of scale relate to firm (which may be multi-plant) economies. See Bain [1968, p.166ff] for a discussion of these points.

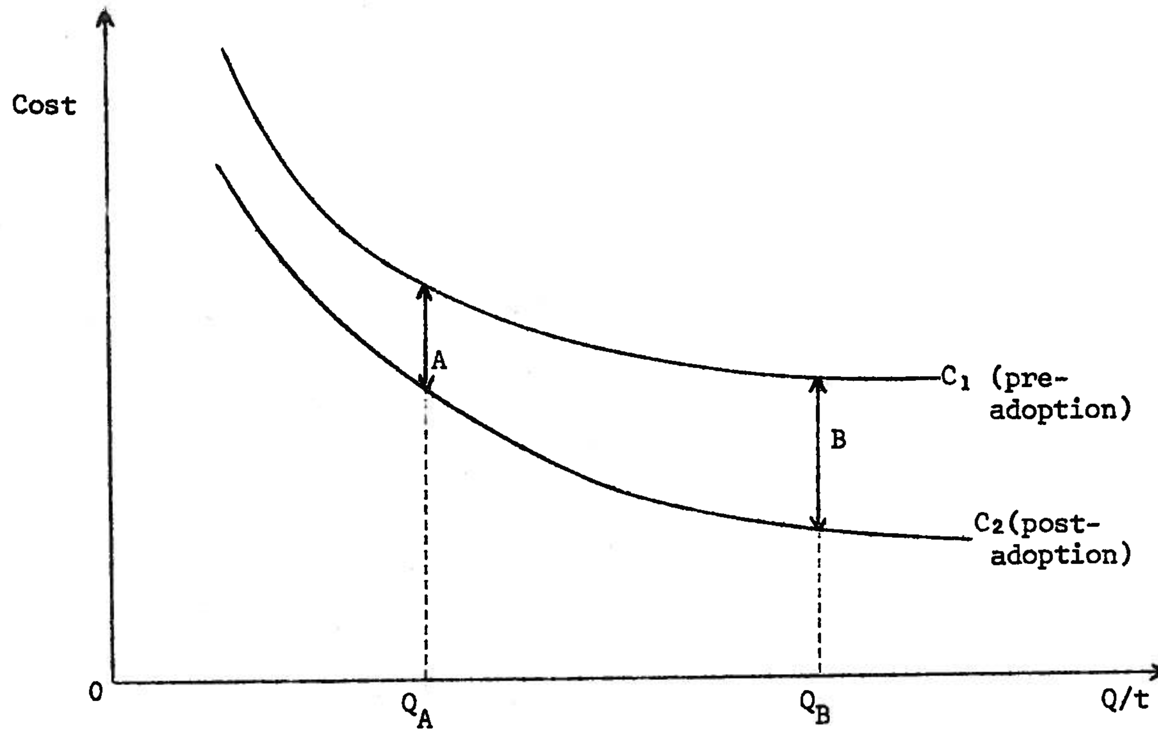
[24] Measured in various ways, e.g. value of capital assets, number of employees, gross value of sales, etc.

[25] To uphold this, along with other assumptions, in empirical attempts to estimate the L.R.A.C. curve, is fraught with difficulties - see Kelly and Kingma [1977, p.31ff]. To add to the confusion over what is the appropriate interpretation of the L.R.A.C., some theorists (e.g. Ferguson [1969, p.211]) argue that *qualitative* changes in technology contribute to a decline in the L.R.A.C. Lancaster [1974,p.155ff] offers a compromise interpretation and considers that the L.R.A.C. is in reality a stepped curve where the level of technology is held constant over particular *ranges* of output.

copper-zinc technology and A and B the per unit cost saving of moving to the new technology for a small and large farm respectively. In this study it is hypothesized that the economies of scale with respect to adopting copper-zinc technology are such that A < B.[26]

FIGURE 7.1

Scale economies associated with adopting Trace Elements for a small (A) and large (B) farm.



In conclusion, it is therefore hypothesized that a negative relationship exists between (average) farm size and the lag in acceptance, whilst a positive relationship exists between (average) farm size and the rate of adoption.

(b) Farmer Mobility:

In response to the temporal-spatial approach to the spread of technology which had its early development in the work by Hägerstrand [1966], it was felt that the movement of information in geographic space

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26 This is analogous to the approach taken when attempting to estimate the benefits (and costs) from research where the adoption of new technologies generated by this research causes a downward shift in the supply curve. See Lindner and Jarrett [1978].

may be influenced to some degree by the spatial mobility of individuals.

A method of estimating the percentage of total copper-zinc adopters[27] who were *not* still resident farm operators at the end of the data period, was presented in Chapter 4. This figure was considered a rough approximation to the degree of farmer mobility for each region of analysis, in the sense that it was an estimate of the level of farmer mobility out of, and consequently into, each region.[28]

It is hypothesized that the entry of new farmers into a region is likely to have a stimulatory effect on the diffusion of copper-zinc fertilizers. This conclusion is reached on the understanding that these new entrants, by their very mobility, have indicated their willingness to accept change and may therefore be more likely to accept the new fertilizer technology. It is also probable that they were attracted to the region in the first place by the knowledge that the application of copper-zinc technology was likely to be profitable. Consequently, higher levels of entry are therefore postulated to be inversely related to the lag in acceptance and directly related to the rate of adoption.

(c) 'Contiguity effect':

In an attempt to explain inter-regional differences in his origin estimate, Griliches [1957] used the earliest date of entry in the immediate (contiguous) neighbourhood of the area under consideration (X_{10}) as an attempt to quantify what he referred to as the 'complementarity' problem. This 'complementarity' problem related to the relative cost (on the part of seed suppliers) of producing a hybrid corn variety for a biologically similar area to the one for which hybrids had already been developed, versus developing a hybrid variety for a biologically dissimilar area.

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27 For the period 1939/40 to 1951/52.

28 This estimate assumes that the farms were not simply abandoned (considered unlikely) or that a large proportion of them were not amalgamated. If this were the case then it could be expected that average farm size would increase over time, but the evidence(see FMS discussion in Section 7.4 below) does not conclusively support this proposition for the period under analysis.

The X_{10} variable mentioned above,

> ...was introduced on the assumption that it may be cheaper, both from the point of view of the additional research needed and from the point of view of setting up a marketing organization, to enter an area contiguous to an area already entered even though the "market potential" there may be lower than in some other area farther away.
>
> [Griliches, 1957, p.511]

Similar site specific research, or more precisely evaluation costs, were deemed relevant for copper-zinc technology. We have also argued earlier that these evaluation procedures were undertaken at the farm level principally by farmers rather than fertilizer suppliers, and that these evaluation costs, in contrast to Griliches' study, are therefore operating on the demand rather than the supply side of the market.

A 'contiguity' variable equivalent to Griliches' X_{10} measure was incorporated into the analysis under the assumptions that

(1) the early adoption of copper-zinc technology by contiguous regions would lower the cost of evaluation for farmers in the area under consideration, and

(2) the early adoption of copper-zinc technology by contiguous regions would lower the perceived risk of obtaining a given profitability response[29] for farmers in the area under consideration.

The cost effect would be acting to reduce the lag in acceptance and raise the rate of adoption, as would the risk effect under assumptions of risk aversity.

4. Unspecified Variables

Of the numerous economic and sociological variables[30] which have remained unspecified in the following analysis, primarily due to a lack of suitable and readily accessible data,[31] two deserve special mention.

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29 The level of response possibly being determined by reference to the response obtained in the contiguous regions.

30 See Rogers and Shoemaker [1971, p.347ff] for a list of other determinants e.g. education levels, age of adopters, etc.

31 It was also felt that the variables discussed above are the *primary* determinants of inter-regional variations in adoption patterns.

The first concerns inter-regional variations in the on-farm cost of trace element fertilizers. As evidenced from the data used in this study, most of the earlier sales of trace elements were in mixture form - i.e. the trace elements (in various concentrations and combinations) were mixed with superphosphate by the manufacturer.[32] In general, the *ex-works* prices for the Birkenhead, Wallaroo and Port Lincoln plants were equivalent for the various mixtures which were offered.[33] This means that transport costs are the prime source of any observed spatial fluctuations in *on-farm* mixture prices.

At first glance, it would appear that this variability in on-farm prices may 'explain' a portion of the observed variations in origin (and for that matter rates of adoption) estimates. However, the problem of quantifying this variability remained unresolved, given the time constraints imposed on this particular study.

The difficulties associated with attempting to quantify the spatial variability in on-farm trace element prices are that

(1) it may be misleading to assume that transport costs are a (linear) function of the distance between the point of manufacture and the point of destination, as various transport rebates were offered by local producers to farmers, particularly in the South East of the State, in order to deter competition from producers centred mainly in Victoria (a neighbouring State),

(2) for some of the geographic regions of analysis, it is not possible to determine which of the three manufacturing sites should be used in any (distance determined) transport cost calculation which may be undertaken,

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32 During the 1960s there was a move towards on-farm mixing.

33 At some stages a (relatively small) loading for some freight charges of chemicals transported from Birkinhead to Wallaroo and Port Lincoln was included in the ex-works price. Ex-works prices in mid 1941 were \$10.10 per ton (net of any subsidies) for plain superphosphate and \$14.95 per ton for a superphosphate-copper 7 lbs-zinc 7 lbs. mixture. (Source: Pers. com. with manufacturers).

(3) over the study period there was a significant shift from rail to road transport and it is therefore difficult to determine the level of deliveries made to each region by the alternative modes of transport, and

(4) over the study period there was a shift from bagged to bulk handling (that incurred associated transport cost differentials), which had a varying spatial influence, depending on the rate of adoption of this form of handling technology within each region.

With these problems in mind, it was doubtful whether a satisfactory measure of inter-regional price variability could be constructed with the available data, and for this reason it was omitted from the analysis.

A second variable, whose inclusion on *a priori* grounds may have been of relevance, is a measure of the capital constraints on copper-zinc adoption. The adoption of trace elements not only incurs costs with respect to the purchase of the fertilizer itself, but may also require additional outlays such as fertilizer spreaders for pasture applications, or combination seed drills for crop applications, land clearing and fencing expenses in the case of undeveloped areas and possibly the purchase of additional stock in order to utilize the additional carrying capacity which may have resulted from trace element usage.[34] Any considerations in this area would also need to take into account the influence which the new technology would have on land prices[35] and the subsequent effect this may have on the availability of credit capital.

To investigate fully the capital implications of copper-zinc technology at the inter-regional level was beyond the resources of this

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34 This fact may have been of importance in areas such as the South East of the State where the application of trace element fertilizers allowed stocking rates to increase from 1 sheep per 40 acres to 2.5 dry sheep equivalents per acre (Coaldrake [1951]).

35 See Herdt and Cochrane [1966] for a study (albeit crude) of the impact of technology on land prices.

investigation. Even a first approximation of the influence on the adoption of copper-zinc fertilizers by some of the capital related variables detailed above, was severely constrained by data availability and could not be incorporated into the present study.

7.3 INDEPENDENT VARIABLES EXPLAINING ORIGIN VALUES: THE EVIDENCE

In the absence of any strong *a priori* reasons for preferring an additive versus multiplicative relationship between the independent variables described above, it was decided to incorporate both linear and log-linear regressions into the analysis. A comprehensive report of the results is presented in Table 1 in Appendix E.[36]

In general terms, it is evident that the combined 'explanatory' strength (as measured by the R^2s) of the independent variables, is reasonably low. This may indicate that the regression equations are to some degree mis-specified, in that one or more significant 'explanatory' variable(s) have been omitted.[37] An alternative possibility is that the lack of randomness in choosing the sample of 34 regions over which the regressions were run,[38] has contributed to these low R^2s. Indeed, an examination of the origin dates presented in Tables 6.1 and 6.2 indicates that most of the origins are concentrated in the earlier years of copper-zinc usage,[39] thereby limiting the degree of variation which was exhibited by the dependent variable.

The main thrust of this empirical work is to investigate the sign and significance of the estimated co-efficients rather than analyse

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[36] For convenience, representative equations are incorporated into the text.

[37] It is also possible that the empirical variables represented a poor approximation for the 'correct' conceptual variables.

[38] The regions on which the origin analyses were conducted were chosen because of their compatibility with the rate of adoption regressions. This made data acquisition a manageable task, given that first source material was required to construct many of the variables included in the study.

[39] This is perhaps to be expected, in that a region for which the adoption process was reasonably well advanced was required in order to facilitate fitting a logistic.

the value of the co-efficients *per se*. A detailed interpretation of the results obtained for each 'explanatory' variable is undertaken below.

Soil Index (SIH, SIL)

Comparative results for the soil index measures are presented in regressions 1, 2 and 3, 4 in Table 1 (Appendix E). SIH represents the proportionate area of each region covered by the high response soils and SIL the proportionate area covered by the low response soils.

In general the soil index variables have the appropriate signs, with the negative SIH co-efficient indicating a shorter lag in acceptance, as the proportion of each area covered by the higher response soils increases. The positive SIL co-efficient indicates an inverse relationship between lag in acceptance and the area covered by low response soils. The change in sign associated with the move from high to low response soils is quite a useful validation of the *a priori* expectations concerning the relationship between this variable and the lag in acceptance, especially in view of the potential volatility of the high and low response measures, given the large proportion of area in the medium range of the index.[40]

Such observations must be tempered by the fact that these variables failed to show consistent statistical significance. This result is perhaps not too surprising, given the first approximation nature of the soil index estimates.

Mean Rainfall (RBAR)

From an inspection of Table 1 Appendix E it is apparent that the RBAR variable achieved consistent statistical significance in both the linear and log-linear formulations. Furthermore, the negative sign

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[40] That is, small changes in the medium category would result in relatively large changes in either the high or low category.

on the RBAR co-efficient matched *a priori* expectations where shorter lags in acceptance are related to higher levels of mean rainfall (or profitability increases).

A representative linear formulation (at the Hundred level) of the basic model referred to in this discussion is given by equation 7.1 below.

$$\underset{(3.12)^{*}}{ORIG = 12.899} - \underset{(.67)}{0.017SIH} - \underset{(2.39)^{*}}{0.115FM1} + \underset{(1.06)^{\dagger}}{0.136CON} + \underset{(.97)}{0.132RVAR}$$

$$- \underset{(.98)}{0.001FMS} - \underset{(1.46)^{**}}{0.283RBAR} \quad \ldots\ldots\ldots\ldots \quad (7.1)$$

*	sig. at the 5 per cent level	R^2 = 0.32
**	sig. at the 10 per cent level	n = 34
†	sig. at the 15 per cent level	( ) = t values

(one-tailed t test)

where

ORIG = origin estimate

SIH = soil index measure (high response category)

FM1 = farmer mobility

CON = contiguity variable

RVAR = risk variable

FMS = farm size and

RBAR = mean rainfall.

Steely Wool

Like the mean rainfall variable, the negative sign on this co-efficient pointed to an inverse relationship between the lag in acceptance and the incidence of steely wool. However, a consistent lack of statistical significance meant that this variable was omitted from Table 1. (Appendix E).

The lack of significance in this case is possibly due to the limited nature of the variable. The data on which it was constructed[41]

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[41] See Appendix D for details.

restricted the variable to a consideration of the area for which evidence of steely wool occurrence was recorded. What it did not indicate was the variation in the *severity* of the problem from one region to another. This factor would undoubtedly be relevant in any attempt to determine the influence which the use of copper-zinc fertilizers would have in improving fleece quality and hence (per unit) profitability.

