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Present Value Models of Agricultural Land Prices in England and Wales

by

Timothy A. Lloyd

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A thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy
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Abstract

This study employs recently developed techniques in time series econometrics to estimate linear models of equilibrium price determination in a competitive market for durable assets. Motivating this study is the unstructured approach employed in previous land price research, where the theoretical model of agent behaviour is invariably mis-specified or left undeveloped and the empirical model prone to the problems of spurious regression. The joint issues of theoretical and statistical congruence play important roles here. Specifically, a theoretical model is developed in which market participants are assumed to price land using present value methods. At the market level this yields a reduced form expression of equilibrium price determination which can be estimated empirically using aggregate data for England and Wales. The concepts of error correction and cointegration are then investigated and applied to the land price model. A unique long run relationship is identified between real agricultural land prices, inflation and real agricultural rents. Taking account of inflation-hedging as a motivation for acquiring farmland, land prices are shown to be principally determined by the returns to land, as embodied by market rents. The empirical model is also congruent with theoretical predictions regarding the unit elasticity between asset prices and returns. The error correction representation of the cointegrating set indicates that the short run response of land prices to rent and inflation is larger than the long run response. Consequently, land prices initially overshoot their equilibrium values following changes in rents or inflation. The period of adjustment to long run equilibrium lasts around three or fours years. The long run real rate of discount on agricultural land is estimated at 3.6% confirming the widely held belief that real rates of return on farmland are low. Present value models incorporating naive, adaptive and rational expectations are also estimated and the adaptive model is favoured by the data.

Acknowledgements

A number of parts of this thesis have already been published in journals, or as discussion papers or presented at conferences. Lloyd *et al.* (1991) is based on the expectations augmented present value model developed in Chapter IV. The critique of the Traill land price model constitutes Lloyd (1990) and the cointegration analysis of Chapter VII has been published as Lloyd and Rayner (1990) and Lloyd (1992). I am grateful to a number of editors, anonymous referees and conference participants for helpful comments. A poster session at the Agricultural Economics Society conference in 1988 was particularly useful in preparation of Chapter V, as were the comments conveyed at seminars given at Cambridge University in 1991 and Newcastle University in 1992.

The work presented here is the product of an iterative process during which the support, encouragement and inspiration of others has been invaluable. The atmosphere at Nottingham has made an otherwise daunting task, enjoyable and I would like to offer thanks to all my colleagues for their contribution to the departmental culture . A number deserve special mention, particularly Chris Orme and Steve Leybourne from whom I have gained more than I could have gleaned from any number of econometric textbooks. Special thanks also to Brian Hill, Geoffrey Reed and Tony Rayner whose supervisions have stretched and enthused me for so long. In particular I would to thank Tony Rayner who has followed the thesis through its many iterations. His insight, support and patience have been exemplary and I remain in his debt. In addition, the learning process would have not been complete without the interest and time that others have given freely in informal discussion. I am grateful to Oliver Morrissey, Steve Leybourne, Christine Ennew and David Greenaway who have all played non-trivial parts in the informal development of ideas and also my general well-being.

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Chapter I
Introduction

There are few topics in agricultural economics that have generated the level of interest to parallel the volume of land market research. It is research that has a fine pedigree, dating back to the Classical analyses of Adam Smith and David Ricardo in the Eighteenth and Nineteenth Centuries. At the heart of these influential writings and more recent theoretical and empirical studies is the price of land and the factors that determine land price. Of all the questions that land market research has sought to answer there can be little doubt that the most common one concerns whether agricultural land prices are justified on the basis of agricultural earning potential. Previous responses to this question have been largely unsatisfactory, since until recently there has been no objective means available to evaluate this problem empirically, and as a result it has remained an untestable hypothesis. Deficiencies in past research motivate this present study which offers a re-examination of this interesting and elusive subject. Using new techniques developed in the field of theoretical econometrics, this thesis attempts to throw new light on this question and resolve many of the issues that have featured in the literature on land price modelling and the determinants of land prices.

The specific aim of this thesis is to develop parsimonious models of land price determination that are theoretically consistent and statistically congruent. Despite the considerable research input in to the land market, the number of econometric models of land prices in the United Kingdom has been surprisingly few. Indeed, there exists only one published econometric model of land prices, that being the model developed by Bruce Traill in the late 1970s. The theoretical foundations and empirical specification of this model epitomizes many of the land price models published in the United States at that time, all of which have failed to capture the underlying behavioural relationships at work in the land market. The mis-specification of the Traill model arises from a misunderstanding of the theory of price determination in capital asset markets and is exacerbated by a number of other methodological errors and expedients, that were employed in the model's development. The methodological deficiencies of the model and its poor performance in tracking trends in real land prices point to the development of land price equations that arise directly from economic theory.

The empirical models estimated here are derived directly from the present value hypothesis of capital asset pricing. Present value methods are attractive for the purpose of modelling, not least because they yield simple reduced form representations of equilibrium price determination. In addition the present value framework is sufficiently tractable to allow a number of issues to be investigated within it, such as the mechanism by which participants in the land market form expectations, and the long run rate of discount used in land acquisition.

It is also apparent that in general, agricultural economists have been slow to recognise the recent advances in econometric methodology that have inspired considerable activity in other branches of applied economics. At the heart of this new methodology is an awareness of the ease with which orthodox techniques of estimation and testing may be mis-used and the consequences this can have on statistical inference. This mis-use of convention techniques typically manifests itself as the acceptance of false hypotheses based on spurious regression. The so-called 'modern econometrics' attempts to remedy this illegitimate use of econometrics by ensuring that empirical data satisfy the assumptions on which estimation and testing are based; assumptions to which few analysts have traditionally paid much attention, despite the crucial role they play in statistical inference, and by implication, policy prescription.

To suggest however that the new methodology merely seeks to remedy bad practise would be to miss its most significant contribution to applied econometrics, that being the concept of cointegration. Whilst the technique of cointegration embodies the elements of good-practice econometrics, it also attempts to 'put the economics back into econometrics' via the direct incorporation of equilibrium relationships in the statistical analysis. As such, cointegration is often interpreted as the empirical counterpart of the equilibrium relationships posited by economic theory. In essence, the aim of this new methodology is to endow econometric models with a statistical credibility and an economic relevance frequently lacking in many of the models that have come to occupy so many of the pages in a typical journal of economics.

There are a number of specific issues that arise from this brief discussion that will be addressed in the Chapters that follow. These may be summarised as,

(i) What can economic theory say about the process of land price determination?

(ii) Are existing models of land price determination congruent with economic theory and do they satisfactorily explain observed behaviour in a statistically valid manner?

(iii) Are there alternative specifications that may be logically deduced from theory which satisfy the statistical requirements of the estimation process?

(iv) Can land prices be justified from their agricultural earning potential? and if not, what other factors play important roles in land price determination?
(v) What is the rate of discount on land purchase? and,
(vi) What is the nature of expectations formation in the land market?

The remainder of this introduction comprises a route-map of the way these issues are tackled. Chapter II sets the scene with a description of the historical events that have shaped the land market, giving special emphasis to the role of government policy, to which much of the changes in the land market may be attributed. It is suggested that legislation has affected the market on two fronts. First, there is the legislation that has been enacted with the specific intention of altering the ownership and operating structure of farmland. The introduction of capital taxation, planning law and numerous Agricultural Holdings Acts have been instrumental in the distribution of ownership and control of farmland, which in turn has affected the price structure of farmland. Second, there is the influence of policies designed to maintain the prosperity of the farm sector through product price support, grant and subsidy. Given that the price of land reflects the economic state and financial security of the industry as a whole, this arm of government policy has been a most potent tool in affecting the level of land prices. The Chapter also seeks to convey the complexity of the land market and the disparate motivations of the different agents involved in the market's operation.

In Chapter III attention focuses on a theoretical model of land price determination developed within a neoclassical framework. The model examines the concepts of stock and flow analysis in the demand and supply of a durable asset, building on the existing literature. The model demonstrates the property of equilibrium price convergence in a market for homogenous units of land and the independence of transactions and price in durable asset markets. The latter is of particular importance since the (spurious) correlation between price and the number of transactions forms the basis of many empirical models of land price determination. Arising from this theoretical model is a reduced form representation of equilibrium price determination which can be estimated econometrically using time series data.

The examination of price determination in Chapter III motivates a closer scrutiny of present value methods of capital asset valuation in Chapter IV. There, simple present value models are shown to have a number of desirable properties, such as, flexibility, the ability to mimic observed land price series and the fact that they allow rates of discount to be derived. The theoretical definition and empirical measures of the returns to land are discussed critically with a view to the estimation of present value models of land price determination in England and Wales. The discussion then proceeds to the issue of expectations formation within the present value framework. Theoretical models of land price determination are derived under naive, adaptive and rational expectations and then estimated empirically using data for England and Wales. Issues such as disequilibrium pricing, variable discount rates and simultaneous estimation are also investigated.

In Chapter V a critique of empirical land price models is presented which focuses on the Traill (1979) model of UK agricultural land prices. This model is shown to be lacking in a number of areas. Specifically, the model adopts a demand orientated specification in which transactions are used as a determinant of price. It is suggested that the model is mis-specified on a number of counts and its explanatory power may be attributed to a spurious correlation between price and transactions and the trending effect of inflation over time. Re-estimation of the model over an extended sample supports these criticisms and suggests that more theoretically coherent and statistically valid models should be developed.

The disquieting statistical performance of the Traill model implies that greater attention ought to be paid to the time series properties of economic variables, and this is the focus of Chapter VI. The discussion begins from the premise that standard techniques of estimation and statistical inference are not applicable to the series one typically encounters in economics. In order to use conventional statistical techniques legitimately, all data must be pre-tested to obtain its time series properties. The mis-use of conventional techniques has serious implications since it violates the assumptions on which estimation is based and thus invalidates statistical inference. A discussion of the techniques developed recently in time series econometrics to overcome this problem forms the basis of Chapter VI, where the concept of stationarity, and a framework for testing are reviewed. The empirical series used in this thesis are then tested using these techniques and appropriate transformations employed so that they may be used in further analysis. Details of the sources and construction of the series used in the empirical analysis are reported in the Data Appendix at the end of the thesis.

Chapter VII focuses on the concept of cointegration and its relationship to the time series properties of economic variables and error correction mechanisms. Since cointegration represents a general specification test for the validity of certain variables in an econometric model, it is applied here to test whether agricultural land values are determined by the land's agricultural earning potential, as measured by cash rents. It also provides a framework in which the predictions of present value model may be tested empirically and this is investigated using two of the most commonly used techniques of cointegration, developed by Engle and Granger (1987) and Johansen (1988). The techniques are described in some detail due to their relative youth in the literature and an evaluation of the pitfalls and opportunities of cointegration is offered.

Chapter VIII departs from the analysis of structural economic models to develop statistical forecasting models of cash rents and land prices. This change of direction stems from the fact that structural models are generally impotent for the purposes of forecasting. The models developed here belong to the autoregressive, integrated, moving average (ARIMA) class, initially developed by Box and Jenkins (1970). These models are complementary to the structural economic models developed in earlier Chapters and provide a basis for future econometric modelling.

The conclusion is presented in Chapter IX where a summary of the results is initially outlined. These results seek to answer the questions that have been posed in this introduction concerning the theoretical specification of land price models and empirical issues such as discount rates and expectations formation. There are however a number of limitations to the analysis and these are discussed in the present context and also with an eye to future research. Indeed, as with most research, in attempting to answer one question the analysis throws up another, perhaps more interesting question, and this thesis is no exception. Consequently, the conclusion ends with some suggestions for future research that have arisen from this study that merit further attention. Whilst this study attempts to offer answers to a number of questions, it also provides a framework for future research on a topic that has important policy implications, particularly so in an era of agricultural policy reform.

Chapter II : A Historical Overview of the Land Market

II.(i) Introduction

The land market in England and Wales has a long and rich history that has evolved over many centuries, reflecting not only the institutional arrangements imposed on it, but the changing state of agriculture. Indeed, the price of land has traditionally been regarded as a barometer of the industry as a whole and a quick glance at a time series of land prices (illustrated in Figure II. 1) acknowledges this view. The troughs and peaks observed in the land price series all neatly coincide with historical events that have affected the prosperity of the industry generally. Whilst the strength of the 'market fundamentals' explanation is undeniable, its simplicity belies a rather more complex reality that has been shaped by the cumulative effect whole host of influences, such as the pattern of ownership and occupancy of the land. This chapter offers a glimpse at these processes and events and focusses on the role of government policy - a factor that has been instrumental in the evolution of the land market. The importance of policy is two-fold, since, in addition to the legislation that has been enacted to deal specifically with the manner in which land is held, traded and taxed, measures taken to affect the industry's prosperity on which agriculture is now reliant, also affect the market for and the price of land.

The overview of events presented here is purely descriptive and merely serves as a backdrop to the largely abstract and statistical developments presented later in which assumption and simplification play important roles for obvious reasons. No attempt is made to quantify the effects of specific legislation on land prices since it is generally fair to say that legislation has more of a cumulative effect on the actions of participants involved in the market, and thus change is of a more evolutionary nature. Thus, whilst a historical time series of land price is presented only occasional reference is made to it, although the reader may prefer more frequent consultation of the series.

This overview concentrates on developments in the land market over the last 150 years since the legislation enacted in this period is pertinent to the characteristics of the market today. Whilst the modern farming landscape owes much to the political and economic considerations that have motivated decision-making more recently in the post war period, there are many artefacts, still evident today, that predate parliamentary involvement. The overview begins at the dawn of the transition from feudalism to capitalism.

II.(ii) The Origins of the Land Market

(a) Enclosing the Open Fields of England

Prior to the Norman Conquest in 1066, feudal agriculture predominated in most of England. In feudal society farmland was cultivated by peasants according to the open field system. In this mode of agriculture the cultivatable land typically comprised three large fields - the open fields - in which peasants would grow crops on strips of land in each. Few hedges or walls existed, and those that did merely marked out one field from another or were erected to contain the livestock that grazed on the common land on which peasants could rear livestock and cut hay. The Norman Conquest heralded the end of feudalism and sowed the seed of capitalism that has prevailed to the present. Among the changes initiated in the transition from feudalism was the restructuring of agricultural land and emergence of the tenant farmer. The open fields were gradually fragmented into individual farmsteads by the process known as 'enclosure'. On each farm stone walls and hedges were erected to mark boundaries and contain the increasing numbers of livestock, primarily sheep, which were reared in large numbers in this era due to the high price that wool commanded. The peasants of feudalism became the labourers and tenant farmers of the new farmsteads under capitalism.

The enclosure process was a gradual one up to 1750, (at which time approximately half of the arable land in England had been enclosed) and often resulted in evictions and bitter disputes over rights to common land. However, in the following century over 3000 parishes were enclosed by Acts of Parliament. Enclosure Commissioners were assigned to each region to settle any disputes, and generally aimed to produce squarish fields from 2 to 24 hectares in size and build new roads. In northern England, Wales and Scotland enclosure was not as common, primarily because feudalism and the associated open field system was not as prevalent in these districts. The characteristic form of the English Countryside, which was created by the enclosure process, was further maintained by landlords (and the small number of owner-occupiers) because of the custom of primogeniture, whereby the entire estate was passed onto the eldest son as opposed to being split up among all the relatives. Thus,

> '. . . by the middle of the nineteenth century the more productive lands of Great Britain were owned by large landlords and farmed by their tenants in units almost always large enough to permit efficient management.' Tracy (1982) p.41

(b) The Corn Laws and the Landed Interest

Whilst agricultural trade protection had been in operation in England since the Middle Ages, the Corn Laws had become an important protective measure by the early nineteenth century, reflecting the economic and political power of the farming interest. Although Britain was the largest manufacturer of industrial products in western Europe by the 1850s with a predominantly urban population, agriculture still accounted for 20% of the workforce, (Orwin and Whetham 1964) and more importantly, the industry was well represented in parliament . Buttressing the economic significance of agriculture were the social and political hierarchies that evolved from the ownership of land. Landownership not only conferred social esteem but political power which was exploited successfully until it could no longer withstand the shifting balance of power that industrialisation brought.

Fearing a flood of imports after the Napoleonic War, imports of wheat were effectively prohibited in 1815, under new legislation. A subsequent relaxation of prohibition in 1828 and use of a sliding scale of import duties did little to remedy the problem and by the 1840s it was apparent that the protectionist legislation had failed to secure anything like the prosperity that its advocates had once promised. The deprivation of the urban poor in the manufacturing centres of Manchester, Glasgow and Birmingham led to a constitutional crisis and the repeal of the Corn Laws in 1846, ending nearly 135 years of agricultural protectionism, and centuries of political dominance by the landed interest.

II. (iii) The Momentum for Change 1875 - 1938

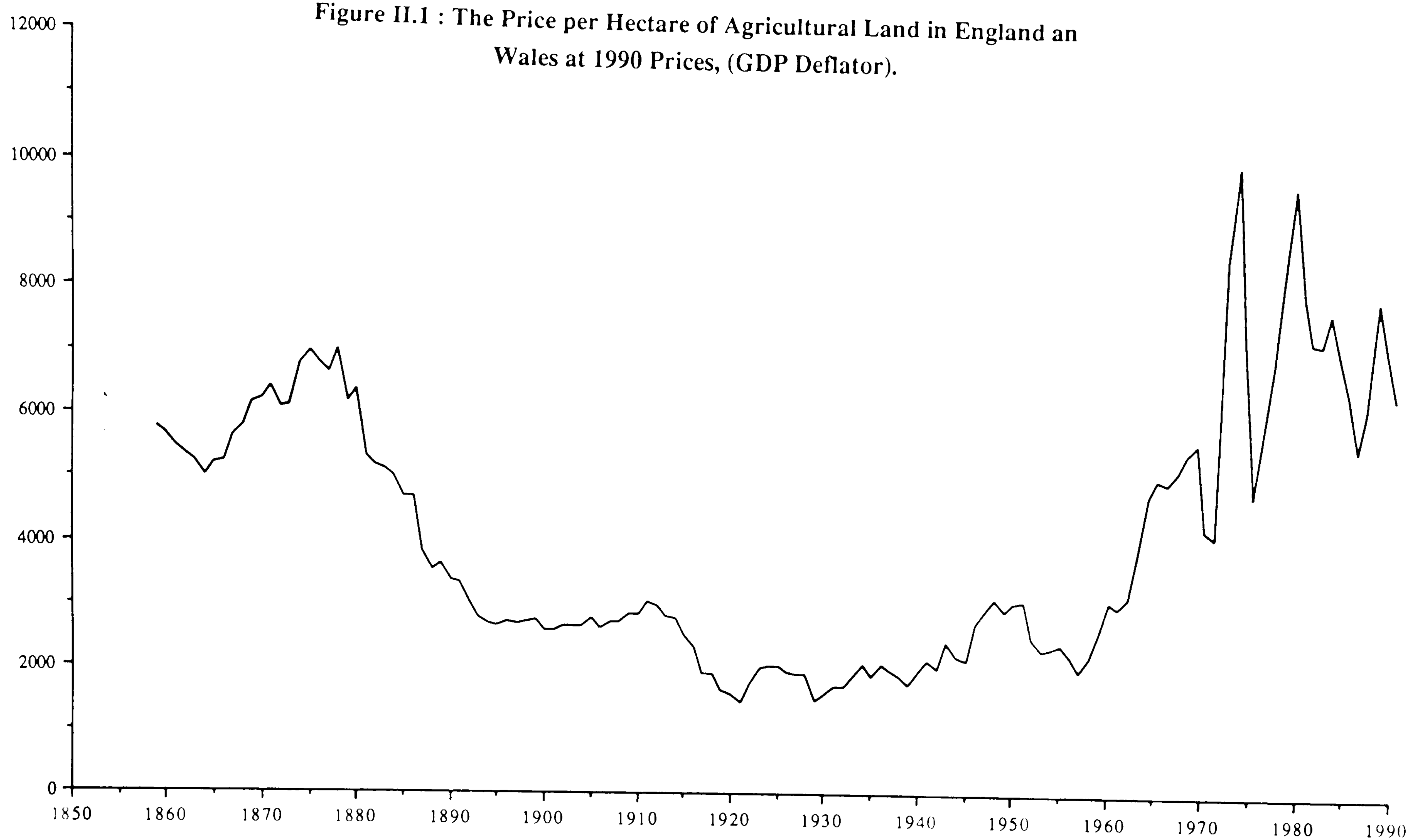
(a) The Great Depression of Agriculture and The Land Laws

During the first thirty years of free-trade agriculture prospered due to the combined effect of buoyant demand for food from a rapidly growing urban population and ironically, a number of foreign wars that restricted international trade. This period also coincided with the adoption of agricultural technology that symbolises the high farming of the Golden Age in the 1860s and as a result agricultural prosperity and land prices grew. By the onset of the Great Depression of agriculture in the mid1870s the dismal prophecies and acrimony that had accompanied the advent of free trade had largely been forgotten. Three Parliamentary Inquiries were undertaken during the depression years (1875-1895) to investigate the causes and possible remedies yet the free trade doctrine had been enshrined into the political ethos of both Liberal and Conservative parties to such an extent that even at the nadir of the depression few sought protectionist measures to alleviate it. Although some doubt has been cast on the severity of the depression in many northern regions of England (see Fletcher 1961, Saul 1972) the effect on farming in the arable counties of south-east England was catastrophic and land prices fell to a third of its value in twenty years, as depicted in Figure II.1. Recommendations made by the inquiries focussed on the antiquated relationship between tenant and landlord which was seen as hampering the process of structural adjustment and thus prolonging the depression that beset the industry. Whilst being inadequate to revive agriculture from the depression the recommendations that were written into law represented the birth of the tenurial laws that govern the tenanted sector to the present day.

The first such legislation was the Agricultural Holdings Act of 1875 which embodied many of the first enquiries recommendations concerning the arrangement between landlord and tenant. Prior to the Act, the only restrictions over the landlords' treatment of tenants, were those contained in the general civil and criminal laws of the land. A landlord could evict tenants without justification or compensation, dictate what was to be farmed and by what means, and furthermore set rents at levels he deemed appropriate. Generally however, landlords were not unsympathetic to tenants, yet in the absence of statutory control governing conduct there was not any protection for tenant farmers, (of which over 90% of all farmers were), against a despotic landlord. Moreover, as a result of having no control over the land he farmed a tenant had little incentive to work and innovate.

Although the 1875 Act sought to reduce the potential for abuse and provide guidelines, its main provision, the compensation to outgoing tenants for certain improvements to the land infrastructure, such as drainage, was largely ineffective. A loophole enabled landowners to evade this payment and in the austerity of the depression it appears that most of them did. Despite this 'false-start' to tenurial legislation, a series of Agricultural Holdings Acts subsequently strengthened the tenants position *viz a viz* the landlord : of note was the more stringent Agricultural Holdings Act of 1883, which closed the loopholes via which most landlords evaded compensation to their tenants and strengthened the tenants position regarding notices to quit, (eviction orders).

Figure II.1 : The Price per Hectare of Agricultural Land in England an Wales at 1990 Prices, (GDP Deflator).



Source : Oxford Institute Series

Another problem highlighted in the first parliamentary enquiry concerned the cost and difficulty involved in selling land. Given that rents were reduced or remitted entirely over long periods during the depression the sale of farmland was frequently the only means of liquidating sufficient capital to maintain a large agricultural estate. In an attempt to ease this problem the Conveyance and Law of Property Act was introduced in 1881, the aim of which was to simplify the procedure through which land transactions were made. Previously, this had been immensely complicated, solicitors having to investigate back many generations the origins of the title deeds being transferred. Furthermore, because the legal fees were related to the actual physical length of the deed that the solicitor drew up, the documents were not known for their simplicity or brevity (Orwin and Whetham, 1964 p.308). In complicated cases the cost of legal fees could exceed the value of the property being sold. Hence, in the same year the Solicitors Renumeration Act was passed, and as a result legal fees were based on the price of property sold.

In the following year provisions in the 1882 Settled Land Act removed the obligations of a 'limited' owner to maintain the Family estate. Traditionally, the inheritor of an estate was entrusted to maintain the land and buildings for future generations, and hence was little more than a steward of the land during his lifetime. Although this sought to preserve the continuity of family estates it frequently inhibited their ability to adjust to changing circumstances, particularly agricultural depression. The 1882 Act reflected this view and allowed the 'limited owner' to sell off any part of the family estate as if he were an owner in fee simple, with the caveat that the Family mansion could not be sold without the permission of the successor to the estate. In a similar vein the Improvement of Land Act (1899) attempted to increase the rate of structural adjustment by providing facilities for landlords requiring finance for capital improvement on their farms.