Rainfall Variability (RVAR, RVAR1)

The variance of yearly rainfall totals (RVAR) over the period 1939/40 to 1964/65 is the risk measure which was employed in this investigation. The RVAR coefficient only achieved statistical significance in the log-linear formulations. However, its positive sign indicates that increases in the level of risk are associated with increases in the lag in acceptance. Such a result is consistent with a risk averse assumption concerning adopters' or, more specifically, innovators' risk propensities. This observation must be made guardedly, given the earlier discussion concerning the appropriateness of rainfall variance as a measure of risk, and the problems of inferring aggregate responses from the level of individual farm operators.[42]

It was thought likely that the lack of significance of the RVAR co-efficient was due to the high level of multicollinearity which was evidenced between the RBAR and RVAR co-efficients.[43] Given the strong *a priori* justification for believing that *both* the regional (mean) profitability increase and the risk associated with attaining such an increase influenced innovative behaviour, it was felt that the exclusion of either one of the variables would introduce specification error into the analysis.[44]

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42 The aggregation problems are generally less severe in the case of the origin as opposed to rate of adoption measure, as the former is determined by year to first usage, where first usage is often by one or a few farmers.

43 Correlation co-efficient $r_{RBAR.RVAR} = .9172$

44 For example, the remaining variable would, in part, be measuring the combined effect of both variables. Furthermore, the significance of this variable is likely to be raised, thereby resulting in inaccurate inferences being made about the included variable's co-efficient. See Koutsoyiannis [1973, pp.245-248].

An alternative method of overcoming this collinearity was sought.

The approach taken was to modify the rainfall variability measure somewhat by recording the number of years (from the 26 year sample) for which rainfall was greater or less than 15 per cent of the mean (RVAR1). The theoretical implication of such a risk measure is that (potential) adopters apply a zero weight to rainfall levels within the plus or minus 15 per cent range. This contrasts with the variance measure where it is assumed that (potential) adopters are applying non-zero weights to *all* levels of rainfall about the mean. Although the variance measure may be preferable for this study, it must be remembered that either measure is simply an attempt to approximate the level of risk as it is *perceived* by potential trace element adopters. The theoretical basis for choosing between either measure is therefore not conclusive. What can be determined, however, is that the high positive correlation co-efficient[45] between the two variables indicates that, on statistical grounds, the RVAR1 measure is a satisfactory proxy for the RVAR risk estimate.

Furthermore, the RVAR1 variable has been successful, to a degree, in reducing the level of collinearity between the mean level of rainfall (RBAR) and the observed level of rainfall variability.[46] An examination of the regression results in Table 1 Appendix E reveals that this risk estimate not only achieves satisfactory levels of statistical significance in both linear and log-linear formulations, but also maintains the positive relationship between the level of risk and the lag in acceptance. Such a result enhances the veracity of the risk averse assumption discussed earlier.

It is also worth noting that in terms of the R^2s, the RVAR1 estimate improves the overall explanatory power of the models described, for both the linear and log-linear formulations as indicated by a comparison of equation 7.2 below with equation 7.1 above.

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45 Correlation co-efficient $r_{RVAR.RVAR1} = .8056$.

46 See Table 7.1.

$$ORIG = 3.415 - 0.014SIH - 0.077FM1 + 0.169CON + 0.652RVAR1 - 0.001FMS - 0.216RBAR \quad (7.2)$$

$$\quad\quad (2.09)^{*} \; (.57) \quad (1.59)^{**} \quad (1.34)^{**} \quad (1.76)^{*} \quad (.95) \quad (2.09)^{*}$$

*	sig. at the 5 per cent level	$R^2 = 0.37$
**	sig. at the 10 per cent level	n = 34
(one-tailed t test)		( ) = t values

Farm Size (FMS)

Although the average farm size variable exhibited the expected negative sign, it lacked statistical significance in all the model specifications presented in Table 1 Appendix E. Such a lack of significance is perhaps not entirely unexpected. The origin measure in this study reflects the actions of a single, or at most a few, regional innovators with respect to trace element usage. The farm size measure, by contrast, is an average measure which captures the scale considerations of *all* potential adopters within each geographic region. The appropriate scale measure for the purposes of explaining inter-regional differences in innovator behaviour is therefore not *average* farm size, but rather a measure which takes into account the distributional nature of farm sizes, with particular emphasis on the proportion of farms which are in the large farm category.[47]

Unfortunately, data limitations preclude such a measure from being constructed, and the role of scale economies in relation to innovator behaviour must necessarily remain unresolved.

Farmer Mobility (FM1)

From an inspection of Table 1 Appendix E, it is evident that for all model specifications this variable (FM1) was negative and, for

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[47] See Pomfret [1976] for a consideration of farm size distribution as opposed to average farm size with respect to the adoption of an innovation in the rural sector.

TABLE 7.1

Hundred Level Correlation Co-efficient Matrix of

'Explanatory' Variables. (N = 34)

SIL	-.25									
FMS	-.26	-.24								
FM1	-.04	.36	-.41							
FM2	.11	.21	-.26	.67						
RBAR	.51	-.08	-.48	-.04	.02					
RVAR	.39	.15	-.59	.11	.13	.92				
RVAR1	.23	.15	-.36	-.20	-.09	.67	.81			
CON	-.18	-.12	.04	-.16	-.14	-.26	-.23	-.20		
ORIG	-.26	.07	.07	-.32	-.33	-.27	-.20	.10	.35	
MRA	-.10	-.32	.63	-.68	-.49	-.11	-.26	-.11	.14	.09
	SIH	SIL	FMS	FM1	FM2	RBAR	RVAR	RVAR1	CON	ORIG

TABLE 7.2

County Level Correlation Co-efficient Matrix of 'Explanatory'

Variables. (N = 11)

CSIS2	-.43						
CFMS	.17	.09					
CFM1	.40	-.42	-.24				
RBAR	.55	-.04	-.39	.44			
RVAR	.49	.01	-.42	.36	.92		
RVAR1	.28	.29	.27	-.19	.41	.59	
MRA	.76	-.44	.11	-.02	.44	.34	.29
	CSIS1	CSIS2	CFMS	CFM1	CRBAR	CRVAR	CRVAR1

all but one, statistically significant. This lends support to the hypothesis that the entry of new farmers into a region is likely to have a stimulatory effect on the diffusion of copper-zinc fertilizers. In this case, the stimulatory effect is in terms of a reduction in the lag in acceptance which is interpreted here as a measure of innovative behaviour. It could be tentatively concluded, therefore, that the new entrants are more likely to be innovators than the extant farmers, although further data would be required in order to confirm this possibility.[48]

Contiguity Effect (CON)

The earliest date of usage in the immediate (contiguous) neighbourhood of the area under consideration, that is, the contiguity variable, maintained a level of statistical significance in all the linear and two of the four log-linear formulations reported in Table 1 Appendix E. It was argued previously in this thesis that the early adoption of copper-zinc technology by contiguous regions would, by lowering the cost of evaluation, act to reduce the lag in acceptance in the region under study. Given the risk averse behaviour which was also indicated by the results, the reduction in the level of perceived risk (of obtaining a given profitability response) which the early adoption of this new fertilizer technology by contiguous regions is deemed to incur, would also act to reduce the lag in acceptance in the region under study.

The positive relationship between the contiguity variable and the lag in acceptance which this reasoning implies was borne out by the regression analysis.

7.4 INDEPENDENT VARIABLES 'EXPLAINING' MODIFIED RATES OF ADOPTION VALUES: THE EVIDENCE.

It was argued in section 7.2.1 above that inter-regional variations in origin and (modified) rates of adoption estimates are *both*

[48] This point is taken up again in Section 7.4.

'explained' in terms of demand rather than supply variables. The demand variables employed in the previous investigation of origin, or lag in acceptance variations, will therefore be discussed in terms of their relationship with the measured variations in inter-regional (average) adoption rates.

Results for both linear and log-linear specifications at the Hundred level are presented in Table 2 (Appendix E). In contrast to the lag in acceptance analysis, log-linear formulations did marginally better in terms of R^2s than the linear models. This suggests some degree of interaction between the independent variables, such that the effect of one 'explanatory' variable on the rate of adoption is dependent on the level of effect of other variables. The empirical evidence concerning the influence of these variables on the estimated rate of adoption is considered below.

<u>Soil Index</u> (SIH, SIL, CSIS1, CSIS2)

The results for both the high (SIH) and low (SIL) response percentages were disappointing in terms of their lack of statistical significance (see equation 7.3 below). The sign on the soil index co-efficient (Table 2 Appendix E) lacked consistency when moving from the linear to log-linear formulations in the case of the SIH estimate, or when moving from one model specification to the other in the case of the the SIL estimate. The volatility of these signs is perhaps of minimal analytical consequence, when it is observed that the variables failed to achieve statistical significance.

$$
\begin{aligned}
MRA = \underset{(2.95)^*}{4723.14} - \underset{(.59)}{6.27SIH} - \underset{(3.48)^*}{69.26FMI} - \underset{(.52)}{30.08RVAR} + \underset{(2.79)^*}{0.73FMS} \\
+ \underset{(.84)}{69.02RBAR} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7.3)
\end{aligned}
$$

* sig. at the 5 per cent level (one-tailed t test)

R^2 = .62

n = 34

( ) = t values

where, MRA = (modified) rate of adoption

SIH = soil index measure (high response category)

FM1 = farmer mobility

RVAR = risk variable

FMS = farm size, and

RBAR = mean rainfall

It was strongly felt that this lack of statistical significance was due to the first approximation nature of the soil index measure, which limited its ability to pick up the relatively detailed soil response variability which an analysis at the Hundred level required. To overcome this problem to some extent a more aggregated approach was sought. Firstly, the high and medium-high soil categories were amalgamated[49] (CSIS1) as were the low and medium-low categories (CSIS2). Regressions 1 and 4 were then re-run, this time at the spatially more aggregated County rather than Hundred level.

Results for these regressions are presented in Table 3 Appendix E, with a representative regression being given in equation 7.4 below.

$$
\begin{aligned}
CMRA = \underset{(1.03)}{1842.52} + \underset{(2.97)^*}{47.69CSIS1} - \underset{(.58)}{0.108CFMS} - \underset{(1.92)^*}{25.55FM1} \\
- \underset{(.93)}{100.01CVAR} + \underset{(.94)}{145.7CRBAR} \quad \ldots\ldots\ldots\ldots\ldots \quad (7.4)
\end{aligned}
$$

* sig. at the 5 per cent level $\bar{R}^2 = .53$

(one-tailed t test) $n = 11$

( ) = t values

Here the variables correspond to those given for equation 7.3 above but apply to the County, not Hundred, level.

Not only did the signs on these two soil index variables match predictions, but both coefficients were significantly different from zero at the 2.5 per cent level. These results suggest that the construction of a soil classification system which exhibits finer (spatial) detail would significantly improve the performance of this profitability proxy at the Hundred level.

[49] This amalgamation involved an unweighted summation of the high and medium-high categories, as the lack of comprehensive experimental (response) data precluded the possibility of weighting the response categories with a sufficient degree of realism.

Mean Rainfall (RBAR)

In all the regressions reported in Tables 2 and 3 in Appendix E the RBAR co-efficient was positive, thereby matching *a priori* expectations concerning the existence of a direct relationship between the rate of adoption and the mean level of profitability increase resulting from the adoption of copper-zinc fertilizers. However, the RBAR coefficient fails to achieve a satisfactory level of statistical significance in regression 7.3 above.

An analysis of Table 7.1 above suggests that this lack of significance may be due to the multicollinearity which exists between RBAR and the other variables included in this model.[50] By substituting RVAR1 for RVAR and thereby lowering the degree of collinearity between RBAR and the risk variable, it is evident from the representative (linear form) equation 7.5 given below that quite reasonable levels of statistical significance are achieved for the RBAR measure.[51]

$$\underset{(3.20)^{*}}{MRA = 7794.99} - \underset{(.77)}{7.93SIH} - \underset{(4.04)^{*}}{80.46FM1} - \underset{(1.46)^{**}}{231.37RVAR1}$$

$$+ \underset{(2.84)^{*}}{0.70FMS} + \underset{(1.56)^{**}}{68.66RBAR} \quad \dots\dots\dots\dots\dots\dots\dots \quad (7.5)$$

* sig. at the 5 per cent level $\qquad R^2 = .65$

** sig. at the 10 per cent level $\qquad n = 34$

(one-tailed t test) $\qquad$ ( ) = t values.

Steely Wool

In sympathy with the investigations on innovative behaviour, the steely wool variable lacked statistical significance as an 'explanator' of imitative behaviour. Once again, it is felt that the failure of this 'qualitative' variable is that it measured only the incidence dimension

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50 In particular RVAR and to a lesser extent SIH and FMS.

51 See also equations (L)3, 4 and (L)4 in Table 2 Appendix E.

and failed, due to data restrictions, to reflect regional differences in the severity of the occurrence of steely wool. For this reason it was omitted from the recorded results.

Rainfall Variability (RVAR, RVAR1)

For the Hundred level regressions presented in Table 2 Appendix E it is evident that the RVAR coefficient failed to achieve satisfactory levels of statistical significance in both the linear and log-linear specifications. Again, this low level of significance may be attributable to the effects of multicollinearity.[52]

Using the rationale outlined with respect to risk as it relates to origin measures, RVAR1 was chosen as a satisfactory proxy (on statistical grounds) for RVAR, and employed as a risk estimate in subsequent regressions with the aim of reducing multicollinearity. To some extent this re-specification was successful in terms of reducing the level of multicollinearity and the RVAR1 coefficient was significantly different from zero at the ten per cent level in the linear specifications. There has also been a slight improvement in the R^2s as a result of these changes.[53]

This significance, combined with the consistent negative sign on the risk coefficient (i.e. both RVAR and RVAR1 coefficients) lends support to the hypothesis that imitators are risk averse. This result, when combined with the findings concerning innovators, fails to support the proposal that rainfall variability, through its influence on geographic patterns of farm ownership, would associate those regions in which the risk is highest with shorter lags in acceptance and higher rates of adoption. It does, however, lend support to the conclusion that all adopters (be they innovators or imitators) are risk averters. However, the problem of aggregation, when combined with uncertainties concerning the

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[52] See Table 7.1.

[53] For example, the R^2s for equations 1 and 3 (Table 2, Appendix E) show a rise from .62 to .65 respectively.

appropriateness of the risk estimates employed in this study, preclude the possibility of any definitive conclusion being drawn.

Farm Size (FMS)

The high statistical significance and positive sign on the farm size coefficient (FMS) for all the models presented in Table 2 Appendix E, indicates the strong relationship which this study attributes between increased farm size and increases in the adoption rate of trace elements. Such a result lends support to the assertion that economies of size with respect to the acquisition and evaluation of information concerning the new fertilizer technology is an important determinant of the rate of adoption.[54]

However, care must be taken when drawing such causal relationships and, given the relatively strong 'explanatory' power of the FMS variable, it was decided to investigate this aspect in more detail. Although the models constructed in this study imply that higher average farm sizes led to higher rates of adoption, it is plausible that the causal relationship runs in the other direction, with the adoption of copper-zinc technology in some way influencing farm size.

The correlation coefficient between the average farm size in each Hundred and time in years[55] was therefore calculated, in order to determine whether or not a consistent relationship between trace element adoption (itself a temporal process) and average farm size existed. Of the 34 regions studied, 16 gave negative correlation coefficients whilst the remaining 18 were positive. Seven of the coefficients were not significantly different from zero at the five per cent level. (Two-tailed t test). Such results appear contrary to the hypothesis that trace

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[54] There exists other acquisition costs that are subject to scale effects (e.g.costs associated with transporting fertilizer to properties and their subsequent application to crops and pastures). It is felt however, that many of these other scale aspects are more appropriately apportioned to superphosphate fertilizer usage (which generally preceded trace element usage) and not to trace element usage *per se*.