Towards the end of the depression it became clear to the newly elected Liberal government that the large agricultural landlords were incapable of reacting to economic change and a widely held belief maintained that landlords and the antiquated system of tenure were responsible for prolonging the depression. As a result a series of laws were passed towards the end of the nineteenth century to erode the accumulated wealth and diminish the economic and political power of the landed interest. Among these were the Tithe Rent Charge Recovery Act of 1891, which transferred the liability of the tithes from tenant to landlord and Stamp Duty also introduced in 1891 as a tax on all transactions of land. However, in its final year of Office the Liberals cast a far more serious blow to the landed aristocracy than any of the previous legislation with the introduction of Estate Duty in 1894. This new tax was payable at death on property owned by an individual and to the extreme annoyance of large landowners it included agricultural property. It's 'graduated' or progressive nature gave little comfort to the landed gentry, for although the tax ranged between only 1 and 8%, it's significance to the owners of the vast estates was daunting and entailed a significant upturn in transactions as large estates became fragmented in order to pay the new tax with significant repercussions on the land market and ownership of land in Britain in the following years.

The 1900 Agricultural Holdings Act introduced arbitration machinery to resolve disputes between landlord and tenant and widened the list of improvements on which tenants could claim compensation, at the termination of a tenancy. Nevertheless, tenants still did not have the freedom to crop or to sell the products that they wished. However, when the Liberal party were returned to Office in 1906 they did so on a wave of public opinion opposed to the traditional class-based structures prevailing in society - of which the traditional system of tenure epitomised. The antiquated cropping restrictions were lifted in provisions of the 1906 Agricultural Holdings Act, providing that soil fertility was not depleted by the chosen rotation. The Act also extended the grounds for compensation to include;
(i) Any repairs not undertaken by the landlord during the lease, a provision reflecting the neglect of many farms during the austerity of the Great Depression, and
(ii) 'disturbance'. This entitled tenants to claim compensation for the termination of a tenancy if the notice to quit was inconsistent with good estate management. Prior to the Act, tenants could be ordered off their farms for any reason (providing one years' notice was given) without any compensation for the upheaval.[1] These legislative changes were subsequently incorporated into the Agricultural Holdings Act of 1908, the first of the modern consolidating Acts.

On the undercurrent of radical tenurial reform in Ireland and Scotland, Lloyd George launched his mandate of extensive social reforms for Britain. The budget of 1909 proposed to raise the additional revenue necessary for the provision of Old Age Pensions and Health Insurance by increasing the death duties and introducing a land tax

1 However, as Orwin and Whetham (1964) note, many tenants were unable to benefit and left their farms without this compensation because of the imprecise way this part of the Act was worded.

on capital gains. The furore that met these proposals provoked a constitutional crisis similar to that which ushered in the repeal of the Corn Laws and resulted in two general elections and severe curtailment of the legislative powers of the Upper House. The proposals never received the Royal Assent but the controversy initiated a Committee of Land Enquiry in 1913 to investigate the rapid sale of agricultural land and its affects on tenant farmers. The recommendations of the Land Enquiry Committee were far reaching and included the improvement of working conditions, security of tenure and the establishment of Land Courts to fix rents. Had they been implemented landlords would have been divested of much of their control, however, the outbreak of the First World War in 1914 diverted the attention of the legislature to the more pressing problems of war.

(b) World War I and Sales of Farmland

By the onset of war Britain imported nearly two-thirds of its food requirements. Although import dependency had a lot to commend it on economic grounds, it left the industry ill-prepared for the demands that war would place upon it. So committed was the UK to *laissez faire* doctrine that even the outbreak of war did not affect the British position regarding free-trade. Astonishingly, Britain entered the First World War without any formal plan of ensuring food supplies to its population during the conflict although by the end of 1916 farmers were called upon to reverse the drift from arable to pasture that had taken place over the preceding forty years with the passing of the Defence of the Realm Act and the Cultivation of Lands Act in 1917 which compelled landowners and farmers to increase arable acreages.

Nearing the close of war the Defence of the Realm Act was superceded by a major piece of war-time legislation, the Corn Production Act (1917). The Act gave the Board of Agriculture powers for a six year period to enforce the 'plough policy' - the continued expansion and improvement of the cultivatable area. In return, farmers were guaranteed high prices for oats and wheat for the 1917-22 harvests, despite the fact that free market prices were far above the guaranteed prices due to war-time scarcity.

There was also considerable alarm at the high rate of land sales that had taken place during and immediately after the war. Writing in 1919, the editor of the Estates Exchange Year Book noted, '. . . the property market [has] experienced phenomenal activity . . .' and ' . . . all England seems to be changing hands'. High product prices and government guarantees effectively underwrote the prosperity of the industry particularly so since in 1920 it appeared as if the government had decided to seal the war-time union of state and industry by passing the Agriculture Act of that year. Provisions in the Act substituted the fixed guarantees of the Corn Production Act with a new scale based on war time scarcity and as a result land prices soared.

A number of other reasons however account for the apparent willingness of landowners to sell, since between 1918 and 1922 an area equivalent to one-quarter of the cultivatable land in England changed hands. In the first instance, there had been little respite in agricultural fortunes since the Golden age in the 1860s and thus when the short-lived agricultural boom surfaced at the close of the war landowners were only too keen to sell, particularly so since provisions in the 1917 Corn Production Act prohibited landlords from increasing their rents on account of the high cereal prices guaranteed in the Act. Stimulating sales of land was the burden of Estate Duty, the diminution of landlord control, and the comparative ease with which land could now be sold owing to the legislative changes in the 1880s. Although the vast majority of farms were sold to the sitting tenants, many were reticent to take on large mortgages, but did so because it was the only way in which they could continue to farm the land, (Ward 1959)[2]. Parliamentary concern at the time focused on the unwarranted eviction of tenants who could not afford to buy the land they farmed on estates which were being sold off to realise capital gains. To address this issue the Land Sales (Restriction of Notices to Quit) Act of 1919 invalidated any notices to quit that had been served if it could be proved that the landlord had sold the holding for capital gain. This broad principle was incorporated into the Agriculture Act of 1920 which tightened the rules governing compensation to an outgoing tenant. In essence, where no breach of tenancy agreement had occurred a tenant was entitled to compensation if evicted. This so-called 'compensation for disturbance' was fixed at a sum equivalent to one year's rent, although if the tenant could prove greater loss and expense arising from the upheaval, up to two year's rent could be awarded.

The general theme of tenant rights was consolidated into the 1923 Agricultural Holdings Act which extended the tenant's freedom to produce and market any farm product without the consent of the landlord, and gave him the right to rent arbitration in cases where the rent was disputed. However, an important loophole remained in the

2 However, Sturmey (1955) argues that sitting tenants had a fiscal motive for acquiring land since the basis for income tax assessment had been changed in 1918 from the annual rent or rental value to twice that figure, and thus any increases in rent would have resulted in increased tax liability.

1923 legislation pertaining to arbitration. Since landlords were not bound to go to arbitration by law, then should the landlord refuse arbitration the only recourse available to the tenant was of leaving the farm and claiming compensation for disturbance.

In addition, agricultural land was granted preferential rates of estate duty under provisions of the 1919 Finance Act on the grounds that capital values were high relative to the net earning capacity of farmland and that the duty payable would be unduly heavy for such an asset.

While the turbulence of the market was short-lived it left a longlasting legacy on the ownership structure of farmland since this period marks the birth of owner-occupation in the UK, a mode of virtually unheard of before the war. Whereas in 1914 some 89% of holdings in Britain were rented or mainly rented, by 1927 the proportion had fallen to 67%, (Hill 1985, p.190) and has fallen ever since.

(c) The Inter-War Depression 1921-1938

The sudden burst of agricultural prosperity at the close of the First World War was arrested abruptly in 1921 by the first of two sharp falls in agricultural product prices of this inter-war period. The second collapse in prices in 1929 marked the onset of the Great Depression from which agriculture and the economy at large did not fully recover until the outbreak of the Second World War. However, the response of the government to each of these shocks was quite different; whereas the first 'crash' prompted a controversial return to *laissez faire*, the latter induced a more protectionist orientation of policy.

Although the 1917 Corn Production Act was ostensibly a product of war-time emergency many farmers perceived the strengthening of government support, implicit in the 1920 Agriculture Act, as confirmation of the beginning of the 'partnership' between state and the farm[3]. In reality, the partnership was fragile and contentious. The first collapse in prices in 1921 - just the sort of emergency that the Agriculture Act was intended to counter - placed an [unacceptable] burden on the Exchequer. At a time when demands for economy were widespread, the government passed the Corn Production (Repeal) Act in August 1921, terminating the financial promises of both the

3 For the 1920 Act not only raised the guaranteed prices for wheat and oats but, more importantly, pledged to continue this assistance indefinately.

1917 and 1920 Acts. The abrupt reversal of policy left the farming community resentful and indignant : the 1921 Repeal Act became known as the 'great betrayal' of agriculture, and etched deep suspicions of any future partnership for over a generation. (Kirk 1979).

As a palliative to the industry in the wake of the great betrayal the government introduced the Agricultural Rates Act of 1923, which granted a 75% exemption for agricultural land and buildings from local rates. The farming community had argued fervently that the tax was unjust because of the high rateable value of farms in relation to their turnover and that the burden became acute in periods low product prices. As the depression worsened agricultural property, (with the exception of the farm house) was granted total exemption from rates as part of the major reforms of local authority finances in 1929.

A number of other small social measures were implemented in this period, most notably in 1926 when the Labour government made provisions in the Smallholdings and Allotment Act of that year which allowed the county councils to extend provision of smallholdings, initiated under the Land Settlement (Facilities) Act of 1919. The 1919 Act provided £20 million to set up small farms for ex-servicemen returning from the war. County Councils were given the responsibility to purchase land and furnish it with the necessary buildings, drainage and so on, on the proviso that all schemes must be self-financing, *i.e.* rents from the farms that were created must be able to repay the government loan. However, the 1926 legislation allowed the County Councils to embark upon resettlement projects that may incur a financial loss. The justification for these schemes was social; their primary aim was to relieve unemployment and not to change the structure of British agriculture. All the farms created were under 50 acres and thus were primarily suited to market gardening and other specialist enterprises.

During the 1920s the government also ventured into the provision of agricultural credit. The Agricultural Credit Act of 1923 established credit co-operatives, designed primarily to assist tenant farmers who had bought their farms at the high prices that prevailed during 1918-21 and who were subsequently experiencing difficulties repaying their mortgages in the collapse of product prices. The absence of farm credit was a notable difference between Britain and other western European countries and the failure of the 1923 Act to achieve its objective prompted the government to establish the Agricultural Mortgage Corporation in England and Wales (with an equivalent organisation in

Scotland), in a further Agricultural Credit Act of 1928. Using the farmers' land as collateral the Corporation provided secured loans, on favourable terms, from the Treasury for the improvement and purchase of agricultural land.

(d) The Preparation for War

Throughout the 1920s the historical precedent of free-trade in Britain was never breached to any significant degree. In this respect, Britain virtually stood alone: whilst Britain was adhering to free-trade, almost all other European countries were adopting increasingly protectionist trade policies and consequently world import demand was rapidly contracting. The second sharp break in prices in 1929 marked the onset of the Great Depression which remained in its most acute phase until 1933. The inability of the *laissez faire* policies to redeem the economy from depression instigated a departure in agricultural policy which resulted in the Agricultural Marketing Acts of 1931 and 1933 and the Wheat Act of 1932. Nevertheless, even in the nadir of depression a deliberate policy of agricultural subsidization and protection was not a viable option, due most notably to the trade links with the Commonwealth.[4]

As the government's attention focussed on the imminence of war, legislation concerning land ownership gave way to the imperative of food production. In contrast to 1914 Britain entered the Second World War with a prepared plan for maintaining food supplies, which built upon and strengthened the pre-1939 *ad-hoc* intervention. Agricultural policy was orientated to achieve this goal through the authoritarian control of the Ministries of Agriculture and Food, which jointly co-ordinated production, distribution and rationing.

In exchange for direct State control, farmers accepted guaranteed prices for their output, all of which had to be sold to the Ministry of Food. These fixed high prices relieved farmers of price instability and induced the required output response. General subsidies on prices were incorporated into the 1939 Agricultural Development Act for oats, barley and fatsheep while per capita subsidies were introduced for hill sheep (1940) and hill cattle (1943). The object of the hill subsidies was to increase the production from upland farms so thereby releasing lowland areas for arable production. With the added incentive of ploughing grants (as part of the 'ploughing-up' campaign) introduced in the 1939 Agricultural Development Act some 3.2 million hectares of permanent

4 This reticence reflected the responsiblities to the Commonwealth rather than a breach of ideology since tariffs on manufactured goods had been used extensively from 1931.

grassland had been converted to arable production by 1944, most of which was diverted into barley, wheat and potato production.

Government also employed various grants to promote higher yields, particularly when further expansion of arable area was no longer feasible. Incentives included production grants to encourage drainage and provision of water supplies (1940), a subsidy on fertilizer (1941) and grant aid to accelerate investment in upland areas under the Hill Farming Act of 1946. The only legislation passed that dealt specifically with the land market were the provisions against speculation that were incorporated into the Defence Regulations of 1941. Nevertheless, provisions in the Act represented a landmark in tenurial law, for it became virtually impossible for a landlord to obtain vacant possession of his land without death or voluntary withdrawal of the tenant. In effect, the 1941 legislation gave the tenant full security of tenure, a feature that was subsequently incorporated into the 1948 Agricultural Holdings Act. The 1948 Act also closed the loophole of the 1923 legislation concerning rent arbitration. Consequently, landlords could not refuse to go to arbitration if it had been requested by the tenant.[5] The Act also instructed arbitrators to allow rent increases in respect of improvements to the farm (such as new buildings, drainage and new capital equipment) that the landlord had paid for with the consent of the tenant. The Act stipulated that once fixed by arbitration the rent could not be increased for another three years. It is interesting to note that although few rents have ever been settled at arbitration this ruling set the standard by which rent reviews were conducted in the market as a whole and the triannual rent review is a feature that persists to the present day.

Not surprisingly, there was a marked resurgence in the land market during the war, not only from farmers wishing to cash in on the guaranteed prices offered, but also from private and corporate investors who sought a safe haven for their accumulated wealth. As Sturmey (1955) so theatrically puts it,

> ' . . . the history of English Farming over the lifetime of those living in 1900-39 suggested that, even if it was the Cinderella among industries in peace, in war-time pumpkins turned into carriages of gold and glass slippers were made to fit its feet, so that any farming venture commenced in the early war years was likely to show substantial returns before the prince Charming tired of his bride and sent her back to the hearth. For the investor this meant largely the chance of capital profits on the

5 As a safeguard against abusing the market this ruling did not apply in the first three years of a new tenancy.

realisation of properties when the war might end.' p.23

By the onset of war there was a marked revival in land ownership and by 1941 a sellers market was firmly in place and did not stabilise until the early 1950s by which time land had appreciated by some 50% over its pre-war level in real terms, (see Figure II.1). Demand was strongest in the vacant possession market than the tenanted sector implying that the demand emanated primarily from within the industry. Ward (1953) attributes this asymmetry to the difficulty in obtaining vacant possession under the 1941 legislation and the resistance of rents to sudden changes in market conditions and a widening of the vacant possession premium from around one-third at the beginning of the war to two-thirds towards the close.

II.(iv) The Consolidation of Trends 1939 - 1970

(a) The Peace-time Partnership between Farm and State

The decade following the restoration of peace witnessed a major reinforcement of state commitment toward agriculture. Although government policy was largely similar to that which had operated during the war, the active encouragement of domestic agricultural production on such a scale, through the 1947 Agriculture Act, was unprecedented in peace-time. The 1947 Act provided a landmark and precedent for all subsequent agricultural policy. The driving force behind government policy was the urgent requirement to increase food supplies, an imperative that could not be immediately satisfied from the world market due to the the neglect caused by six years of world war and Britain's impoverished reserves of foreign currency. Food rationing was not completely removed until 1955 and in 1947 rations increased in severity to the point where each ration was significantly smaller than at any stage during the war. Against this backround, the government set a broad production target in 1947 of a 20% increase in net agricultural output, (in addition to the 30% increase achieved since the outbreak of war), to be attained by 1952 which was itself revised upwards to a level 60 % above pre-war production, however this was the last of such 'industry wide' production targets.

The 1947 Act formalized the 'twin pillars' of agricultural policy - stability and efficiency. Part I of the Act set out the guaranteed price mechanism via deficiency payments system that would be implemented to ensure stability. This system operated for the 12 review commodities, (which accounted for approximately 80% of farm output) until Britain's accession to the European Community in 1973. Measures that were to be used to improve efficiency formed the provisions in Part II of the Act.[6] The guarantees offered in the Act gave renewed confidence to the land market which had faltered temporarily at the close of war due to uncertainty surrounding the continuation of support and land prices rose well above the rate of general inflation throughout the Act 's operation as is illustrated in Figure II.1.

During the mid-1950s there was a discernible shift of agricultural policy away from the general expansion (characteristic of the immediate post-war period) towards a policy of 'selective expansion'. Underlying this new orientation was the growing burden of agricultural support and the realisation that although all the industry wide production targets had been achieved, the product composition of these totals were neither expected nor wanted. While expansion of those products which had an import saving role was encouraged (due to a persistent balance of payments problem), direct measures were adopted to constrain support expenditure. The policy of 'selective expansion' involved reductions to guaranteed prices, limiting the supply on which price support was eligible and import controls, all of which were implemented during the 1950s and 1960s in an attempt to curb support costs and more latterly to facilitate a harmonisation of policies operated by the European Community.

Allied to selective expansion was the increasing emphasis put on measures to promote greater efficiency, which from the mid-1950s became an increasingly dominant feature of policy, reflecting the cost of deficiency payments and the tendency for price support to inhibit structural adjustment. In addition to a number of capital grants that were made available to farmers wishing to adopt new production techniques, financial assistance for farm amalgamation was also initiated in provisions of the 1957 Agriculture Act and subsequently expanded to form the Farm Amalgamation and Boundary Adjustment Scheme introduced under provisions of the 1967 Agriculture Act. However, the schemes were largely unsuccessful since although grants were made available to existing farmers to purchase 'uncommercial' units of land (defined as those of < 100 Standard Man Days) to form a commercial holding (> 600 Standard Man Days) the grants offered applied only to the *ancillary cost* of amalgamation and thus excluded the purchase cost of the land itself.[7] Thus although the rate of grant appeared quite

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6 In fact, the distinction between Part I and II of the Act is blurred by the fact that the guaranteed prices were set at a level high enough to encourage capital investment ; in essence, they incorporated an allowance for capital.

7 The 1967 Act also provided lump-sum payments or pensions to farmers selling unviable holdings

attractive, (30% under the 1957 legislation raised to 50% in the 1967 Act) it was of little practical benefit and the amalgamation of farms proceeded unaffected by the legislation.

Nevertheless, the adoption of machinery and other labour saving technologies generally favoured larger holdings and as a result the rate of amalgamation was believed to be high during the prosperity of the post-war period. Evidence from Scotland reported by Peters (1966) revealed that over one-third of all land sold was purchased by neighbouring farmers and this seems to bear out the anecdotal evidence of land agents in England and Wales, where amalgamation demand was frequently cited as a major factor contributing to the 'over-valuation' of land. Since additional land typically leads to a more efficient utilisation of fixed capital, farmers are generally prepared to pay a high price, far in excess of it's agricultural earning potential - to obtain the land, which in any case may not come up for sale again for thirty years or more.

(b) The Development of Planning Controls

Prior to 1947 there was little effective control over the use to which owners could put their land. Although a string of planning legislation had been enacted since the turn of the century, the first specific planning legislation concerning the use to which land may be put was the Town and Country Planning Act of 1932 which authorized local authorities to prepare a zoning scheme for permitted land-use, defining specific zones for residential, industrial and agricultural use. Planning consent would be given providing that developers did not attempt to introduce non-conforming uses of land in the specified zones of the schemes. However, refusal to grant planning permission required compensation to landowners for the loss of their right to use their land in the way they desired. As compensation was frequently expensive and appropriated from Local Authority coffers the schemes were largely ineffective in controlling development on agricultural land and consequently, a sprawl of urban development occurred between the wars and land lost from agriculture peaked in 1930s at some 25,000 ha per year, (Vale 1985).

The public outcry over urban sprawl and growing momentum of the 'green belt' movement spearheaded by the Garden Cities and Town and Country Planning Association spurred the desire for more stringent legislation, which manifested as the 1947 Town and Country Planning Act. This Act consolidated all previous planning law

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under the Farm Amalgamation scheme above. (Grants to encourage retirement were first introduced in 1963).

and marked a distinct change of emphasis in planning law that has been upheld to the present day: prior to the Act an owner could use land for whatever purpose he saw fit, yet due to the requirement of planning permission that was stipulated in the Act, a landowner has no option but to retain land in its present use unless specific permission is granted for a change in land use. The Act established green belts around major urban centres and within four years of the Act 6% of the total land area in England and Wales was designated as green belt land (Vale 1985). As a result of the legislation annual losses of farmland fell from the peak in the 1930s to about 15,000 ha. throughout the 1950-1980 period.

Because the Act defined uses to which land could be put, but did not compensate landowners for planning refusal, it increased the wedge between the prices obtained for land sold for agricultural purposes and that sold for development. The premium paid for planning permission varies but is occasionally 100 times the agricultural value should the land be sold for residential or retail development, however changes of land use that necessitate compulsory purchase to build roads and motorways yield modest development multipliers between 5 and 10, Commission of the European Communities (1980). Provisions in the 1947 Act established a Development Gains Tax to prevent vast windfall gains accruing to owners of land that were granted planning permission. This was replaced in 1976 with Development Land Tax, itself abolished in 1985, where all liability became subject to Capital Gains Tax although the effect of tax relief given to farmers reinvesting in land has been significant, particularly so during general property booms.

(c) Tenurial Legislation of 1958

Despite the continuing improvement of agricultural prosperity afforded by the Agriculture Act of 1947 farm rents remained artificially low due to provisions in the 1948 Agriculture Act concerning the criteria that arbitrators should take into account when assessing a disputed rent claim. The legislation prescribed that rents should be fixed at 'that rent properly payable' although because there was no explanation as to what constituted a 'proper' rent there was considerable confusion and uncertainty as to how arbitrators would interpret this phrase. As a result landlords generally acted conservatively in rent negotiations with their sitting tenants, wishing to avoid the cost and inconvenience of arbitration, since the procedure was generally viewed as favouring the tenant. Consequently rents for existing tenancies barely kept pace with inflation despite rising product prices, yet rents for new tenancies negotiated on the open market reflected the general prosperity of the period since only rent changes on existing tenancies could seek arbitration. The restraint on rents continued until 1958 when provisions in the Agricultural Holdings Act of that year changed the instructions to rent arbitrators. Thereafter, arbitrators had to assess increases in rents in relation to open market values, *i.e.* those rents tendered for new tenancies, and a marked increase in rents for established tenancies followed.

Hill (1985) argues that the restraint on rents played an important role in establishing the premium for vacant possession land during this period. The premium rose rapidly after the war and stood at around 100% until changes introduced in the 1958 Agriculture Act took effect in the 1960s. This high premium reflected that the two classes of property in this era yielded very different returns. Whereas the purchaser of a farm with vacant possession could either farm the land himself or install a tenant at a market rent, the purchaser of land with a sitting tenant could only expect to receive rents well below the market level, and in many cases below that which made landowning profitable. The distinction was of little importance before the war since tenants could be evicted with one year's notice yet the provisions against land speculation introduced by Defence Regulation in 1941 and consolidated in the 1948 Agricultural Holdings Act, made it virtually impossible to evict a tenant and hence gain vacant possession. Faced with increased responsibilities and low returns a steady stream of farms were sold to sitting tenants, who

> '. . .were in the enviable position of being able to secure 'vacant possession' at a minimum premium, just sufficient to outbid investors for farms sold subject to tenancies' Ward (1953) p.151

Despite these obvious pecuniary advantages Ward (1953) claims that the trend toward owner occupation was due more to the desire of landlords to liquidate assets rather than a demand for ownership by tenants. Furthermore, financial institutions such as the Agricultural Mortgage Corporation were more than willing to provide the necessary finance since the sitting tenant could secure the purchase of the land they farmed at little more than without-possession prices, but then own an asset that could be sold for the significantly higher vacant possession price. In this manner the move towards owner occupation was intensified, although slowed down noticeably during the 1960s.