[55] For the period 1939/40 to 1964/65.

element usage has a consistent (or at least dominant) influence on changing farm size.

In an attempt to test further the causal relationship between trace elements and farm size, it was decided to establish the correlation between the average farm size in each region in 1939/40 and the SIH and SIL soil index. This was done on the understanding that the pre-trace element productivity level of the soil may have had a (long term) influence on farm size. The correlation coefficients between average farm size in 1939/40 and SIH and SIL are -.2089 and -.1814 respectively. Both coefficients are not significantly different from zero at the five per cent level, and therefore fail to indicate that the lack of trace element usage in the pre-1939/40 years, through its influence on soil productivity, had a significant (cross-sectional) effect on farm size.

These results tend to confirm the original hypothesis that farm size, through its hypothesized economies of size effect, influences the rate of adoption and that the causal link does not run in the opposite direction.

Farmer Mobility (FM1, FM2)

In both the linear and log-linear models presented in Table 2 Appendix E the farmer mobility proxy (FM1) had both a negative sign and a high level of statistical significance. An alternative measure of farmer mobility (FM2) was tried, where FM1 is the percentage and FM2 the absolute number of copper-zinc adopters who were not still resident farm operators at the end of the data period. Although the absolute measures were statistically significant and also had negative signs, the model specifications including these variables did not do quite as well (in terms of R^2s) as those which incorporated the FM1 proxy, and were therefore discarded.

In either specification, the negative sign was *contrary* to *a priori* expectations. It was argued earlier that the entry of new farmers into a region is likely to have a stimulatory effect on the diffusion of copper-zinc fertilizers, whilst the negative sign achieved in these regressions indicates that it is actually inhibiting the rate of imitation. This result contrasts dramatically with the investigations concerning innovative behaviour, where it was found that higher levels of farmer mobility were indeed associated with smaller lags in acceptance.

A tentative hypothesis which may reconcile these apparently conflicting results, is that the observed stimulatory effect on innovative behaviour which is associated with higher levels of farmer mobility, may be due to the fact that innovators tend to be the entrant rather than extant farmer. However, the subsequent imitation by existing farmers in a region may be inhibited to some extent if the initial users of copper-zinc fertilizers are 'new' rather than 'established' farmers. The cause of this inhibition with respect to imitation could be due to

1. a lack of developed communication channels between 'new' and 'existing' farmers, and/or
2. a lack of credibility in the results obtained by 'new' farmers (following their use of trace elements), as perceived by the 'established' farmers within a particular region.

The latter of these two factors is to some extent compatible with the findings of Ryan and Gross [1943], who observed that farmers considered some sources of information 'more influential' with respect to the adoption of hybrid corn technology than others.

It must be stressed that the above hypothesis would require more extensive investigation than was possible in this study, to determine its validity or otherwise. However, the consistent signs and statistical significance which the farmer mobility variable displayed, suggests that such an investigation may prove fruitful.

7.5 SUMMARY

Of the three measures of profitability considered, one (steely wool) was dropped from the reported results, due to a consistent lack of statistical significance. This was thought to reflect the inadequate nature of the steely wool variable itself, rather than an indication that the qualitative effects of copper-zinc usage on wool production were inconsequential with respect to decisions concerning the adoption (or rejection) of the new fertilizer technology.

The soil index measure, again probably due to the first approximation nature of the variable, failed to show statistical significance in the Hundred level regressions. The signs of the soil index coefficients in the case of the origin regressions did, however, indicate that the lag in acceptance was inversely related to profitability increases. Profitability increases appear to have similar stimulatory effects on the actions of imitators when aggregate soil index measures (CSIS1, CSIS2) were regressed on adoption rates at the County level.

The RVAR and, to a greater extent the RVAR1 risk proxy, gave results which were indicative of risk averse behaviour on the part of *both* regional innovators and regional imitators. In reaching this conclusion, caution was prescribed on the grounds that RVAR and RVAR1 were only *estimates* of the level of perceived risk associated with attaining a level of profitability response resulting from trace element usage. Furthermore, it was noted that aggregate studies such as this are hampered by a lack of information concerning the appropriateness of inferring aggregate risk propensities from a concept which relates more specifically to the level of individual adopter (i.e. farmer) units.

The aspects of information acquisition and evaluation which were incorporated into the innovative and imitative investigations of this study gave generally satisfactory results in statistical terms. One exception to this was the farm size variable in the (Hundred level) origin regressions. Here it was felt that a shift from an average to a distributional measure of farm size (FMS) may have clarified the role of this variable in relation to innovative behaviour. In contrast, the assertion that economies of size with respect to the acquisition and evaluation of information concerning copper-zinc technology are an important determinant of the rate of adoption, is supported by the sign and significance of the FMS coefficient.

The farmer mobility (FM1) variable indicated that the entry of new farmers had a statistically significant stimulatory effect on innovative behaviour but an inhibiting effect on the rate of adoption or imitation. Such a result points to the possibility that a lack of developed communication channels between 'new' and existing farmers, along with a lack of credibility in the trace element results of 'new' farmers, as perceived by the 'established' farmers, could account for this inhibiting effect.

It was observed that, in keeping with Griliches' findings, the early adoption of copper-zinc technology by contiguous regions reduced the lag in acceptance in the region under study. Here it was argued that early adoption by contiguous regions lowered the cost of evaluation for farmers, which contrasts with Griliches' supply orientated approach where the costs of hybrid corn development and marketing were lowered from the point of view of the seed supplier.

The relatively low explanatory significance (given by the observed R^2s) of the variables described above with respect to inter-regional variations in origin estimates, was attributed (in part at least) to the lack of variability which data constraints imposed on the dependent variable. In contrast, the R^2 value for regression 7.5 above indicates that approximately 65 per cent of the inter-regional variation in adoption rates has been 'explained' by profitability, risk and those aspects of information acquisition and evaluation which were incorporated into the study. Such a level of explanatory power compares favourably with the results presented by Griliches [1957, p.518].

In conclusion, an inspection of the t values of the explanatory coefficients indicates that the aspects of information acquisition and assessment incorporated in this study had a *relatively* dominant influence on both the innovative and imitative aspects of copper-zinc adoption. Profitability influences, as measured by the mean rainfall and soil index variables, did not do quite as well, although indications were that the first approximation nature of the soil index measure may have contributed to some extent to its poor showing.

This result is perhaps understandable, when it is remembered that the outlay required to purchase trace elements was small when compared with the cost of complementary fertilizers which are virtually an essential input into the Australian agricultural scene (i.e. phosphates). It must also be remembered that the regions included in this study were biased towards those which exhibited relatively high profitability gains from copper-zinc usage, and that the incorporation of other regions of the State which were less responsive to copper-zinc applications may have enhanced the relative significance of the profitability variable.

Finally, this study attempted to account for the influence of risk on the inter-regional variations of observed patterns of copper-zinc adoption. In general, the results indicated that the aspect of risk which was quantified in this study was not as important an influence on adoption patterns as the variables discussed above, although its influence on imitative behaviour was perhaps greater than its influence on the innovative aspects of copper-zinc adoption.

CHAPTER 8

CONCLUSIONS

This study has applied a Griliches-type logistic function to a large body of data in order to quantify inter-regional differences in copper-zinc adoption. The choice of logistic to perform such a task was not taken 'blindly'. A detailed discussion, at the theoretical level, of the assumptions embodied in a logistic function which are of relevance for a diffusion study such as this was presented in Chapter 3. The veracity of the symmetry assumption in relation to the copper-zinc data employed in this thesis was then investigated empirically. The results of Chapter 5 engendered confidence in our ability to utilize a symmetric logistic function in an attempt to summarize the temporal adoption pattern for each of the chosen Counties and Hundreds.

It was then argued that the lag in acceptance parameter represents innovative aspects, whilst the (modified) rate of adoption parameter is in essence a measure of the imitative aspects, of copper-zinc adoption. Furthermore it was argued that in the case of copper-zinc technology, *both* the innovative and imitative aspects of adoption were primarily functions of demand orientated factors. This was contrasted to Griliches' hybrid corn study where the origin measure was primarily supply determined whilst the rate of adoption was a demand determined phenomenon.

The first section of Chapter 7 was devoted to a discussion of the demand determinants of copper-zinc adoption in the light of the management emphasis that this study pursues in relation to innovation adoption. The observed pattern of adoption was thought, on *a priori* grounds, to be principally a function of,

(1) the (expected) profitability increase resulting from trace element adoption,

(2) the risk associated with achieving such a level of profitability increase, and

(3) certain aspects of information acquisition and assessment concerning the new fertilizer technology.

Mention was made of the problems associated with inferring aggregate adoption responses from variables that are generated by a consideration of copper-zinc adoption at the farm or adopter unit level.

The empirical results suggested that both innovative and imitative aspects of copper-zinc adoption were strongly influenced by the information aspects that were included in this analysis. In accordance with Griliches' findings, profitability factors were also found to exert a significant stimulatory influence on the innovative and imitative aspects of adoption. It was recognized that the inclusion of a risk estimate shifted the emphasis of the study away from an implicit profit maximizing stance to that of a utility maximizing approach. However, although the results suggested that both innovators and imitators displayed risk averse propensities, the lower levels of statistical significance that were obtained by the risk proxy may (in part) reflect the major problems associated with an investigation of risk at the aggregate level.

The levels of 'explanation' achieved in the rate of adoption regressions indicated that almost two thirds of the cross sectional variability in the (modified) rate of adoption parameter was accounted for. The R^2s for the origin regressions were almost half this figure and were felt to reflect *inter alia* the limited data base of the dependent variable. Although caution must be prescribed when attempting to generalize the results obtained by a study of trace element diffusion, it is felt that they may give some insight into the factors that influence the spread of 'divisible', and essentially non-capital intensive innovations, in the Australian rural sector.

APPENDIX A

THE GEOGRAPHIC UNITS OF ANALYSIS

Having disaggregated the F.S.L. delivery data to Hundred level, it was then decided to choose the Hundreds for which a logistic curve would be fitted on the basis that the total number of adopters over the data period (i.e. 1939/40 - 1951/52) exceeded 30.[1] This criterion was chosen in an attempt to avoid any problems that an excessively small sample size may incur. This contrasts markedly with Romeo's 1977 study where he generated a series of ten inter-industry logistic curves for industries with, for example, only 2, 4, 6 and 7 (sample) firms per industry. In fact, only one out of the ten industries which he studied had in excess of 30 sample firms.

For 13 of the 34 Hundreds for which the cumulated adopter number was greater than 30, it was found that the total number of adopters exceeded the potential number of adopters (as measured by the modified average number of holdings) thereby implying a cumulative adoption level for 1951/52 in excess of 100 per cent! Such a result is plainly fallacious and was felt to largely reflect allocative errors arising from the disaggregation procedures that were applied to the adopter data.

As stated in Chapter 4 the F.S.L. listings recorded *inter alia* the names and (in many cases) the postal address of each adopter. Therefore it is likely that allocating adopters to a particular region by reference to their postal address will incur errors for relatively small regional units (e.g. Hundreds) given that the postal address may not correspond to the property address, but generally to the nearest or most accessible town that offers postal facilities.

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1 This criterion was also the basis on which suitable Counties were chosen.

In rural South Australia during the 1940s and early 1950s it is likely that in the relatively undeveloped areas, holding-town distances would be such that an adopter could be allocated to a particular Hundred when in fact his holding is in another (and possibly neighbouring) Hundred. This statement is supported by the observation that the Hundreds for which total adopter numbers exceeded the holding number were centred mainly in the relatively undeveloped areas such as Kangaroo Island and the Upper South East.

As it was felt that in the majority of cases this misallocation problem could be overcome by aggregating some Hundreds, it was decided to combine the 13 Hundreds that had greater than 100 per cent adoption with the Hundreds that were contiguous to them. For any Hundreds that consequently overlapped between two or more regions, adopters and holdings were divided equally among each region.

This misallocation problem did not appear to have any significance at the County level and it was therefore not deemed necessary to undertake any form of spatial aggregation for those regions.

APPENDIX B

a_3 AND Sk_2 SKEW CO-EFFICIENTS

Table 1: By County

Counties[1]	[2]a_3	[3]Sk_2	Total No. of Adopters
Cardwell	-.629	-.215	111
Flinders	-.712	-.270	242
Musgrave	-.919	-.347	115

Table 2: By Hundred

Hundreds[1]	a_3	Sk_2	Total No. of Adopters
Willunga[4]	-.217	.409	101
Stirling	-.676	-.232	104
Coombe	-.451	-.647	83
Moorowie	-1.401	-.049	35
Lincoln	-.524	-.376	46
Blanche	-.557	.787	201
Hindmarsh	-.168	-.490	69
Kongorong	.383	1.418	38
Macdonnell	-.649	-.010	79
Mt. Muirhead	-.140	-.240	243
Penola	-.758	-.078	83
Rivoli Bay	-.099	-.773	99
Goolwa	-.754	-.562	54
Myponga	.030	.036	42
Nangkita	-.430	-.172	63
Binnum	-.184	.059	43
Bowaka	-.722	-.313	53
Comaum	.065	.365	63
Joyce	.049	.710	133
Waterhouse	-.512	.520	53

Please see p.121 for Notes.

APPENDIX B (Continued)

Notes:

1 The Counties and Hundreds listed here are a sub-set of the Counties and Hundreds for which logistic parameters were estimated. They were chosen on criteria aimed at reducing the problems associated with small sample sizes (criteria a and b) and minimizing the effect of substantial truncation of the L.H. side of the distribution (c). The criteria required that

(a) the total number of copper-zinc adopters for each region was ≥ 35,

(b) the number of years exhibiting non-zero levels of adoption ≥ 8,

(c) the 1951/52 adoption frequency must be (approximately) 1/3 or less of the modal adoption frequency.