(d) Post War Fiscal Incentives on Land

In addition to state protection, relatively high rates of general inflation in the post war era combined to make land attractive to investors from outside agriculture mainly because farmland was regarded as a sound hedge against inflationary pressures. This compounded the introduction of a cheap-money policy in 1947 which resulted in a fall in the yield of more typical investments such as gilt-edged securities and equities, and as a result land prices rose sharply in that year. Consequently, not only were the traditional large landowning organisations investing heavily in land but this period also attracted a new breed of investor, the financial institutions and private businessmen. For these investors, landownership was a good hedge against inflation and carried with it considerable fiscal advantages. Of note was the maintenance claim and the capital expenditure claim incorporated into the Income Tax Act of 1945, which, at the time, was heralded as the 'most far reaching income tax and surtax relief ever granted to landlords' (Read 1951). In acknowledgement of the repairing liability of the owner, an allowance of 12.5% and 25% on the gross assessment for income tax was granted in respect of maintenance on farmhouses and cottages respectively - further refunds could be claimed for maintainence above these amounts. More importantly, refunds on tax could be claimed on that proportion of gross income spent on improving the quality of the land. Moreover, should the improved land subsequently be sold the capital profit is not taxed and thus the tax relief acts as a double incentive to purchase agricultural land as an investment. As Ward (1953), states,

> "The result of 'ploughing back' capital into the land in this manner is an increase in capital values which is not subject to taxation and therefore provides a strong investment incentive to the landlord or owner occupier paying a high rate of income tax or surtax" p.153

Although farmland had been granted abatement from estate duty since 1919, on the basis that capital values were high relative to to net earning capacity, this relief was fixed at 45% of the normal duty payable by provisions in the 1949 Finance Act since as Sturmey (1955) states,

> 'The biggest factor bringing land into the market is death duties , and sales for this reason would seem to take place irrespective of market conditions' p.20.

Due to the progressive nature of estate duty this relief was substantial for owners of large areas of farmland- so much so that, it encouraged capital transfers into land and a significant number of wealthy individuals made 'death-bed' transactions in land to diminish tax liability. Indeed, Ward (1953) attributes much of the investment in agricultural property in the immediate post-war era to this preferential treatment of farm based wealth. A further impetus for the investment momentum was the 1961 Trustees Investment Act which removed restrictions on trustees from the necessity to invest all their funds in gilt-edged government stock and as a result agricultural land became a candidate for such funds.

In a comparison of the investment performance of agricultural land and corporate equity during the post war period Nicolas Byrne writing in the Farmland Market calculates that both the capital gain on land and open-market rents had grown far more than the Financial Times Ordinary share index and dividends. Whereas £100 invested in land in 1945 was worth nearly 15 times in nominal terms by 1973 equities could only boast a modest growth multiple of 2.5, similar to the rate of inflation: an index of open-market rents had grown 2.75 times yet dividends barely 1.5 times having adjusted for inflation.

In 1962 Capital Gains Tax (CGT) was introduced in the Finance Act of that year but was subsequently modified in 1965 which remained the base date for computing capital gains liability until the 1988 budget. CGT is charged on the sale or gift of an asset which has appreciated by more than the rate of general inflation, given by the retail price index. Prior to 1988 the tax was levied at a flat rate of 30% on the disposal of chargeable assets. The gain relates to the difference to the vendor of the initial cost and selling price adjusted for inflation. Where the disposal is in the form of a gift the market value of the asset is given to be the disposal value. For assets acquired before 1965 then the difference is calculated the basis of the assets price in 1965.

Although when introduced CGT had the avowed aim of taxing gains arising from speculation in the land market, farmers and landowners have subsequently been granted a number of reliefs in view of the vast accumulation of inherited wealth required in order to farm.[8] Most importantly is the facility for working farmers to defer CGT liability on the sale of farmland providing that the proceeds of the sale are then used to purchase similar chargeable assets. This concession, known as 'roll-over' relief, was extended to include gifts of farming assets and has been supplemented by retirement relief, which allows a working farmer to reduce his CGT liability providing he is over 65 years of age.

8 For example, the cost of farm improvements and construction of farm biuldings can be added to the acquisition cost to reduce the amount of capital gain liable to CGT, and the farmhouse, animals and moveable property are also exempt.

Whilst the effect of roll-over relief has not been quantified, it is generally recognised to be an important influence in the land market. For although the price of land sold for development is excluded from land price series that analysts use, there is generally believed to be a potent indirect affect if the proceeds from the sale are used to acquire more farmland, as is often the case since the proceeds are exempt from CGT. The effect is particularly acute when a farmer sells farmland to development and re-enters a thin land market since development values are many times higher than agricultural values. As Peters (1966) notes, with some 15,000 ha. of farmland being sold to developers annually the effect may be significant, and was one reason cited in his article for the high land values relative to returns that were observed in this period. More generally, anecdotal evidence from land agents suggests that up to half the purchases of farmland may be financed with roll-over funds in years when large capital gains may be realised, (*Farmland Market* 1989).

Importantly however, owners of tenanted land cannot claim roll-over relief because the land does not qualify as a business asset. Whilst this discrimination is yet another reason cited for the demise of the tenanted farms it is also recognised that such landlords (particularly the institutional owners) do not generally sell land in order to buy more but sell in order to accrue capital profits and thus the legislation may actually retain more land in the tenanted sector than otherwise.

II.(v) A New Era of Volatility

(a) Accession to the European Community and Macroeconomic Instability

Accession to the EC in January 1973 concluded over a decade of negotiations during which the UK had made two unsuccessful bids (in 1963 and 1969) at membership. Adherence to the principles of economic union and adoption of the price support mechanisms of the Common Agricultural Policy (CAP) entailed higher consumer prices, underlined in a parliamentary White Paper of 1970 which estimated that retail food prices might rise by 18-26% inducing a 4-5% increase in the cost of living.[9] This inflationary pressure was nevertheless overshadowed by the first of two oil crises

9 However, the high and unpredictable burden that had been placed on the Exchequer throughout the 1960s by the deficiency payment system had led the government to progressively implement CAP-type support measures anyway and Tracy (1989) notes that it was the aim of the conservative government elected in 1970 to shift support completely towards this system for financial reasons independent of accession.

and a world food commodity 'shortage' in the early 1970s which resulted in double-figure inflation and low economic growth in the economy generally. Nevertheless, the 1970s represented a prosperous period for agriculture since uncertain supplies and high world prices for many commodities, (short-lived though they were) became a potent stimulus for agricultural expansion within the EC. A government White Paper *Food From Our Own Resources* actively encouraged the expansion of certain foodstuffs on these grounds, and the fall in the value of Sterling against most major currencies, observed in this period only served to intensify the impetus for agricultural expansion.

Thus despite a general backdrop of stagflation it is not surprising that agriculture fared well during most of the 1970s particularly so since the CAP had adopted an element of the UK's pre-accession Annual Review machinery, the so called 'objective method' of determining farm product prices, which allowed industry representatives to incorporate rising production costs into high support prices.

(b) The Land Price Boom

The combined effect of soaring inflation, economic recession and CAP support mechanisms had dramatic ramifications on the land market and led to the most turbulent period in the market's history since the frenetic activity in the 1920s. In real terms, land values in 1975 were only slightly higher than those prevailing in 1971 yet this conceals the doubling of land prices during 1972 and 1973 and the subsequent free-fall in 1974. The volatility of the land market during this short-lived period had all the hallmarks of a speculative bubble. Whilst it is true that financial institutions increased their holdings of tenanted land by more than 500%, analysis by Munton (1975) indicates that the majority of sales were to private individuals, who were acquiring vacant possession land irrespective of quality with the intention of reselling for development. It appears as though the sudden emergence of institutional investors simply pushed what is typically a thin market into an unstable state.

On the supply side, farmers were reluctant to sell yet eager to acquire land on the strength of prospects for farming within the EEC, particularly so amidst the world food crisis. Thus even had the financial institutions not entered the market, speculation by wealthy individuals and the strength of farming demand would have raised farmland prices considerably. However, at the same time that land began to look more attractive, the traditional investments of pension funds and life assurance companies, began to look increasing poor alternatives to land : good quality commercial property was in short supply, industrial equities looked increasing vunerable and fixed-interest stocks would be the first to be overtaken in an inflationary spiral. As a result these financial institutions also began to purchase land, particularly in the tenanted sector since they did not have sufficient farming expertise to manage vacant possession farms themselves. Compounding these events was the sheer amount of funds that the institutional buyers had at there disposal. Writing at the beginning of 1974 William De Salis, economics secretary of the Country Landowners Association noted,

> 'Life assurance companies and pension funds had £2,200 million of new money to invest in 1972 alone, and the 1973 figure was probably £2,500 million. An investment of £10 million in land in any one year by an insurance company may well represent a very small proportion of a major institution's placement of funds in that year. So it takes only a handful of life assurance companies to have a major effect' Farmland Market 1974 p.17

Given that the total value of sales in 1973, a quite extraordinary year, amounted to only £205 million, even marginal shifts in pension fund portfolios can have had a destabilising effect on the land market. So acute was the demand for tenanted farms by financial institutions that the price of this land rose more rapidly than that for vacant possession with the result that the vacant possession premium fell to around 16%, its lowest level since the 1930s, Munton (1975).

In 1974 there was an abrupt break in prices. Whilst some commentators have sought to account the downturn in prices to the proposed introduction of new fiscal measures, namely Capital Transfer Tax and a Wealth Tax or to a reduction in available funds due to falling business profits, the free-fall of prices in 1974 owes as much to the nature of the boom in 1973. To the extent that the boom was driven by speculation, the downturn simply reflected that land was perceived to be overvalued by 1973. When the bubble burst, the number of farms for sale burgeoned temporarily, particularly in the tenanted sector since this is where the institutions had bought most extensively, and land prices fell rapidly. As with most speculative 'crashes' an over-compensation occurred due to the herding instincts of the speculative investors, so that by the 1975 trough in prices, land had become seriously undervalued. A rapid rate of price increase followed that lasted well into 1979. Land prices were appreciating at nearly 20% per annum even in real terms so that by the peak in 1979 land values were nearly as high in real terms as they had been in the boom of 1973.

(c) New Fiscal Measures

The volatility of the land market during this brief period led directly to a number of changes to fiscal policy; namely the introduction of Capital Transfer Tax (CTT) and Development Land Tax (DLT). In an attempt to close the numerous loopholes in Estate Duty, such as lifetime transfers, which had in effect made it a voluntary tax, 'paid by those who disliked their heirs more than they disliked the Inland Revenue' (Sandford 1983), the Labour government replaced Estate Duty with the more stringent CTT in 1975.[10] When first put before Parliament the tax represented, ' . . . a determined attack on the maldistribution of wealth in Britain.' (Hansard 1974), since in addition to the taxation of lifetime transfers, it abandoned the generous agricultural reliefs available under Estate Duty. However, by the time the Finance Act received the Royal Assent concessions to full time farmers had been granted and these in turn were modified and extended in the following year in the form of Agricultural and Business Relief. Nevertheless, the reliefs only applied to those actively engaged in farming, and as such private landlords did not generally qualify for these reliefs on their let land, (in contrast to their position under estate duty where owners of all land received a 45% abatement from tax liability). This change had important repercussions on farm tenure since it encouraged landowners to take their tenanted land in hand whenever formal tenancies naturally expired. Because land taken in hand, (*i.e.* 'farmed' by the landowner, perhaps as a partnership, or as a farming company) was deemed to qualify for Agricultural relief and/or Business relief - amounting to a 50% reduction in CTT liability - the large landowner had a potent incentive not to renew tenancies and both the Country Landowners Association and the National Farmers Union believed that the legislation would accelerate the demise of the tenanted sector.

A further response to the high prices of agricultural land was the introduction of Development Land Tax in 1976 chargeable when the disposal of land realised a development value. The tax was similar to the short lived development gains tax of the 1947 planning legislation and had a similar objective, namely, to enable society to share in the gains which accrued to land sold with planning permission. Under DLT all capital gains in excess of £75,000 were taxed at a flat rate of 60%. Although the tax was repealed in 1985 (whereupon land sold to developers became liable to CGT) unlike CGT there were no roll-over provisions where the proceeds were reinvested in land,

10 CCT is levied at the time of gift at increasing rates, having regard to the cumulative total of lifetime gifts, with a final cumulation of the assets passing on death. Although originally the rates were the same for lifetime gifts and transfers on death major changes have taken place. See Later.

and as a consequence a marked upturn of land sold for development was witnessed after the repeal of DLT in 1985.

(d) Tenurial Legislation in the 1970s

In 1976 a major amendment was made to the tenurial legislation with the passing of the Agriculture (Miscellaneous Provisions) Act which caused a greater furore than any other piece of tenurial legislation (Nix, Hill and Williams 1989). Prior to that time a tenancy agreement was terminated with the death of the tenant. However, provisions of the 1976 Act granted security of tenure not only for the existing tenant but for two subsequent generations subject to certain 'eligablility' and 'suitablity' conditions. Whilst the motivation for the legislation was to retain more land in the tenanted sector, the Act was heavily criticised on a number of counts, but most notably on the grounds that it would actually reduce the size of tenanted sector.

Owners of let land argued that it represented an unacceptable infringement of their freedom, and like similar legislation in the past, would be followed by a diminution of new tenancies coming onto the market: landowners preferring to amalgamate the land into other tenanted holdings, take it in hand to farm themselves, or sell and thereby realise a vacant possession price, rather than offer a new tenancy which would prevail for 100 years or more. As a result the entry of 'new blood' into the industry would be stifled with long term implications for the efficiency of the industry, since it is these potential entrants that are generally believed to be the most educated about best-practice farming.

In light of the changes to legislation embodied in the 1976 Act the Agricultural Holdings (Notices to Quit) Act of 1977 consolidated previous legislation on serving eviction notices and the tenants right to seek appeal to an Agricultural Land Tribunal in respect of the eviction order. Although the 1977 Act (like previous tenurial legislation) was intended to give tenants security and landlords safeguards against abuse it only served to heighten the grievances of landowners who maintained that legislation afforded tenants, particularly poor ones, too much protection. Whereas in 1927 64% of farmland was rented this proportion had only fallen to 62% by 1950 and was 30% in 1990, although due to complex manner in which land is held and farmed for reasons of tax planning a more accurate estimate is believed to be around 30-35%.

(e) The Northfield Report and its Repercussions on the Land Market

In 1979 the report from the Northfield enquiry into the ownership and occupation of farmland was published. Although it was the emergence of financial institutions in the land market that motivated the report, the Committee concluded that only a very small proportion of land (1.2%) was found to be held by such institutions, with a further 8.5% being held by the traditional landowning institutions such as the Crown, Church, Universities and charities. Furthermore, *on average* only 10% of farmland was purchased by financial institutions annually so that by 2020 financial institutions were projected to own some 11% of farmland. Despite the contributory role role played by institutional investors in land price boom, Northfield concluded that in general their effect on land prices was negligible. As a result rather than impose punitive restrictions on the activities of the financial institutions (which had been threatened) most of the recommendations of the Committee pertained to possible changes in capital taxation and tenurial legislation to prevent further decline of the tenant sector and much of the legislative changes introduced in the 1980s respond directly to the recommendations of the Committee of Inquiry. For example, so persuasive was the argument concerning exclusion of owners of tenanted land from the relief to CTT that concessions were granted to landlords in 1981.

In addition, changes were made to the tenurial legislation of 1976 under provisions in the Agricultural Holdings Act in 1984, following a joint submission by the CLA and NFU acting on a Northfield recommendation. Although a repeal of the 1976 legislation was initially requested to stem the decline of new tenancies, it was recognised this had to be offset by the need to ensure that tenants were not abused. This was particularly so, when much of the tenanted sector was being purchased by financial institutions, who, it was argued, have the potential to be the worst sort of absentee landlord, although such claims are frequently exaggerated by the rural fundamentalists.[11] The main provision of the 1984 Act stated that whilst the rights of succession provided for in the 1976 Act should remain for existing tenancies this should not apply to new lettings, unless by voluntary agreement.

The 1984 Act also changes the instructions to rent arbitrators concerning the term 'rent properly payable' due to the concern expressed by the NFU in the 'joint submission'

11 Whilst the Country Landowners Association suggest that the downward trend is actually because of the legislation, the number of farms leaving the tenanted sector has fallen at the same rate after the 1976 legislation as it did before, at some 3000 per year.

that arbitrators were frequently including such factors as 'scarcity' and 'proximity' in fixing rents since the reduction in new tenancies led to the removal of the sole reference point used by rent arbitrators in setting rents for sitting tenants. As a result of the 1984 legislation the key factor to be taken into account was the productivity and earning capacity of the holding; factors such as the scarcity of holdings available for rent in a locality, and the convenience of offering land to a tenant (or tenderer) who may farm other land close by were to be excluded. The Act also amended provisions in the 1948 Agriculture Act concerning short-term lettings and introduced fiscal attractions to owners of let land. Essentially, the changes broadened the scope of a landowner to offer a short term tenancy (*i.e.*without security of tenure) as opposed to a fully protected tenancy agreement and reclassified rental income as earned (rather than unearned) income thus making landlords immune from the 15% investment income surcharge. These amendments have subsequently been consolidated in the 1986 Agricultural Holdings Act which governs virtually all the law pertaining to landlord and tenant to the present day.

Since the 1976 legislation there has been a keen interest in forms of farming partnership that do not confer full tenant status in law. Utilising a loophole (some say deliberate since it has not been closed in the 1984 Act) in the 1948 legislation a normal tenancy may be established for more than one year and less than two which does not give security of tenure to the tenant. Since this type of tenancy (often called a Gladstone v. Bower tenancy) can be renewed it is a potentially attractive arrangement and has been frequently used. Keen interest has also been shown in unconventional types of arrangement such as farming partnerships and share farming which bestow important advantages to the landowner while giving the farmer opportunity to farm. These arrangements have increased significantly as tenurial legislation has developed and it is argued that landlords and farmers have entered into such arrangement far more frequently than new tenancies, (Panes 1980). In addition to the benefits introduced in the 1984 legislation concerning short term lettings these arrangements carry other fiscal advantages, most notably with regard to CTT liability since a landowner letting land farmed in partnership or as a share contract may be classed as a working farmer and thus may be eligible for relief from CTT.

Nevertheless, the tenure issue still remains an important one, to the extent that the Minister of Agriculture has recently made public his intention to alter the tenurial legislation further and a consultation document is currently being drawn up.

Responding to yet another recommendation by Lord Northfield, and a change in political persuasion, the newly elected Conservative government introduced the Planning and Land Act of 1980 which accommodated the longstanding criticism by landowners and developers alike, that planning procedures were unnecessarily involved and too restrictive. The Act attempted to speed up the planning process but more importantly actively encouraged the planning authorities to be sensitive to the requirements of developers where a specific proposal accrued economic benefits to the local economy. Although no *carte blanche* to developers, the Act facilitated a circumvention of green-belt plans and other restrictions that were previously not negotiable.

After the boom, the land market remained relatively buoyant through to 1978 with considerable interest shown in vacant possession and tenanted land. Land with vacant possession was demanded by farmers for amalgamation on the strength of CAP support policies and also by wealthy individuals for residential and amenity considerations, particularly for land near villages and towns. Despite the fiscal and tenurial legislation in the mid-1970s which undoutably encouraged some landlords to sell their let land the market for tenanted land was buoyant. Interest in this land did not come from tenants wishing to buy their land; indeed, there was a marked downturn in tenant demand since tenants perceived purchase to be a relative luxury given their newly won security of tenure. Rather, there was a steady and strong demand by financial institutions which stepped in and took their place.

(f) A Re-orientation of Policy[12]

1977 saw the emergence of a discernible re-orientation of Community policy toward agriculture. Pricing policy and the need to reform were brought progressively into sharper focus by the growth in output and accumulation of surplus products. The appointment of a new head of the Commission in 1977 heralded the beginning of a 'prudent price policy' : a mere 3% rise in average support prices being proposed by the Commission in that year, far removed from the double-figure settlements of 1974/5. In the vanguard of budgetary reform was the UK who had been a vocal reformer, primarily because it had been a net donor to the EC budget since accession.[13] The

12 A major aspect of this reorienation of CAP policy since the late 1970s was the shift towards structural, social and environmental policies.

13 Prior to entry a government White Paper had estimated that due to the UK's reliance on food imports the import levy system operated by the EC would result in the UK contributing 31% of

1979 White Paper, *Farming and the Nation* was indicative of the UK's position. The document went to great pains to assure domestic agriculture of further expansion and the continuation of national support measures (in the form of grants, tax reliefs and technical education and advice), but it also declared a policy to constrain EC prices with a view to limit the expansion of supplies.

Despite numerous attempts to restrain prices and the introduction of guarantee threshold quantities for the major products the entrenched positions of a number of Agriculture Ministers prevented any rigorous reform. Indeed, the 1982/83 package included an average increase in farm product prices of 10.4% in ecu terms. The inadequacy of these measures became increasingly evident as the financial implications of continued oversupply became critical during the mid-1980s. Furthermore the impending accession of Spain and Portugal (in addition to Greek membership in 1981) placed even greater demands on the Community budget. In a further attempt to limit agriculture expenditure the Commission report, *Adjustments to the CAP*, stressed the need for a 'restrictive' price policy. Although the co-responsibility principle[14] had been applied to milk production since 1977 under the 'Action Programme' for milk, the guaranteed threshold was exceeded by nearly 7% in 1983 and constituted the most urgent problem at that time. Under the regulations of the co-responsibility system this level of overproduction would entail price reductions of 12% in the following year. In an attempt to resist such dramatic price cuts the Agriculture Council hastily adopted the system of milk quotas at the Fountainbleau Sumitt. In addition, the Agriculture Council adopted the co-responsibility principle in the cereals sector which came into operation for the 1986/7 year and which was subsequently strengthened by quality standards and small price reductions on intervention grains and an additional levy on milk production over quota.

In 1988 a major new initiative was launched, that of 'Budgetary Discipline' with the intention of limiting expenditure of the CAP. To achieve the requirements of budgetary discipline the stabilizer mechanism and supplementary measures were introduced. The Stabilizer mechanism involved setting production thresholds for a number of products most notably cereals - Maximum Guaranteed Quantities - which if exceeded resulted in a *pro rata* reduction in prices. In addition schemes were implemented to encourage early retirement of farmers (with the land being left fallow for at least five years), direct

the EC budget, yet due to the small number of farmers in the UK (the major beneficiaries of EC expenditure), the UK would receive only 6% of EC spending in return. Tracy (1989).

14 This entails farmers paying a tax on production that exceeds an agreed threshold.

income aids, grants for extensification (reduction of farm output by 20%) and arable land set-aside. The set-aside scheme is voluntary and allows annual grants of some £150 per hectare for land to be received by farmers leaving 20% of their land fallow or under non-supported commodities.

(g) The Land Market in the 1980s

Throughout the 1980s prices for both vacant possession and tenanted land descended rapidly in real terms. This trend was abated temporarily in 1987 and 1988 by the surge in non-agricultural demand for farmland that followed on the back of the short-lived property boom and bouyancy of the macro-economy. In 1979 land prices stood at levels comparable to those prevailing at the height of the land price boom in the early 1970s and at the heart of the downward trend lay a realisation that land had become considerably overvalued. As the market faltered in late 1979 on this realistion, the chill winds of change emanating from Brussels and the uncertain prospects for the macro economy motivated a major revision in expectations. Rising interest rates which continued into 1980 and 1981, made farm purchase immediately more expensive and added to the attractions of alternative investments. As the economy slipped into recession urban development came to a standstill and the introduction of DLT meant there was little 'roll-over' money in the market unlike the situation that had been witnessed in the 1970s.

By the mid-1980s the purchases of land from the institutional investors had virtually ceased. Whereas net annual purchases were around 17,000 ha. in the 1970s, by 1984 only some 600 ha. had been added to their stock reflecting uncertainties of the CAP, rising interest rates, and resistance to rent increases by tenant farmers. Although there continued to be strong demand for farms in the southeast with residential potential, the storm clouds that had been gathering burst in 1984 with the ill-prepared introduction of Milk Quotas.