2 $a_3 = {}^{M_3}/_{S^3}$ where

$$M_3 = \frac{\Sigma f_i (x_i - \bar{x})^3}{n}$$

$$\left(\bar{x} = \frac{\Sigma\, x_i f_i}{n},\quad n = \Sigma f_i\right.$$

and

$$S^3 = \left(\frac{\Sigma f_i (x_i - \bar{x})^2}{n - 1}\right)^{3/2}$$

f_i = no. of adopters in year i,

x_i = years from i=1 to 13)

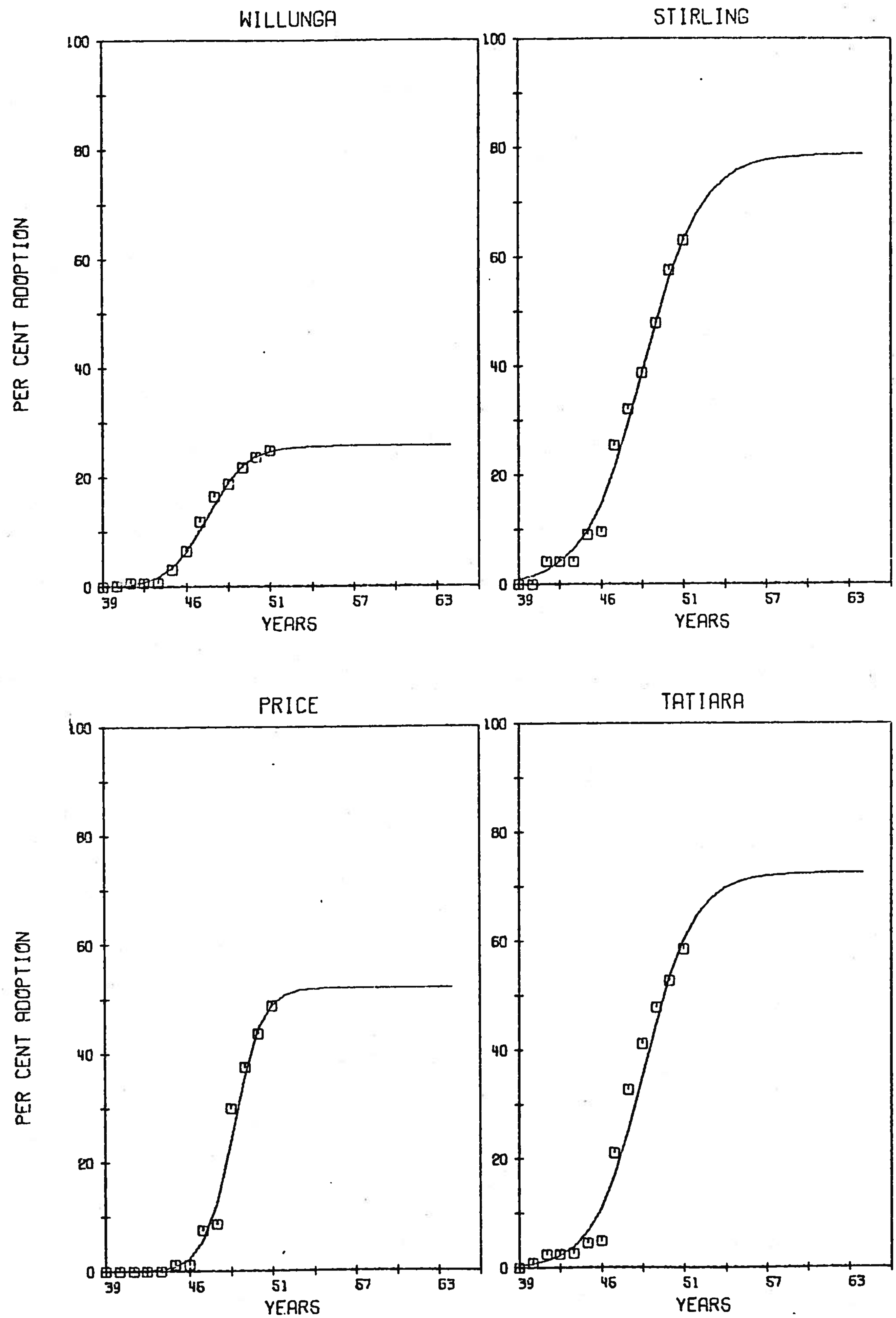
3 $$Sk_2 = \frac{3(\bar{x} - x_{me})}{s}$$

x_{me} = value of x_i at $\frac{\Sigma x_i f_i}{2}$

4 Due to data constraints Willunga is actually a Council District and not a Hundred.

APPENDIX C

1. PERCENT ADOPTION BY YEAR FOR HUNDREDS



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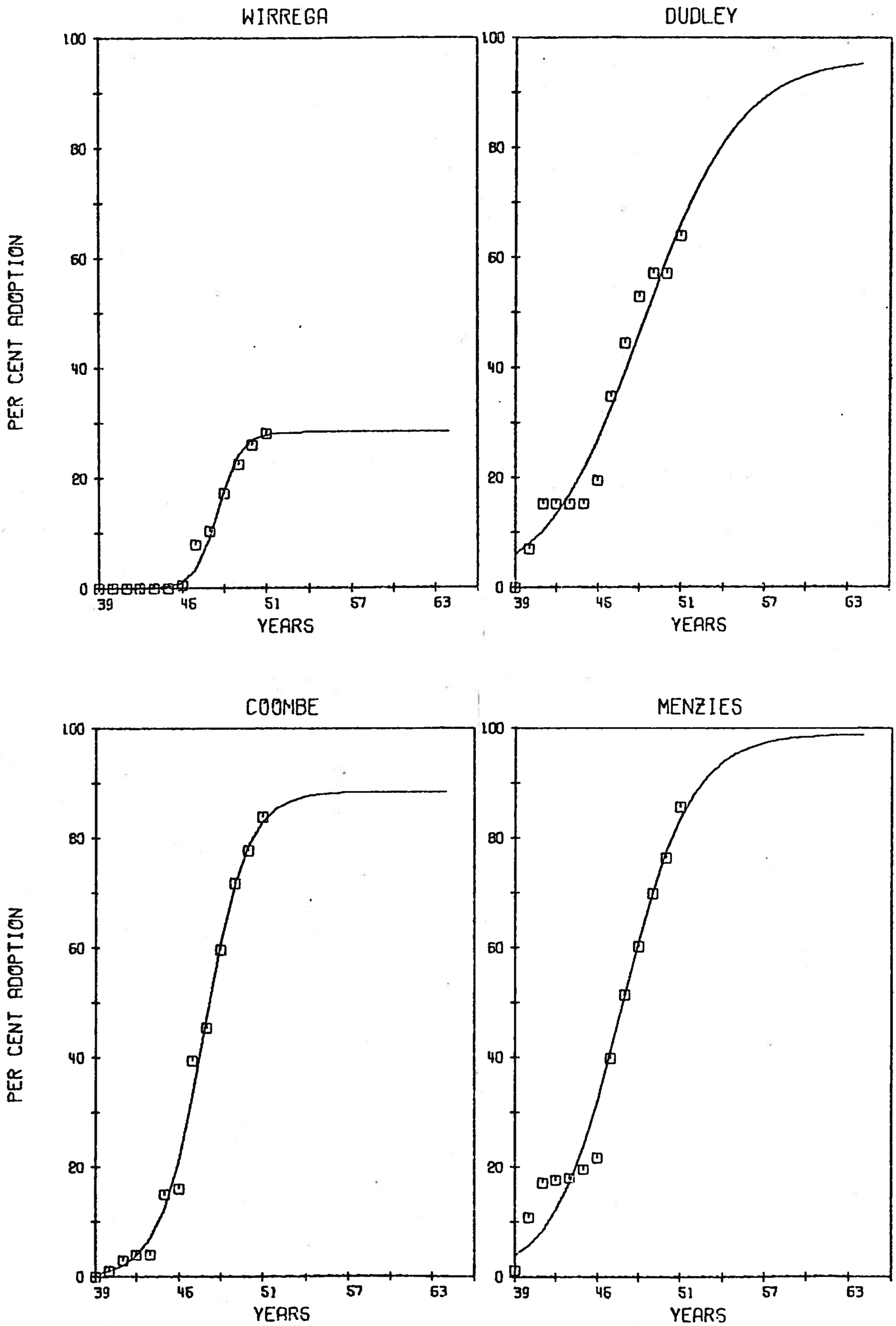

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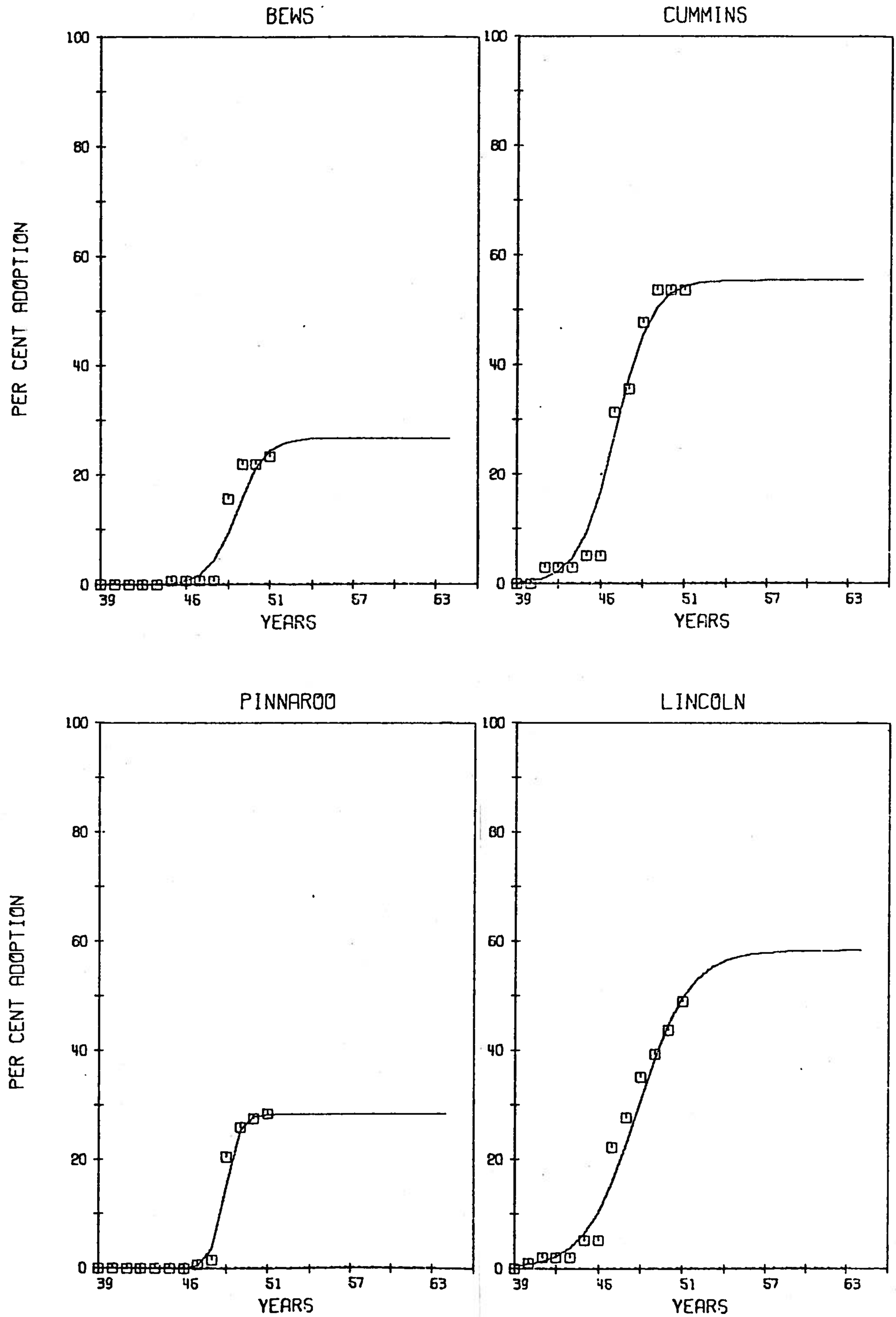

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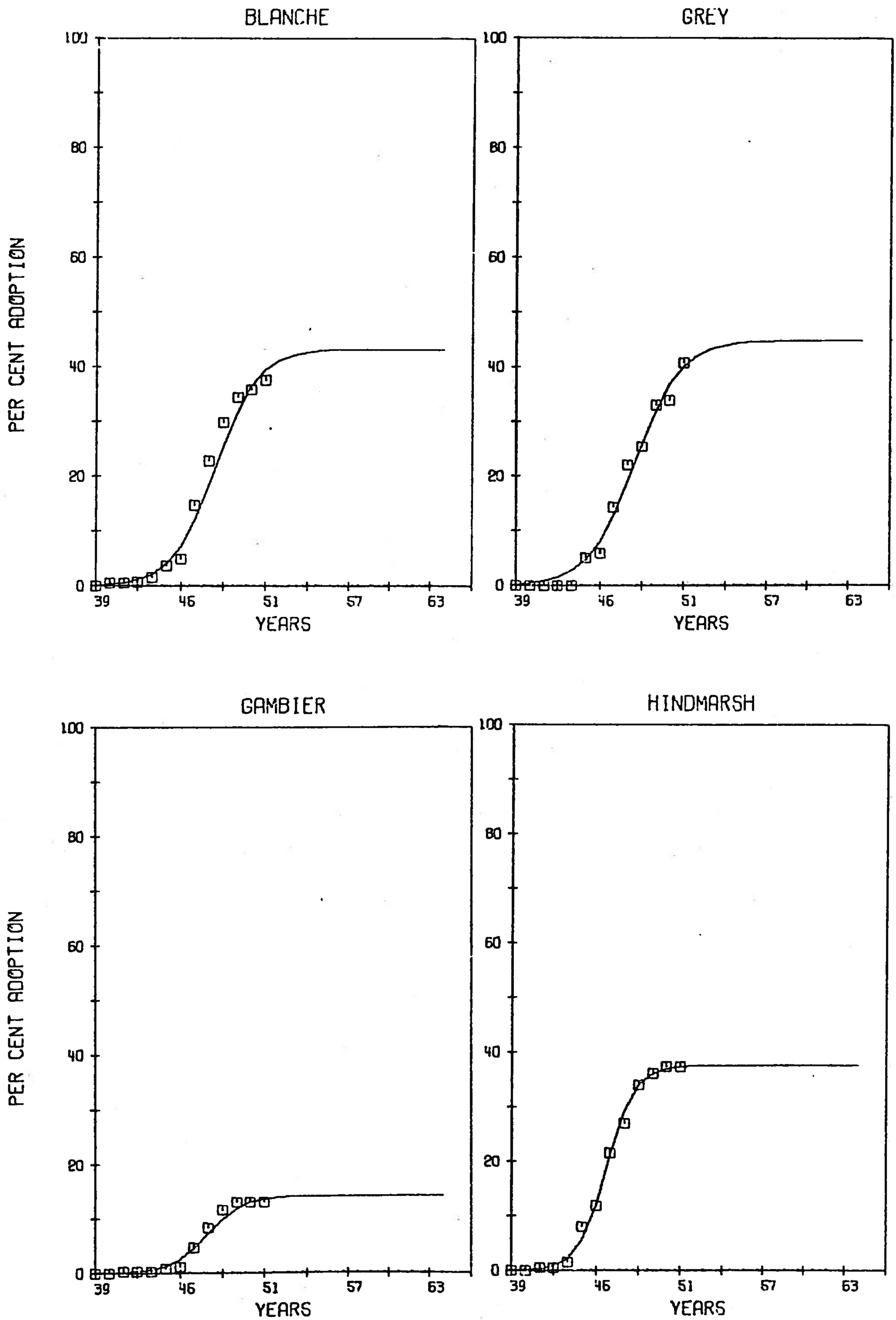