The introduction of quotas brought the sale of dairy farms to an immediate standstill in 1984 although when the market resumed in 1985 the effects of quota were somewhat disparate. When it became clear that milk quotas were attached to the land and could not be transferred without sale of the land, obtaining a good price for dairy land relied almost entirely on its milk quota allotment. Whilst land with a high quota maintained the highest of farmland prices in the generally gloomy 1980s, the value of dairy holdings without any quota dropped by some 40% in a year. Land agents in 1985 were valuing an average allotment of quota at around £500 per ha. Milk quotas were only partly responsible for the sharp downturn in land prices in 1985 which fell some 15-20% on the year. Of perhaps more importance was the changes in the CAP that milk quotas signalled: many commentators feared the introduction of quotas for cereals as well, and there was a considerable liquidation of assets held in land, by unprofitable farmers and nervous investors alike. Indeed, institutional investors were beginning to take a very jaundiced view of the market with rents hardly budging and alternative investments doing much better. Further, amendments to the rules concerning arbitration in the 1984 Agricultural Holdings Act complicated the arbitration procedure, which from then on necessitated the opinions of solicitors, surveyors and farm management consultants in order to mount a successful claim. With these costs exceeding the disputed rent increase many landlords liquidated their holdings and the value of let land fell between 20-25% in 1985, on top of the 10-15% falls in 1984.

Turning to fiscal issues, in 1986 Capital Transfer Tax was abolished and Inheritance Tax established in its stead. Whilst it is fair to say that when first introduced CTT was widely considered to be a particularly onerous tax that would lead to the fragmentation of medium aswell as large farms, successive reliefs granted since 1979 have diluted its initial potency. The concessions were introduced often with the prime purpose of easing the burden of the farming interest. For example, in 1981 owners of tenanted land were also entitled to claim relief from CTT liability as well as working farmers - as recommended by the Northfield report in 1979. The replacement of CTT with Inheritance Tax further reduced its severity so that to all intents and purposes Inheritance Tax is as permissive as Estate Duty. The tax has thus come full circle in that it can be avoided altogether with the only a modicum of tax planning, as was the case with Estate Duty. However, since CTT had been largely 'toothless' for some time, the change to IT was little more than a change in name and consequently had no discernible impact on the land market itself.

(h) Institutional Investors in the 1980s

The 1980s witnessed an abrupt reversal of the flood of institutional interest in the land market. Large scale institutional investment in land ceased at the beginning of the 1980s with a final spurt of activity immediately after publication of the Northfield Report, which cleared the way for continued institutional ownership with the result that ownership peaked in 1984 with 2% of farmland owned by financial institutions, some 86% of that being tenanted land. However, as soon as it became clear that the political will existed in Brussels to reform the CAP the institutions began selling their farmland whenever it became prudent to do so - nearly 60,000 ha being liquidated in 1987 and 1988 alone, approximately 8% of their total holdings. While it is true that some 200,000 to 225,000 hectares of land is traded annually, entailing that the institutions were only buying in the 1970s and selling in the late 1980s around 7 or 8% of the total, it should not be forgotten that between 80 and 90% of land sold is with vacant possession and thus the influence of the institutions in the tenanted sector may be particularly significant in years where large sales occur. For example in 1988/9 about 40% of sales were by financial institutions and this clearly artificially depressed tenanted land prices, as indicated by the vacant possession premium which climbed to over 100%. Whilst the financial institutions can offer many advantages to the industry the role they play in price instability is probably not one of them.

Despite owning high quality arable land where the effects of quotas, price reductions and set-aside are less important, institutions have been liquidating land acquired in the 1970s due to the somewhat gloomy prospects for capital growth and rents. Although the initial yield of farmland has historically been relatively low, capital gains have adequately compensated for this in the past, but the poor prospects for capital growth in the 1990s accounts for the large sales of farmland and increased interest in forestry due to the belief that long term prospects appear to be better than those in farming.

(i) A Two-Tier Market

The influence of non-agricultural demand for farmland has been a persistent one during the twentieth century, yet in general the influence has been diluted sufficiently by agricultural demand not to merit critical attention. Although Ward (1953) commented on the strong demand for residential holdings and hobby farms during the post war housing shortage, it was not until the 1980s when a combination of retrenchment of policy and the urban property boom led to the emergence of a two-tier market for farmland. EC support policies geared to restraining rather then encouraging output reduced agricultural demand and encouraged institutional investors to liquidate their assets, particularly so since there were more attractive investment elsewhere in the economy. By the time the property boom of 1988 was in full swing, there was considerable demand for residential 'farms', a £350,000 house in London being equivalent to a 70 hectare farm at 1988 prices. Furthermore, the high prices of land sold for development ensured that there were substantial roll-over funds waiting to go into land.

As a consequence, whereas land and buildings that had only commercial potential sold for prices that reflected the modest agricultural earning potential and worsening prospects within the CAP, small farms with attractive views, quaint farmhouses and outbuildings situated near to major road or rail networks - particularly in the Home Counties - could command prices that were divorced from their agricultural potential. Nevertheless, it was not only the south-east of England in which residential demand was influential, for even in relatively remote parts of England residential and amenity considerations were as important to land agents as soil quality. By 1988 Strutt and Parker reported that commercial farms in Devon and Cornwall were averaging £5,300 per hectare whereas farms that were mainly residential sold for more than twice that at an average of £11,800 per hectare, (Financial Times 8.7.89).

So influential was the non-agricultural demand that the Statutory land price series reveals a distinct resurgence in farmland prices from 1987 through to 1989, despite the continued weakening of farm product prices throughout this period. However, the artificiality of the resurgence was revealed during 1989 as rising interest rates ushered in economic recession. In fact interest rates almost doubled during the year choking the property boom and with it the non-farming demand for land. In addition developers ceased purchasing land speculatively as the value of industrial land fell 50% in 1989 which meant much fewer roll-over funds moving into land. The Farmland Market reported that the relative importance of roll-over funds slackened to 14% of total acreage purchased in 1989 compared to 42% in 1988.

As the effects of high interest rates and recession rippled throughout the economy farmland prices fell sharply in 1990 and appear to be on a downward trend with only set-aside payments and grants that take the emphasis away from agricultural production putting a floor to the market. By 1991 non-farming demand had almost vanished with the result that,

> 'Not so since the early 1970s has the value of farmland moved so sharply towards reflecting little more than its productive capacity' Farmland Market 1991.

This view seems to be widely held and most commentators suggest that the outlook for the land market seems to rest on the commercial viability of land and not residential amenity considerations. Should the GATT talks coerce more stringent measures to restrain production and prices within the CAP, the downward trend is expected to accelerate although acute price falls are not expected.

II.(vi) Some Concluding Comments

This overview has served to illustrate the multi-faceted nature of the land market. In tracing the evolution of the market, trends in ownership, occupancy, transactions and price have been identified and some tentative explanations provided where possible. However, probably the most striking feature of this overview is the sheer amount of legislation that has affected the land market, reflecting the political importance of land and agriculture generally. The fact that the emergence of legislation relating to land coincided with the decline of the land owning class in Britain is not a mere coincidence: much of the early legislation was aimed directly at changing the way in which land was owned and farmed. Since then state intervention in agriculture has burgeoned into a complex web of laws and regulations on which the prosperity of the industry now rests. Deciphering the effects of any one piece of legislation is a treacherous and ultimately futile exercise: participants in the land market form a heterogeneous group with different aspirations, means and ability and hence the actions of the aggregate take considerable time to emerge. Furthermore, by the very nature of the asset land does not lend itself easily to instantaneous change. Consequently, legislation has more of a cumulative effect on the actions of participants involved in its ownership and use, and in turn this is reflected in the evolutionary nature of change that is observed in general in the land market.

What is undeniably clear is the strength of the link between the land market and agriculture: in the absence of a title, the land price series illustrated in Figure 1 could easily be mistaken for a ratio of output and input prices in agriculture, or for farm incomes, or some other measure of farming prosperity. Whilst it is true that non-farming demand has played an important role during short periods of the postwar period, agricultural demand, whether from farmers or financial institutions dominates the market and what's more, looks likely to do so. Despite the retrenchment in policy the price of land seems tied to the financial reward obtained from its utilisation and it is this theme that is developed in the rest of the thesis.

Chapter III
Price Determination in Durable Asset Markets

III. (i) Introduction

The purpose of the following chapter is to present a basic analytical framework of price determination in the land market. The analysis seeks to clarify the concepts of supply and demand in the context of durable asset markets and explore the micro-economic foundations of the empirical land price models discussed in subsequent chapters. Necessarily, what follows is a theoretical abstraction relying heavily on assumption. The model is a purely heuristic device, serving to isolate the principal forces and mechanisms at work, and in so doing clarify the misconceptions that may still persist with regard to the determination of price and quantity traded in a market for a durable asset such as land.

The methodology has been formulated by numerous writers since the turn of the century. The works of Wicksell (1954)[1], and Wicksteed (1910), cast a significant insight into the mechanism of market exchange, demand and supply and the pricing of factors. These tools of analysis have been grasped by subsequent economists who have applied and extended this understanding in many contexts. For example, Clower (1954), adapted these principles with reference to the process of investment of durable goods and Clark (1969) alluded to a conceptual approach in asset pricing (as presented here), in his largely empirical work on land values. Surprisingly, until Harvey (1974), description of the theoretical framework of the land market was generally cursory. As Harvey (1974) remarks,

> "The modern explanations [on the concept of the land market] have been extremely brief and do not discuss the nature or role of transactions in any detail..." [p.61]

The second point Harvey raises in the quotation is of considerable importance for it emphasizes the need to clarify the nature of price determination and the function of transactions in durable asset markets, such as that for land. This is necessary since they are distinct from the more common simultaneous determination of price and quantity in markets for non-durables. This distinction however, is either absent or disregarded in empirical researches into the land market both before, (*e.g.* Tweeten and Nelson

1 First published in German in 1893.

1967), and after, (*e.g.* Traill 1980), Harvey's account. The reasons for this divergence between the theory and modelling of the land market are discussed later. The work presented here is a synthesis of established economic doctrine. It applies and develops the work of Clower (1954), Currie (1981) and Harvey (1974). The Chapter begins by setting out the assumptions of the micro-economic model used to examine the process of asset price determination. Following this a discussion of the role of transactions is presented and the process of price determination examined in detail. Trade and land prices are examined in a simple four-agent model in Appendix A. The independence of trade and prices suggested by this analysis is then demonstrated with the aid of some comparative statics. Finally, a reduced form equation of the market is presented that will be used as a basis for empirical modelling of the land market.

III.(ii) Framework and Assumptions

To begin, let us conceive of a number of homogenous units of land which comprise the immutable stock of land. This stock of land is to be allocated among individuals via the price system, in a situation where input, output and financial markets are all perfectly competitive. It is further assumed that each individual in the market forms a valuation of land on the basis of a subjective expectation of the discounted net returns to land ownership accruing over the period of ownership. In each time period differences in valuations across individuals will lead to a reallocation of the land stock via trade, so that in equilibrium those individuals that own land are content to do so at the prevailing market price. Before we proceed to examine the mechanism that leads to equilibrium it will be worthwhile to examine some of the underlying assumptions in a little detail.

The requirement for all units of land to be homogenous is used primarily to simplify the analysis. It implies that there is a constant ratio between the stock of land and the flow of services derived from it at any given point in time: the price of land therefore relates to units of constant quality. If it is further assumed that the stock of land is fixed, then the determination of equilibrium price reduces to a problem of finding that price at which agents in the market are willing to hold the entire stock. For simplicity it is assumed that any individual will not wish to hold any more than one unit of land at any one time, and therefore participates in the market as either a prospective purchaser or current owner, the two types of agent being mutually exclusive.

We may now examine the optimizing behaviour of economic agents in the market. It is assumed that each participant in the market has access to full information pertaining to the market over the relevant past and is able to compute a valuation of land on the basis of expected future net returns discounted by an appropriate discount rate. Combining this valuation with a simple decision rule results in purchase, sale or no change in behaviour. The decision rule employed is; if the individual's valuation of land exceeds the prevailing market price that agent will wish to purchase land ; conversely, if the valuation is below the market price the individual will not wish to buy (if he does not already own land) and will wish to sell (if he does).