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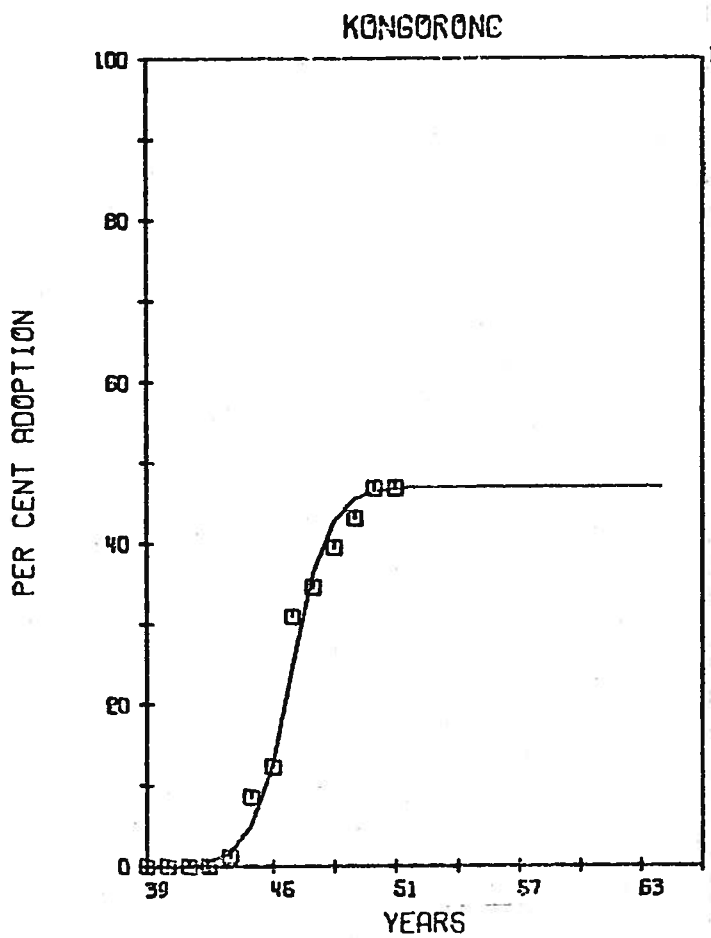

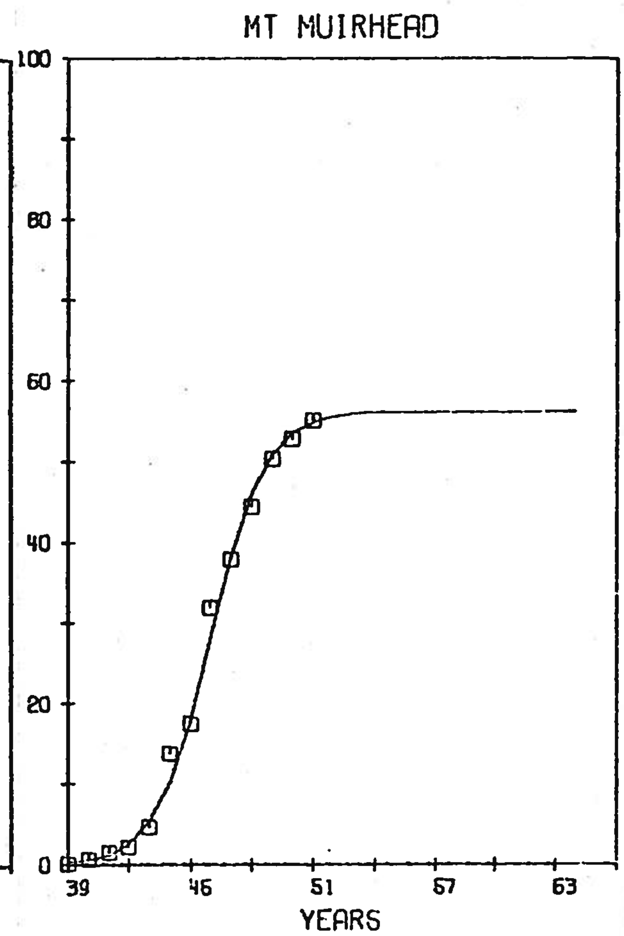

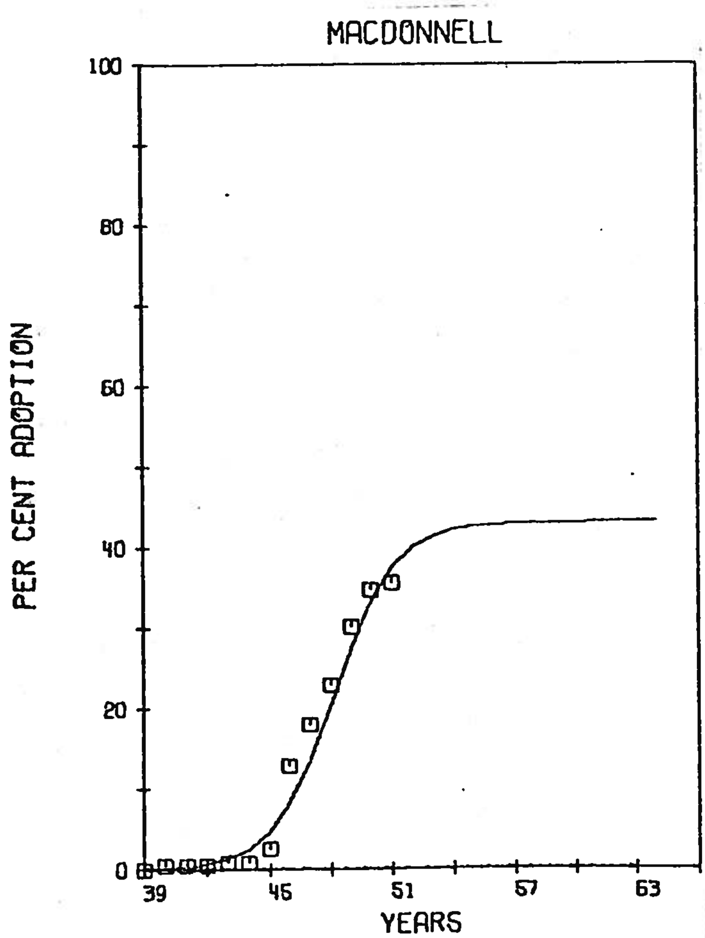

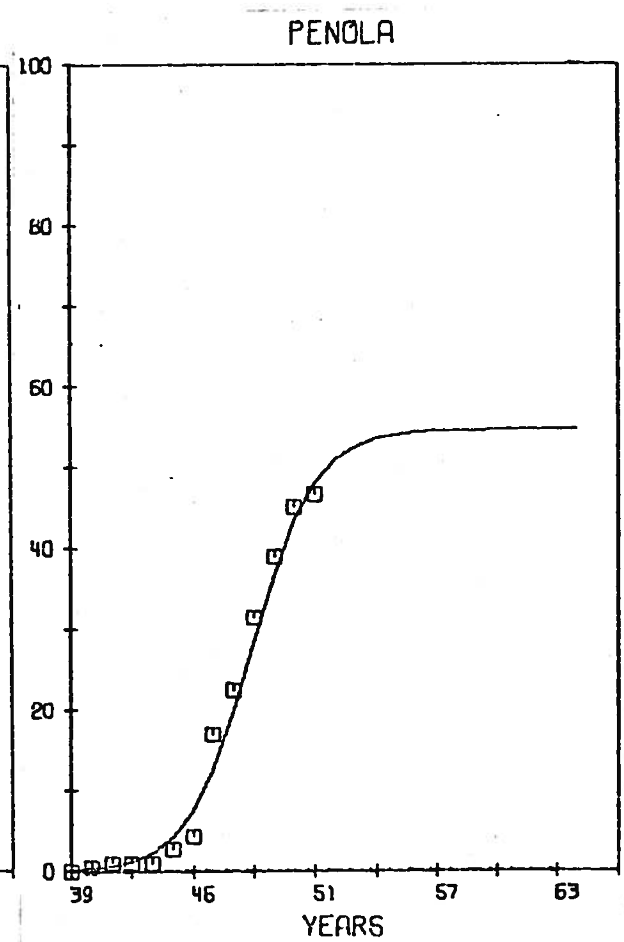

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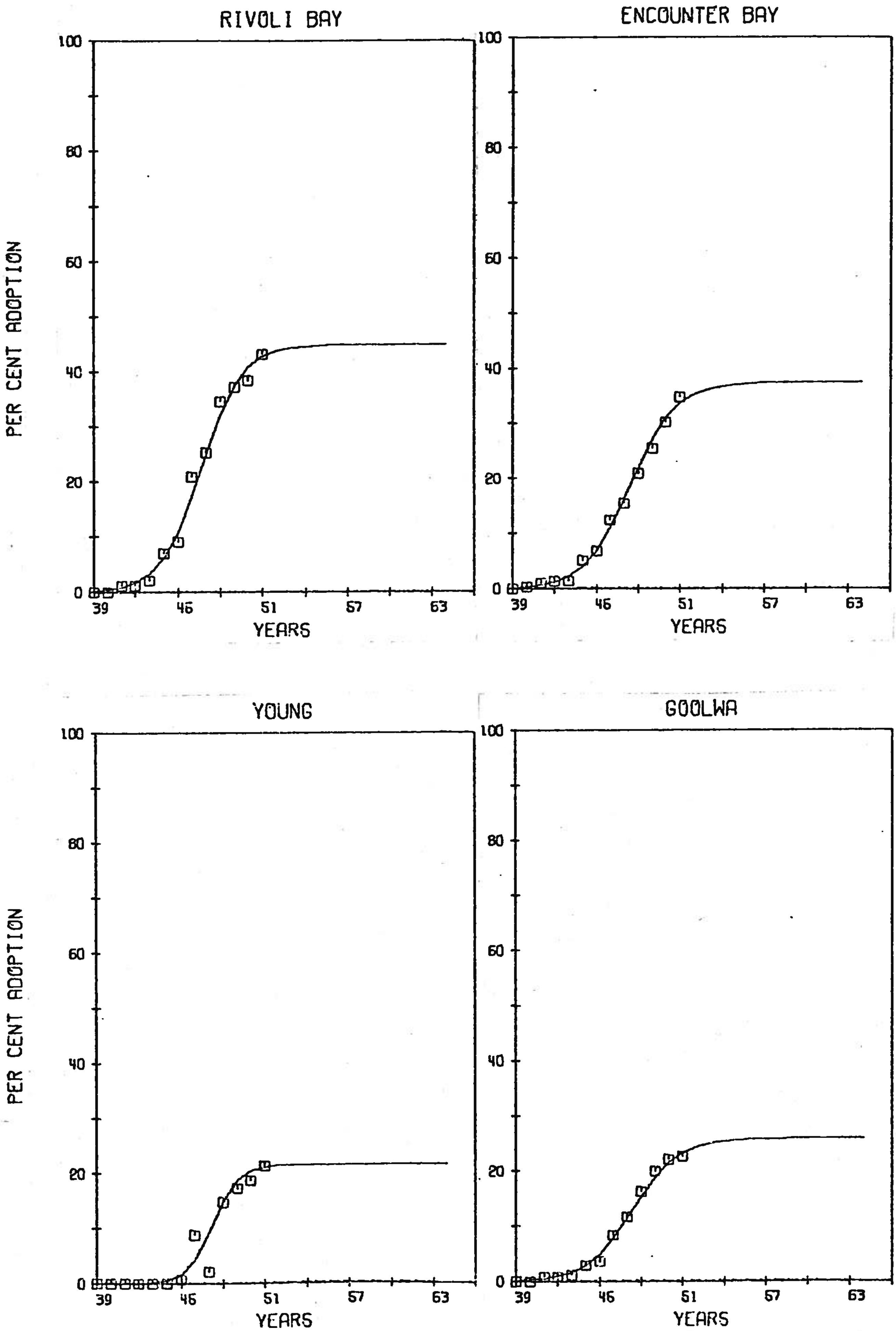

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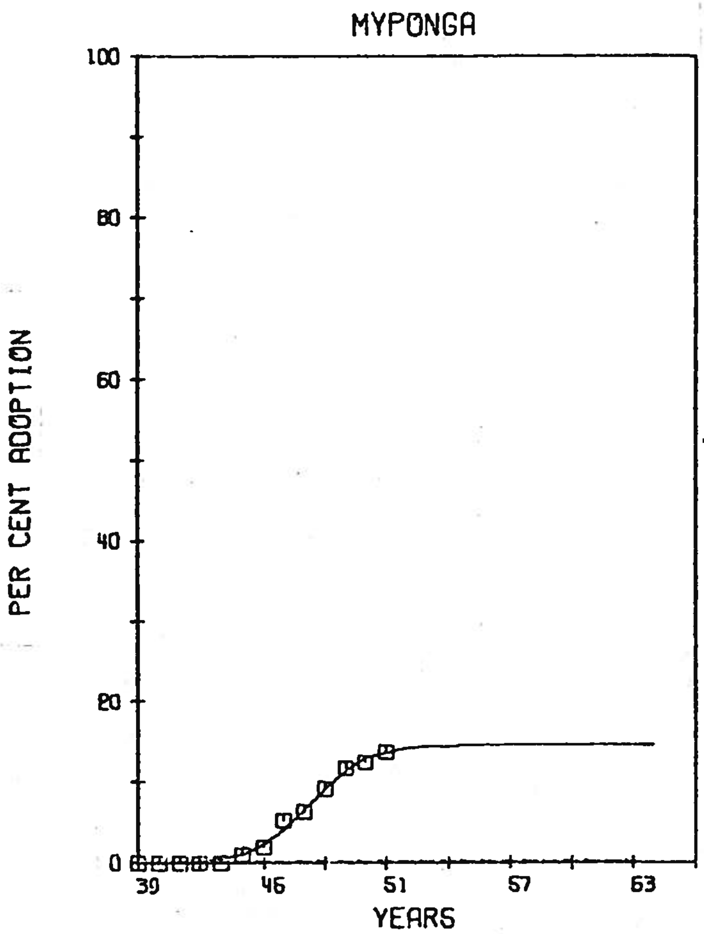

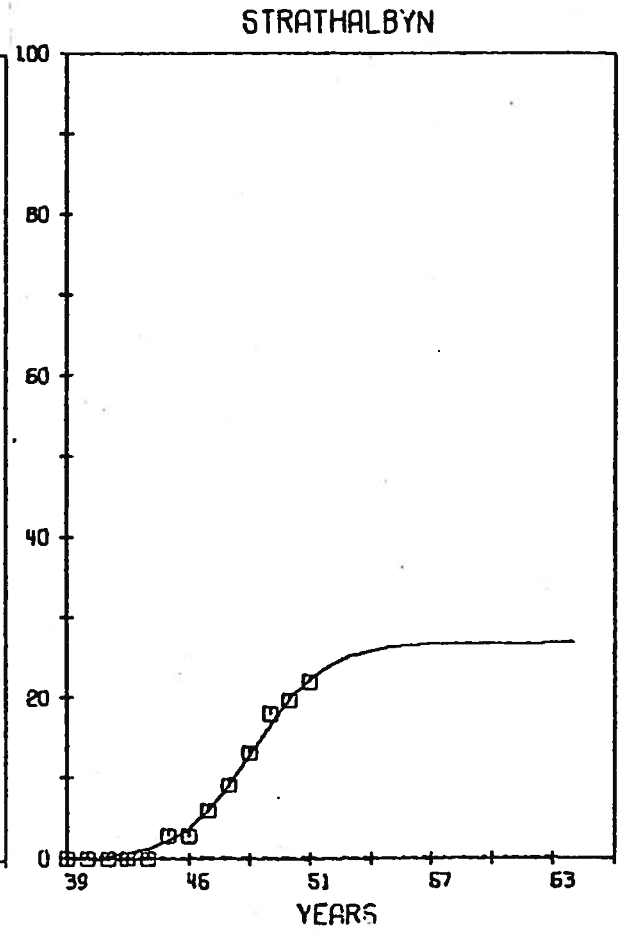

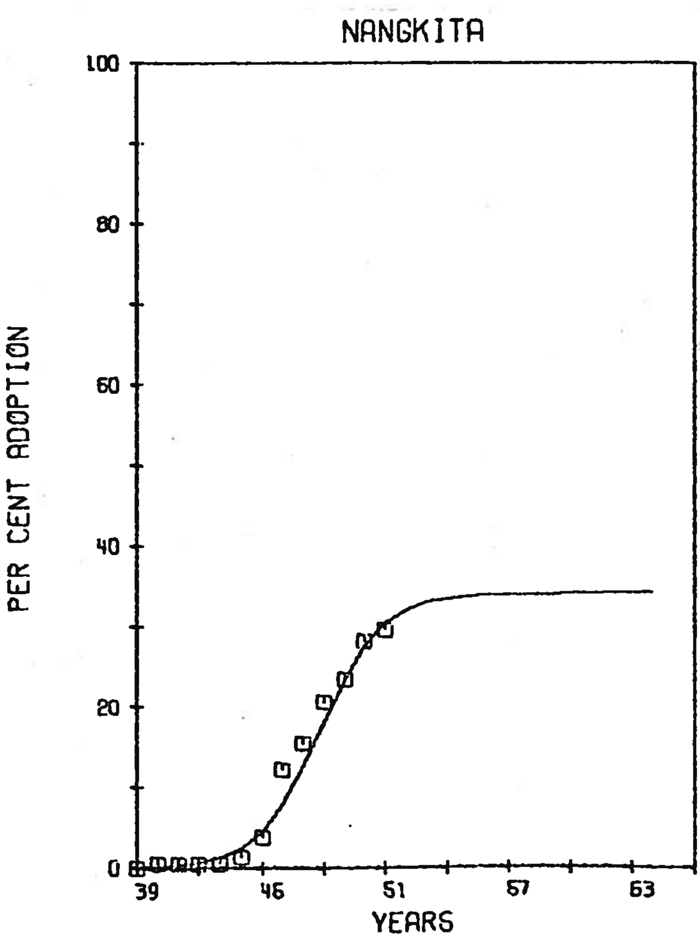

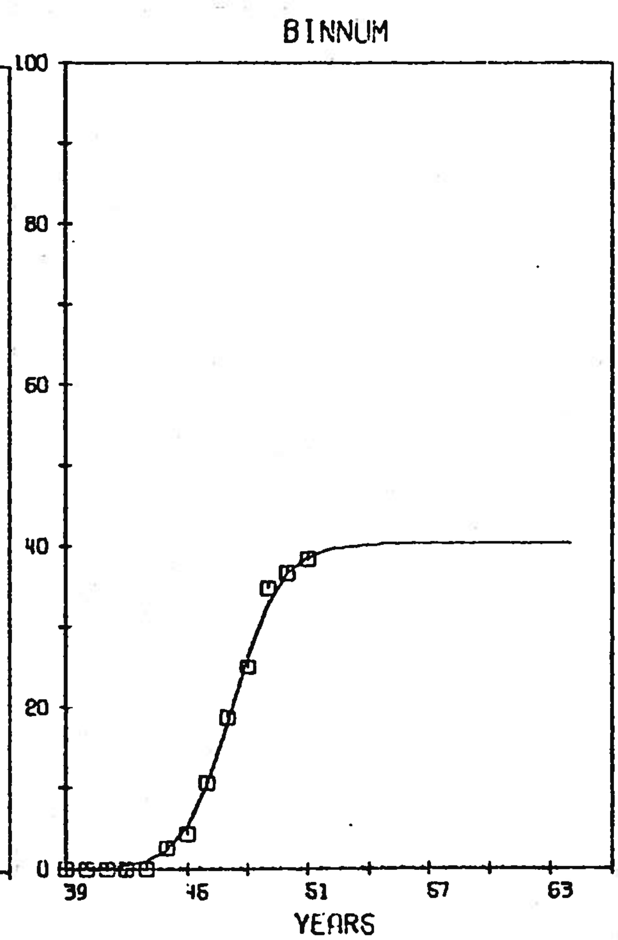

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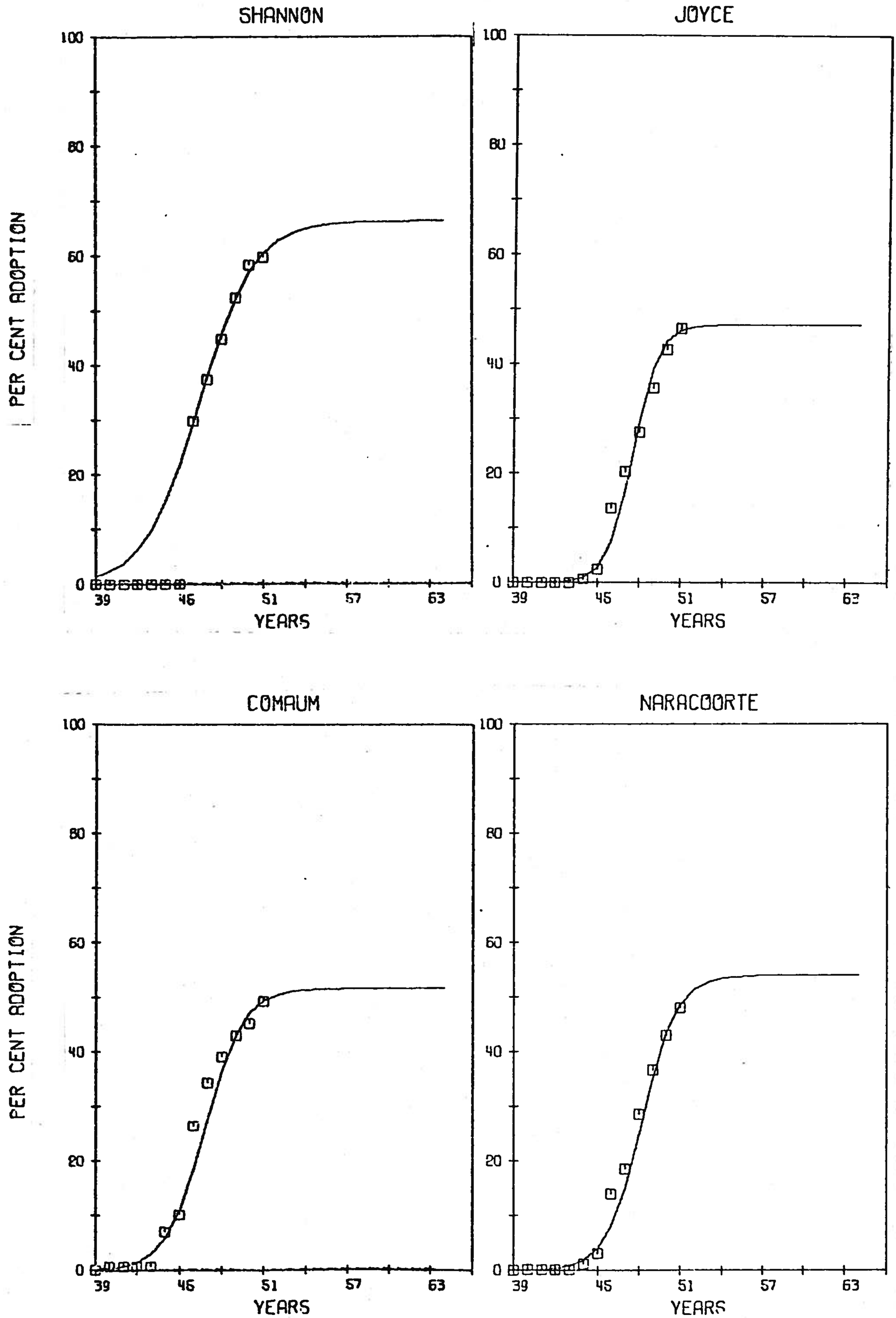

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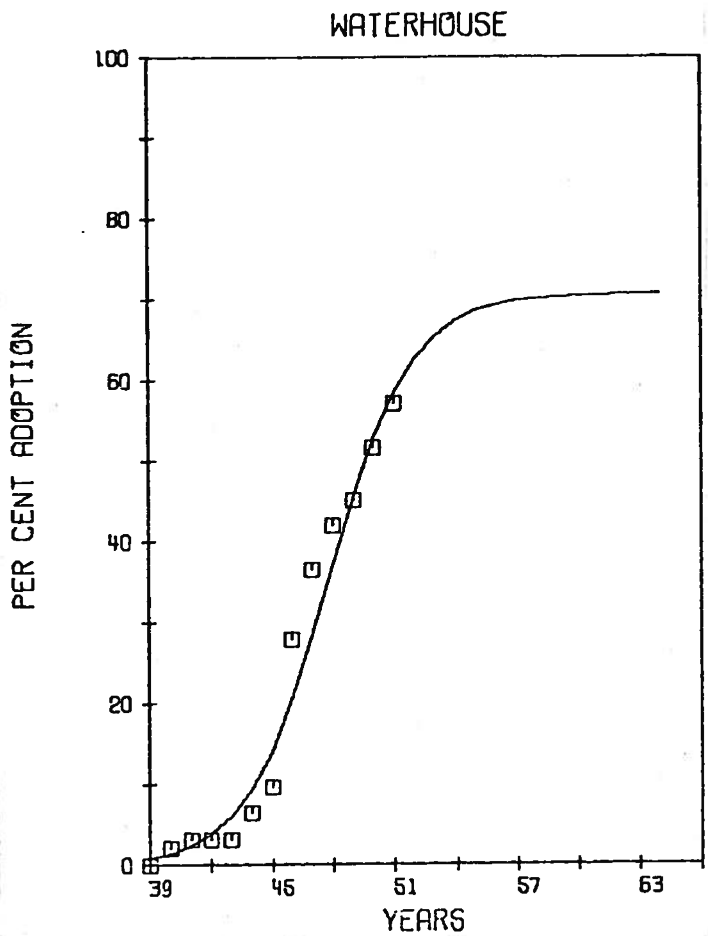
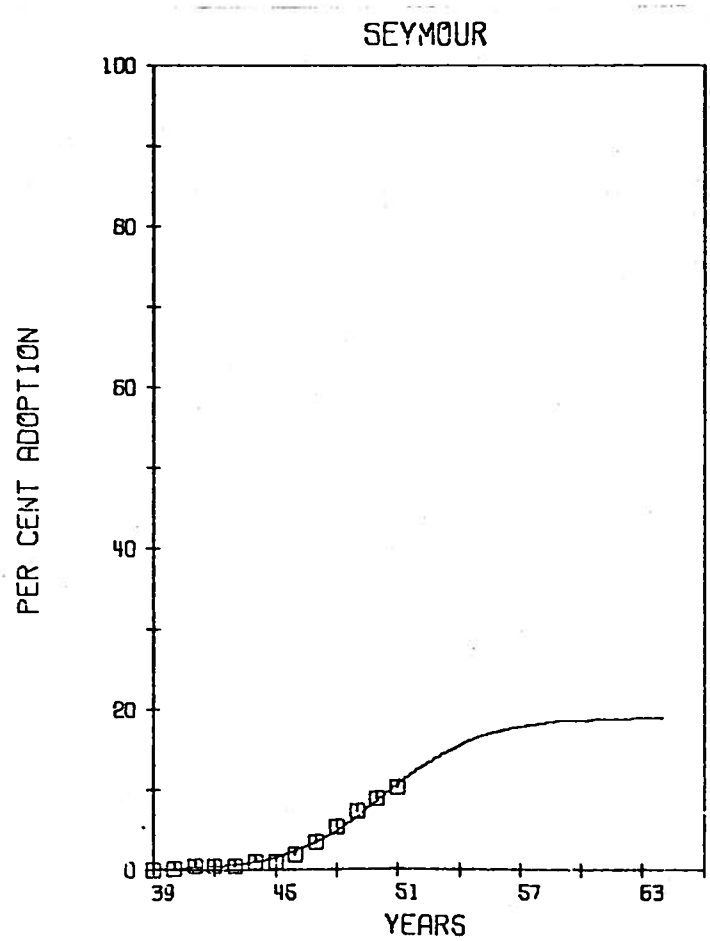




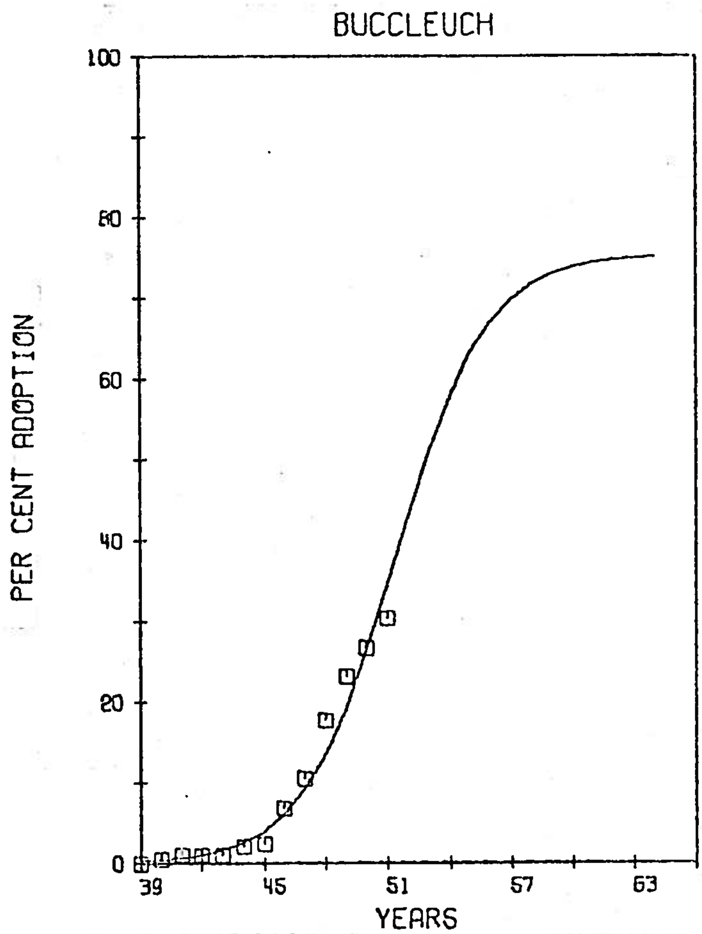
LEGEND

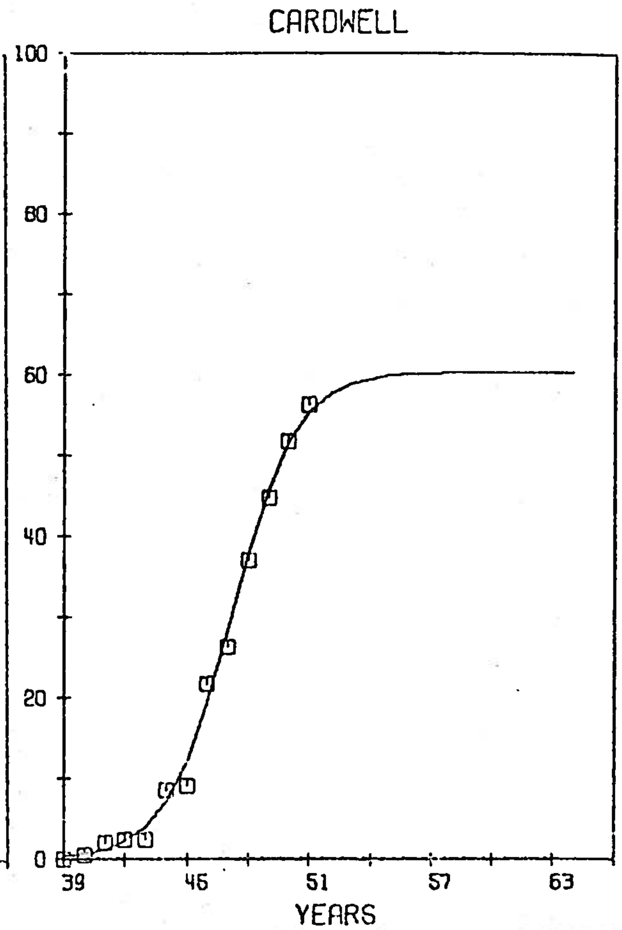
— Fitted logistic

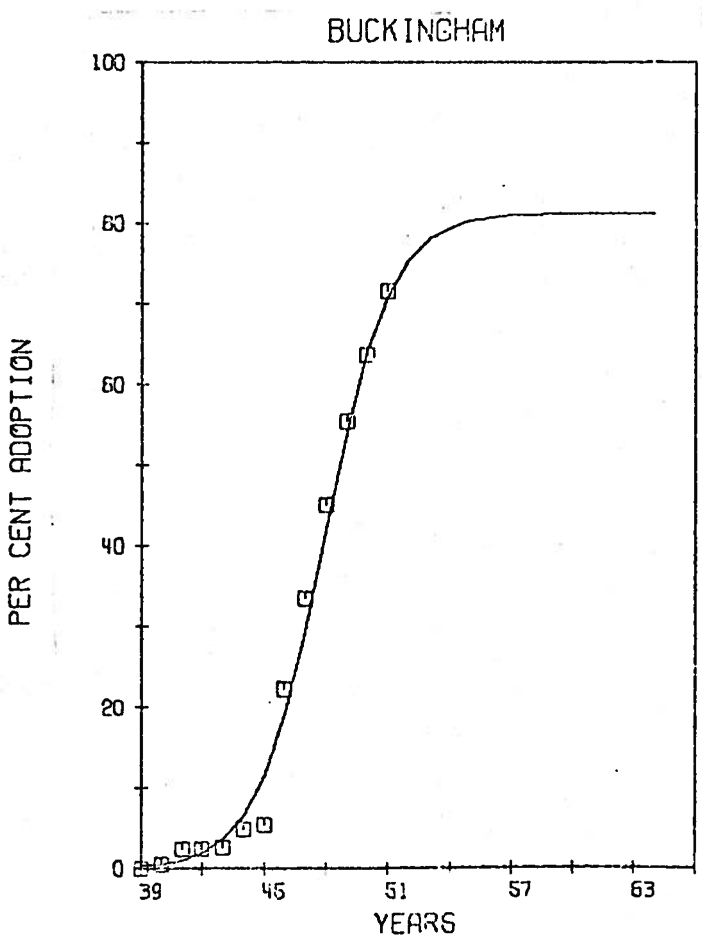
□ Cumulative percentage number of adopters per year

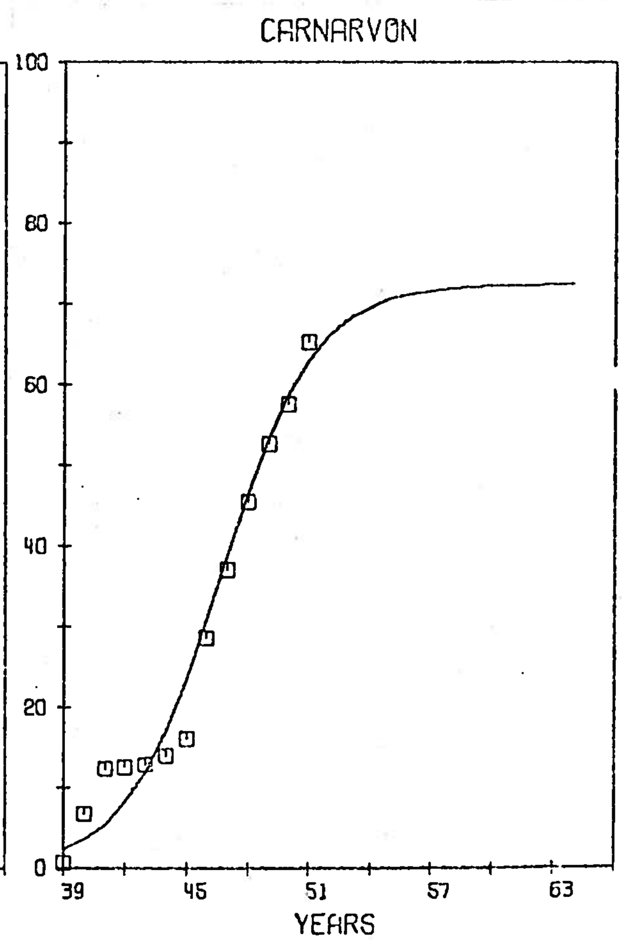
APPENDIX C (Continued)

2. PERCENT ADOPTION BY YEAR FOR COUNTIES









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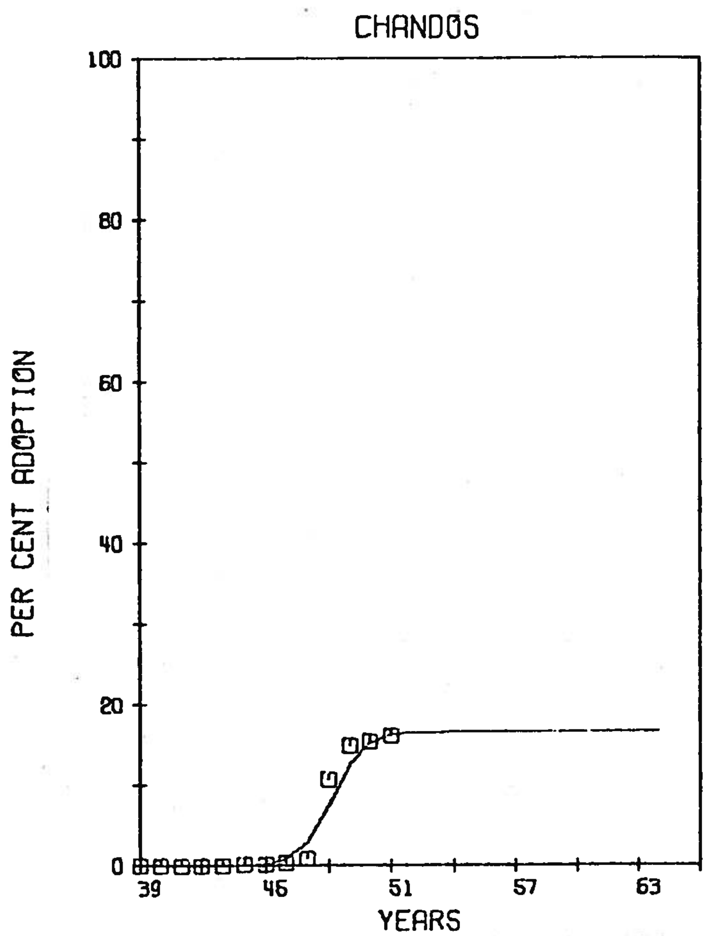

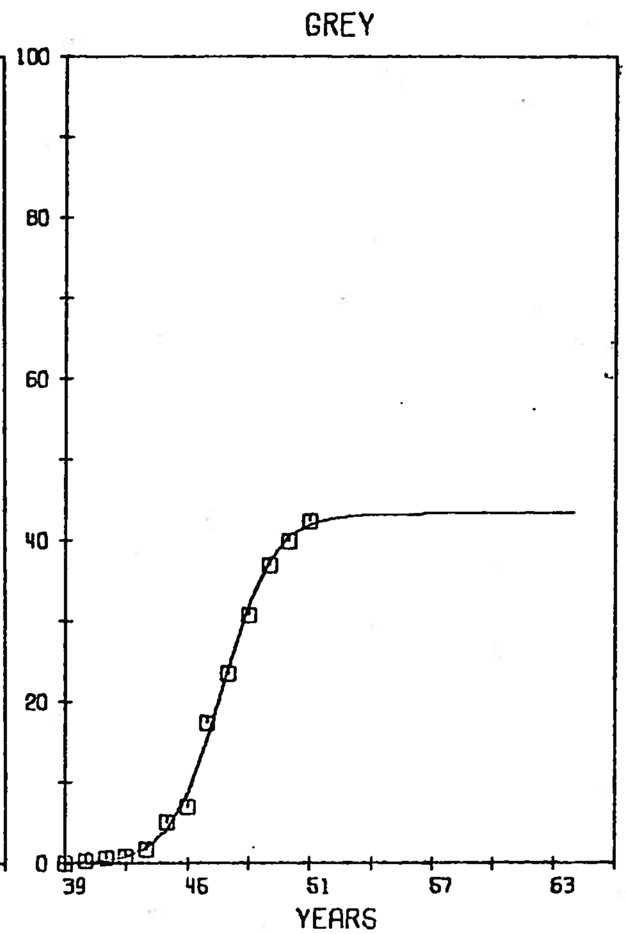

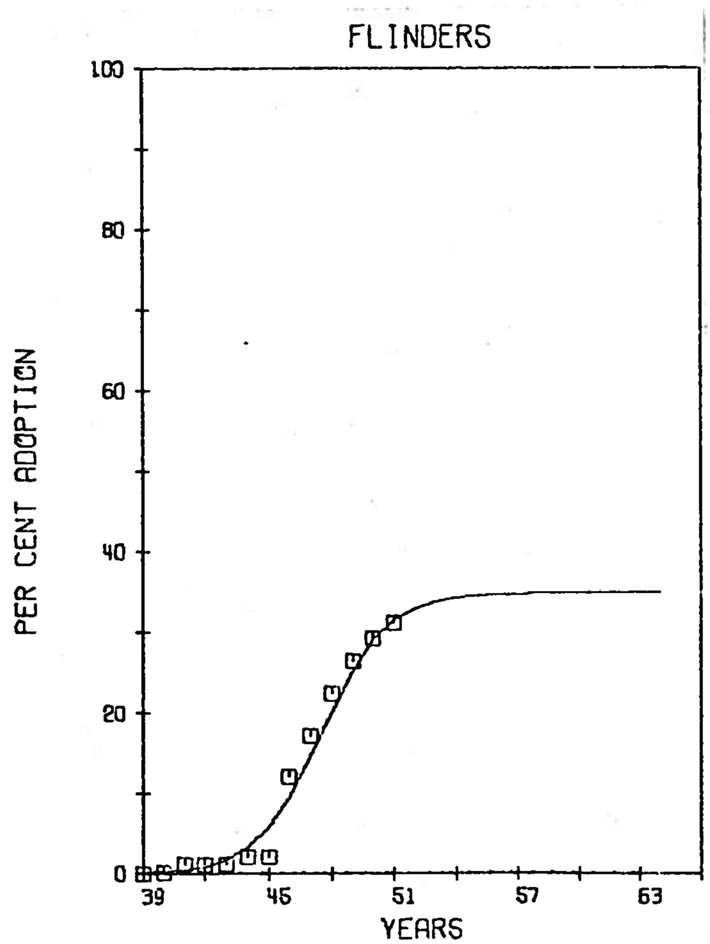

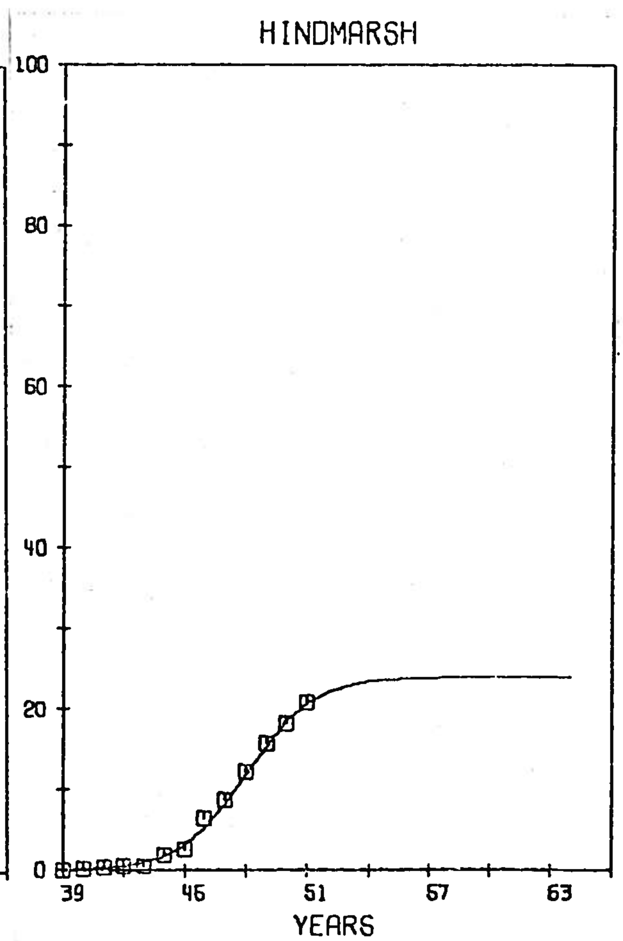

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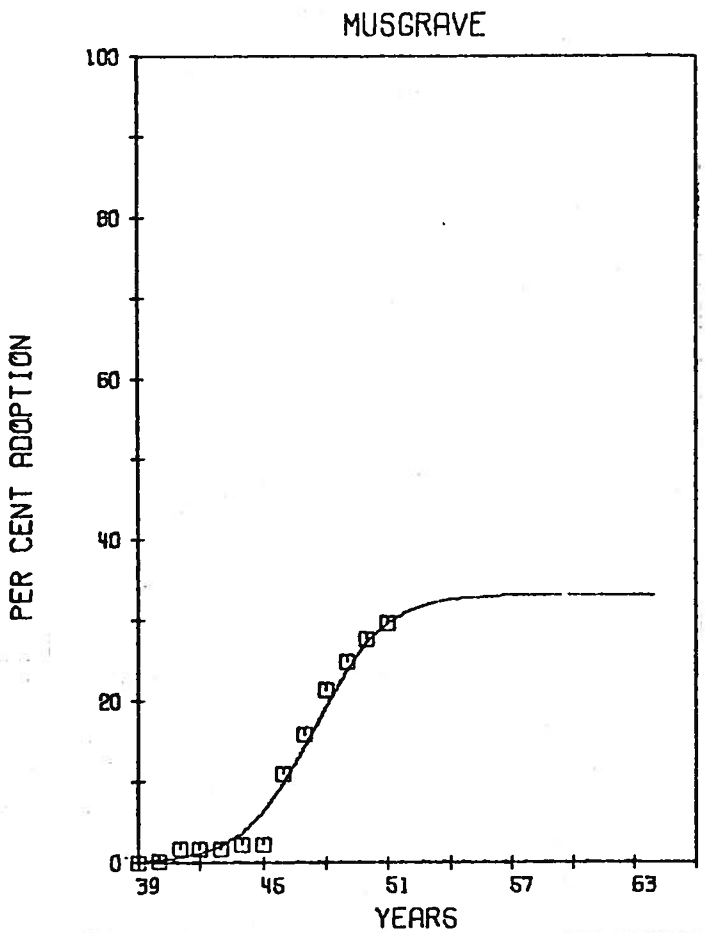

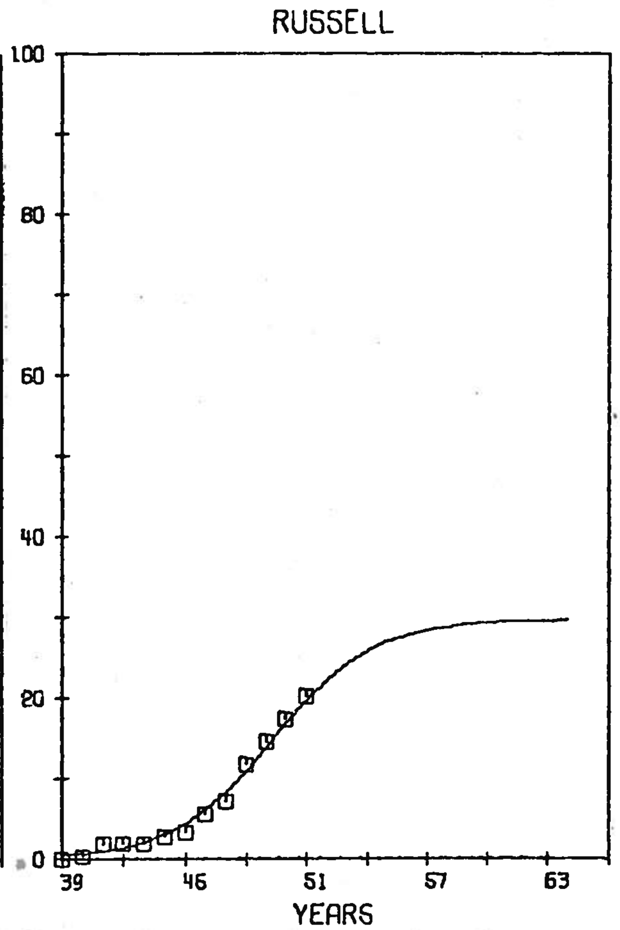

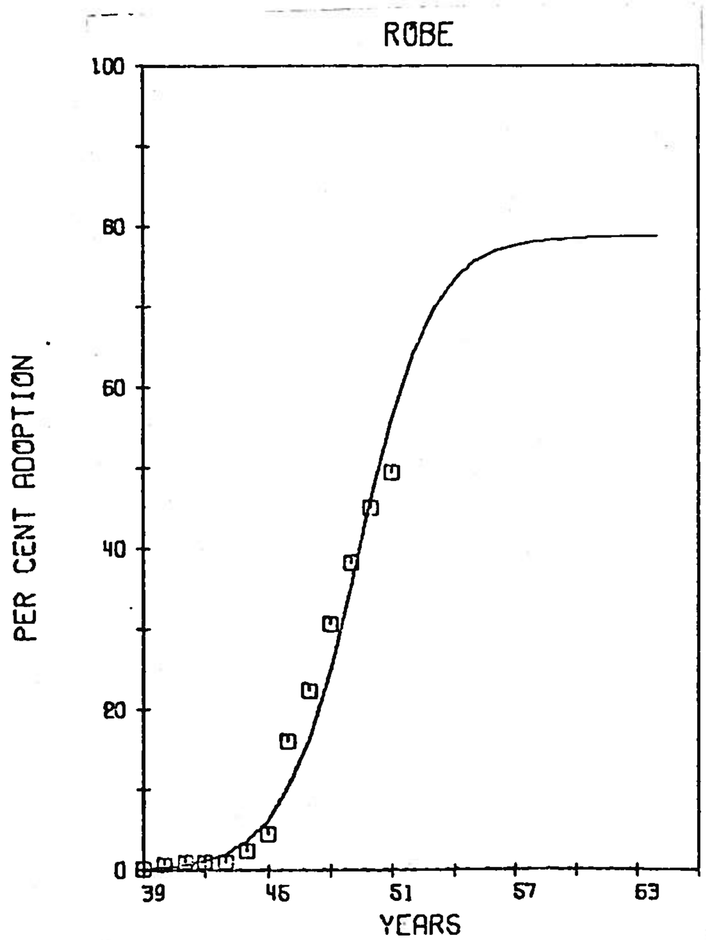

LEGEND

— Fitted logistic

☐ Cumulative Percentage number of adopters per year.

APPENDIX D

1. SOIL INDEX

Given the lack of broad scale experimental data, a subjective but nevertheless informed ranking of soil types with respect to their absolute level of responsiveness to copper-zinc applications was made independently by three soil scientists. These estimates were used in conjunction with compatible data found in Tiver [1955], Ferres and Trumble [1943] and Donald and Prescott [1975] to compile the ranking detailed in Table 1 below. The soil classificatory units employed are based on the Great Soil Groups that are described in Stephens [1956].

TABLE 1

Soil Types by Response Category

Soil Type	Response Category
Alluvial	Low
Skeletal	Low-Medium
Calcareous	High
Podzols	High
Grey-brown, brown, red, yellow and meadow Podzolic	Medium
Lateritic Podzolic	High
Krasnozems	Low
Terra Rossa	Low-Medium
Black Earths	Low
Rendzina and Ground Water Rendzina	Medium
Solonetz and Solodized Solonetz	Medium-High
Solodic	Medium-High
Red-brown Earths	Low
Solonized brown	Medium
Lateritic red Earths	Low
Grey and brown Clays	Low-Medium

The responsiveness was in terms of increased dry matter yields in the case of pastures and increased grain yields in the case of cereals.[1] Although the absolute increase in pasture yields(and therefore the absolute potential profitability increase)may not equal the absolute increase in cereal yields, it was felt that the ranking of soil types with respect to either of these aspects would in general result in a similar ordering. (As this soil index is applied to a cross sectional analysis, it is sufficient to use a relative rather than absolute measure of soil responsiveness). The soil types were then grouped under five response categories, namely, high, medium-high, medium, medium-low and low. (See Table 2 below).

The final step in the construction of this soil index is to determine the proportionate area of each geographic unit of analysis that is covered by soils in each of the five response categories listed above. This was achieved by reference to the CSIRO's 1968 soil map of South Australia. In order to make the Northcote system of soil classification that was used in this soil map compatible with the Great Soil Group categories employed above, it was necessary to again enlist the help of the soil scientists as well as the table presented in Northcote's [1960, p.44ff] Atlas of Australian Soils. Although exact compatability between these two classificatory systems is impossible to achieve due to the different criteria that they employ to classify soils, the degree of compatability that was obtained was considered sufficiently accurate for the purposes of this study.

Details concerning the proportionate area of each geographic region of analysis that was covered by soils in each of the five response categories is given below. (Table 3).

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[1] This measure of profitability increase resulting from the use of copper-zinc mixtures is a *potential* increase in the sense that management or climatic factors may influence this increase somewhat. In the case of climate, the ranking was constructed on the understanding that climate was not a constraint on the soil response achieved.

TABLE 2

Counties by Soil Response Category

County	High	High-Medium	Medium	Medium-Low	Low
Buccleuch	8	10	82	0	0
Buckingham	14	67	0	6	13
Cardwell	22	63	11	0	0
Carnarvon	26	18	30	26	0
Chandos	42	0	60	0	0
Flinders	8	31	24	34	1
Grey	24	44	10	18	0
Hindmarsh	15	17	27	28	9
Musgrave	3	17	10	70	0
Robe	20	49	25	4	0
Russell	30	0	44	9	8

TABLE 3

Hundreds by Soil Response Category

Hundred	High	High-Medium	Medium	Medium-Low	Low
Willunga	0	19	19	24	38
Price	3	0	97	0	0
Stirling	4	92	0	4	0
Tatiara	0	77	0	23	0
Wirrega	0	53	0	47	0
Coombe	15	71	15	0	0
Dudley	9	47	0	44	0
Menzies	8	44	29	19	0
Bews	0	38	62	0	0
Pinnaroo	8	0	93	0	0
Cummins	0	85	3	1	11
Lincoln	0	21	24	55	0
Blanche	35	57	0	9	0
Gambier	70	28	0	2	0
Grey	0	100	0	0	0
Hindmarsh	49	2	43	12	0
Kongorong	5	0	0	92	0
Macdonnell	18	31	0	49	0
Mt. Muirhead	18	18	36	11	13
Penola	0	85	12	4	0
Rivoli Bay	16	12	48	22	2
Young	30	66	0	5	0
Encounter Bay	28	4	68	0	0
Goolwa	5	51	32	0	12
Myponga	0	0	65	35	0
Nangkita	0	53	47	0	0
Strathalbyn	0	0	13	41	46
Binnum	3	68	0	29	0
Shannon	0	52	0	30	17
Comaum	30	30	26	16	0
Joyce	18	65	15	0	2
Naracoorte	19	41	38	1	0
Waterhouse	39	15	22	24	0
Seymour	10	0	82	0	8

APPENDIX D (Continued)

2. RAINFALL DATA

Yearly rainfall totals by County for the period 1939/40 to 1964/65 were also obtained from various issues of the South Australian Statistical Register. Hundred level data was obtained by reference to the compatible County figures. (N.B. Hundreds are a sub-set of Counties). Although these rainfall variables performed quite well in the analysis, it was felt that a finer classification of the rainfall statistics would have improved the results.

3. STEELY WOOL

The proportionate area of each hundred for which the evidence of steely wool occurrence was recorded was calculated by reference to the original and enlarged version of the map constructed by Lee in 1948 and presented as Figure 8 in C.S.I.R.O.'s 1976 publication. By collaborating with wool brokers, Lee was able to obtain the names of all South Australian growers whose clips (for the period 1939-1946) contained steely wool. After locating their holdings, he plotted them and thereby constructed a composite map representing the copper deficient areas for the settled areas (i.e. the areas within the Counties) of the State. (Steely wool is the result of a copper deficiency).

In fact this map only represents part of the picture with respect to the extent of copper deficiencies at the State level in that only sheep-carrying areas had the potential to register copper deficiencies with the steely wool measure used. Nevertheless it does provide an approximate measure of the incidence (but *not* the severity) of steely wool on a broad scale and for this reason was employed in this study. (Given its general lack of significance at the Hundred level, this measure was not included in the County regressions).

APPENDIX D (Continued)

4. FARM SIZE

Average farm size (acres) = average total holding acreage/average holding number for the period 1939/40 to 1964/65. Yearly holding acreages and numbers were obtained from various issues of the South Australian Statistical Register.

APPENDIX E

REGRESSION RESULTS

Table 1: Regression of ORIGIN (ORIG) on various 'explanatory' variables.

(Hundred Level)

N = 34

Equation no.	1	(L)1[1]	2	(L)2	3	(L)3	4	(L)4
CONST.	12.89 (3.12)*	10.19 (2.49)*	12.82 (3.07)*	10.74 (2.64)*	3.42 (2.09)*	1.39 (.22)	3.60 (.57)	.574 (.09)
(L) SIH	-.017 (.67)	-.052 (.67)			-.014 (.57)	-.045 (.58)		
(L) SIL			.022 (.55)	-.001 (.01)			.015 (.41)	-.008 (.09)
(L) FM1	-.115 (2.39)*	-1.42 (2.24)*	-.118 (2.43)*	-1.43 (2.21)*	-.077 (1.59)**	-.758 (1.05)†	-.080 (1.58)**	-.662 (.89)
(L) CON	.136 (1.06)†	.15 (.89)	.154 (1.18)†	.16 (.94)	.169 (1.34)**	.183 (1.10)†	.181 (1.44)**	.195 (1.16)†
(L) RVAR	.132 (.97)	1.02 (1.28)†	.118 (.80)	1.22 (1.56)**				
(L) RVAR1					.652 (1.76)*	2.47 (1.59)**	.641 (1.65)**	2.83 (1.87)*
(L) RBAR	-.283 (1.46)**	-1.98 (1.59)**	-.280 (1.38)**	-2.39 (2.03)*	-.216 (2.09)*	-1.12 (1.77)*	-.277 (2.29)*	-1.33 (2.23)*
(L) FMS	-.001 (.98)	-.100 (.54)	-.001 (.86)	-.09 (.48)	-.001 (.95)	-.064 (.35)	-.001 (.83)	-.056 (.30)
R^2	.32	.31	.32	.30	.37	.33	.37	.32

Notes:

1 (L) 1 is the log-linear version of equation 1.

2 ( ) = t values.

3 * sig. at the 5 per cent level (one-tailed t test)

** sig. at the 10 per cent level

† sig. at the 15 per cent level.

4 SIH and SIL = soil index measure (high and low response categories respectively); FM1 = farmer mobility; CON = contiguity variable; RVAR(1) = risk variable(s); FMS = farm size; RBAR = mean rainfall.

APPENDIX E (Continued)

Table 2: Regression of (Modified) Rate of Adoption (MRA) on various 'Explanatory' Variables (Hundred Level).

N = 34

Equation No.	1	(L)1[1]	2	(L)2	3	(L)3	4	(L)4
CONST.	4723.14 (2.95)*	9.95 (4.51)*	4912.40 (3.08)*	9.77 (4.53)*	7794.99 (3.20)*	11.35 (3.31)*	7811.75 (3.05)*	11.47 (3.32)*
(L) SIH	-6.27 (.59)	.017 (.38)			-7.93 (.77)	.005 (.11)		
(L) SIL			-1.3 (.07)	-.007 (.13)			3.96 (.25)	.004 (.08)
(L) FM1	-69.26 (3.48)*	-1.36 (3.92)*	-69.08 (3.40)*	-1.34 (3.79)*	-80.46 (4.04)*	-1.46 (3.69)*	-80.72 (3.78)*	-1.48 (3.57)*
(L)RVAR	-30.08 (.52)	.099 (.23)	-19.40 (.31)	.052 (.12)				
(L)RVAR1					-231.37 (1.46)**	-.48 (.56)	-221.71 (1.32)**	-.53 (.63)
(L)RBAR	69.02 (.84)	.27 (.40)	46.25 (.54)	.38 (.59)	68.66 (1.56)**	.53 (1.50)**	56.52 (1.35)**	.56 (1.75)*
(L) FMS	.73 (2.79)*	.30 (2.95)*	.75 (2.86)*	.29 (2.91)*	.70 (2.84)*	.26 (2.58)*	.72 (2.90)*	.26 (2.58)*
R^2	.62	.65	.62	.65	.65	.66	.64	.66

See Notes at bottom of Table 1.

APPENDIX E (Continued)

Table 3: Regression of (Modified) Rate of Adoption (CMRA) on various 'explanatory' variables (County Level)

N = 11

Equation No.	1	(L)[1]	2	(L)2	3	(L)3	4	(L)4
CONST.	1842.52 (1.03)	4.83 (1.23)†	1396.13 (0.72)	3.14 (1.21)†	3362.95 (1.03)	4.87 (1.02)	2350.26 (.69)	4.59 (1.37)**
(L)CSIS1	47.69 (2.97)*	.54 (1.46)**			45.62 (2.65)*	.47 (1.28)**		
(L)CSIS2			-38.77 (2.48)*	-.17 (5.97)*			-38.67 (2.41)*	-.17 (2.52)*
(L)CFM1	-25.55 (1.92)*	-.69 (1.35)**	-30.58 (1.94)*	-.65 (1.75)*	-26.01 (1.66)**	-.60 (1.14)†	-31.45 (1.83)*	-.71 (1.81)*
(L)CRVAR	-100.01 (0.93)	-.56 (.63)	-48.73 (.41)	-.35 (.51)				
(L)CRVAR1					-103.65 (.36)	-.20 (.15)	-67.83 (.22)	-.66 (.65)
(L)CRBAR	145.78 (0.94)	1.59 (1.18)†	264.69 (1.59)**	2.50 (2.31)*	50.20 (.44)	.99 (1.00)	218.96 (2.14)*	2.25 (3.62)*
(L)CFMS	-.108 (.58)	.12 (.52)	.21 (1.21)†	.21 (1.33)**	-.03 (.14)	.19 (.87)	.25 (1.21)†	.25 (1.74)*
$\bar{R}^2$	.53	.35	.41	.58	.46	.31	.40	.59

See Notes at bottom of Table 1.

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