Four points need to be made concerning valuations. First, valuations are based upon the concept of present value. Clearly, in practice, individuals may use some other method of valuation, or even no method at all, in which case the valuation is an outcome from a purely random generating process and represents no more than a guess. It is assumed here that agents use present value methods, or rather, they act as if they do in assigning their own valuations to the land. Second, any particular valuation is assumed to hold irrespective of whether the agent currently owns land or not, *i.e.* there are no transactions costs. Third, an agent's valuation will be revised in light of new information but will hold in the absence of any new information. Consequently, the valuation encapsulates all information pertinent to the individual about the future and is an expectation that the individual believes will materialise. In essence, each agent acts as if he has perfect foresight. Fourth, valuations are assumed to vary across agents. Despite the assumptions of homogenous units of land and perfect information, individuals are required to act on past information differently. Whilst this assumption appears to run counter to intuition at first glance, it need not be a cause for concern. Net returns to land ownership are unlikely to be the same for all owners due to the varying importance individuals attach to non-pecuniary returns of landownership, differences in farming ability and the discount rate that each participant uses to convert expected future returns to an equivalent present value. Moreover, because an individual's valuation is based on expectations and these are necessarily stochastic, valuations across individuals (and over time for any one individual) may differ considerably.

Let us now focus on the precise nature of the net present value concept, *i.e.* the discounted value of the expected flow of net income from land. First, it is important to make the distinction between income derived from land ownership and that derived from farming. Whereas returns from farming represent the reward to the physical and managerial effort of the cultivator, the reward to land ownership can be thought of as a payment to an owner of land for the use of the flow of services from the land. Should the landowner be required to perform maintenance of the land and the structures on it, an additional payment will be required from the cultivator to perform these duties. Whilst in practice these components of the rental payment may be difficult to identify, conceptually the distinction is apparent.

Although the point above stresses the distinction between returns to land ownership and returns from farming, this does not deny a link between the two. The demand for land, like any other factor of production, is derived from the demand for the output that it generates. Consequently, the demand for the flow of services from land will be derived from the demand for agricultural products implying a causality between land prices and such factors as the input-output price ratio and technology via rents.

Theoretically, we can dismiss the differences between owner-occupancy and the landlord-tenant tenure systems by assuming that owner-occupiers recognise the market cost of the land they farm and impute a value for net rent. As Harvey (1974) puts it;

> "The owner of land can be thought of as renting the land in his capacity as the farmer from himself as the landlord." (p. 64)

The present value of a stream of net rents may not be the only determinant of land price. Individuals may attach some importance to the ownership of land itself and hence may purchase land for the subjective satisfaction that owning land bestows, as well as its value as a factor of production. As Currie (1976) wrote,

> "Land has always been much more than simply an economic asset. The most tangible non-pecuniary attractions arise from the various potential uses of land for residence, amenity and recreation. The most nebulous attraction is the frequently quoted landownership *per se*". (p.215)

In practice, some individuals may attribute considerable significance to, 'being the master of all one surveys' or to 'the social prestige of land ownership' or to 'the preservation of the Family estate'. Indeed, a survey by Denman (1957) into the determinants of farmland demand indicated that such 'psychic utility' exerts a non-trivial influence on land prices. Whilst difficult to quantify empirically the presence of non-pecuniary returns to landownership need not present a problem in this conceptual analysis providing that participants can attach a pecuniary value to it. To avoid unnecessary abstraction it is assumed that non-pecuniary benefits to landownership may exist and participants are willing to pay for them. An agent's valuation therefore represents the discounted sum of both pecuniary and non-pecuniary returns to land accruing over the period of ownership.

In order for the desire to purchase land to be consistent with the concept of 'effective demand', a perfect market for financial capital must exist. It is therefore assumed that each individual has unrestricted access to credit at the prevailing interest rate and thus the supply of credit is perfectly elastic. Transaction costs are ignored for simplicity, so that the rate of interest defines both the cost of borrowing and return on capital. As investment in financial capital represents the market alternative to land purchase, the interest rate represents the opportunity cost to investors in land and thus the interest rate will define the market rate for discounting future income streams from land. If an agent uses the market rate of interest to discount expected income then P_t can be interpreted as being the (maximum) sum of money that could be borrowed *now* given the expected profile of net income. Similarly, it is the (minimum) sum of money which if loaned in the capital market would accrue an equivalent stream of income over the period of ownership. However, participants in the market may not automatically use this market rate in the discounting exercise but elect to adopt private discount rates that differ from the interest rate prevailing in the financial market.

On the basis of these assumptions we are now ready to define a simple formula for obtaining the present value of a stream of net returns that we assume rational agents use to obtain their valuations of a unit of land at any point in time. Although we will discuss this concept in more detail later, it will be assumed here that valuations are computed in an inflation free environment according to,

$$P_t = \delta \sum_{j=0}^{\infty} \delta^j \mathrm{E}_t\left[R_{t+j}\right] \qquad \text{(III.1)}$$

where P_t is an agent's valuation computed at the beginning of time t; δ is the discounting constant, defined as $(1/1+r)$ where r is the agents rate of discount, E_t is the agent's expectation conditional upon information available at the beginning of time period t and R_t the net returns to land ownership comprising both pecuniary and non-pecuniary returns in period t. Hence, the present value of a unit of land is the discounted sum of the future income stream from that land.

To recap the assumptions of the model are;

1. There is a large number of homogenous ownership units in the land market.

2. There are sufficient agents in the land market to own all ownership units at a non-zero price, *i.e.* there is excess demand for land at a price of zero.
3. Each participating agent wishes to hold only one unit of land.
4. There are no transaction costs in transfer of ownership or any other barriers to ownership.
5. Input and output markets are perfectly competitive.
6. Any non-pecuniary benefit to land ownership is quantifiable.
7. Individuals aim to maximise their income (pecuniary or otherwise).
8. No government regulation of any kind.
9. The decision to purchase land is based solely on an individuals net present valuation of land.
10. Individuals act with perfect knowledge of the present period and subjective certainty of future periods.
11. There is a perfect capital market in which the supply of credit is perfectly elastic for any individual at the prevailing rate of interest.

III.(iii) The Demand and Supply of a Durable Asset

(a) A Stock Concept

Like other economic commodities the price of land is determined by the opposing forces of supply and demand. Attention however, needs to be paid to the actual definition of these concepts. Because a durable asset has a useful life that extends over many production periods, (in the limit, perpetuity) the term 'supply' does not have the conventional (flow) meaning of 'that amount entering the market per time period'; rather it refers to the accumulated *stock* of the commodity, not all of which will necessarily be offered for sale. Indeed, only a small fraction of the stock may be traded in any given period. Furthermore, given that additions to or depletions from the stock of land will be negligible, even over considerable time horizons the supply of land can reasonably be treated as fixed.

The demand for the stock of land may also be interpreted similarly, in that it describes the desire of *all* participants in the market to hold land and not simply those agents wishing to purchase land. In other words, the demand for the stock of land originates from prospective purchasers and current owners of land.

The concept of stock demand can be clarified using the following reasoning developed by Wicksteed (1910)[2]. Given that each agent has a valuation of land determined by its net present value, the stock demand curve represents a ranking of those valuations in descending order, irrespective of whether the individual is seeking to purchase at a particular price or an owner registering the worth he attaches to the unit he currently owns. Thus we can define the valuation of a current owner (his *reservation price*) as the minimum sum he would be prepared to accept in exchange for his land. Conversely, the valuation of a prospective purchaser (his *offer price*) represents the maximum sum he would be prepared to buy land for.

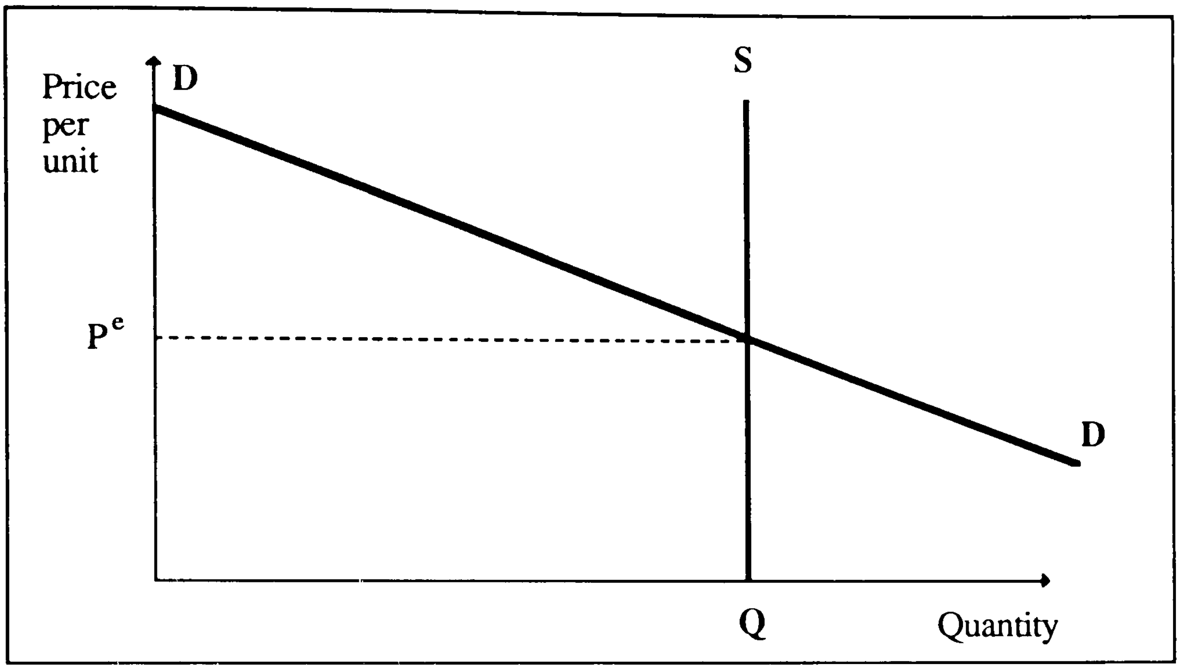
The implication here is that the stock demand curve includes the 'offer prices' of individuals wishing to buy land, and the 'reservation prices' of individuals who currently hold land. As the market price of land rises not only are there fewer people willing to buy land but fewer reservation prices implying a negative relationship will hold between the quantity demanded and price. As if in an auction room, a unit of land will only be sold at a price equal to or above the reserve price set by its current owner. The reservation price of the owner simply means that the owner has a *positive demand* for his land at, or below that price. As Wicksteed (1910) asserts;

> "It would be stretching language too far to talk of the seller at a reserved price as being a purchaser, but obviously her effect upon the market is precisely the same as if she were; and when we state the conditions that determine the market price, in their ultimate forms of "quantity of the commodity in the market" and "relative scales [of prices and quantities] of the persons constituting the market" we have already included in the latter not only the whole body of purchasers but the whole body of sellers at reserved prices". (pp.230)

Figure III.1 illustrates a fixed quantity of land available, denoted by the stock supply curve **QS**, and a ranking of valuations denoted by the stock demand curve **DD**. The intersection of these curves purely establishes an equilibrium market price (P^e) based on the demand to hold the stock of land. Bearing in mind that at any given price, demand for the total stock will be composed of individuals who are simply registering that they have a positive demand for land at that price (and therefore do not necessarily want to buy land), the number of transactions is naturally independent of the process of price determination. The equilibrium merely refers to a current price at which individuals are *collectively* willing to hold that stock of land.

2 Particularly pp.228-237.

Figure III.1: Equilibrium Price Determination Using Stock Demand and Supply Curves



Furthermore, it is unlikely that the equilibrium price will remain constant over consecutive periods. For although each individual is certain that his expectation of future income and discount rates will hold at a given point in time, (the 'perfect foresight' assumption), there will be revision of expectations at successive points in time, which may shift the demand curve and hence the equilibrium price. As Clower (1954) writes;

> ". . . because foresight is unlikely to ever propose what hindsight knows, the market for any durable good is necessarily "speculative". Thus, current market price is a highly temporary phenomenon". (pp.66)

(b) A Flow Concept

We have now established the process by which price is determined for an asset in fixed supply and have inferred that the level of transactions is independent of price in such circumstances. Equilibrium price reflects a valuation of land such that all individuals, (collectively), are prepared to hold the existing stock at a point in time. It says nothing regarding the allocation of land among individuals. Conceivably, at the equilibrium price there will be some individuals who own land but wish to sell, (their $P_t < P^e$), and some individuals who wish to buy land at the current price, (their $P_t > P^e$). So, at the *market* equilibrium price there may exist *individuals* who are not in equilibrium.

Trade in land will take place at the equilibrium price to resolve what can be thought of an *intra* -market disequilibrium. As Harvey (1974), asserts;

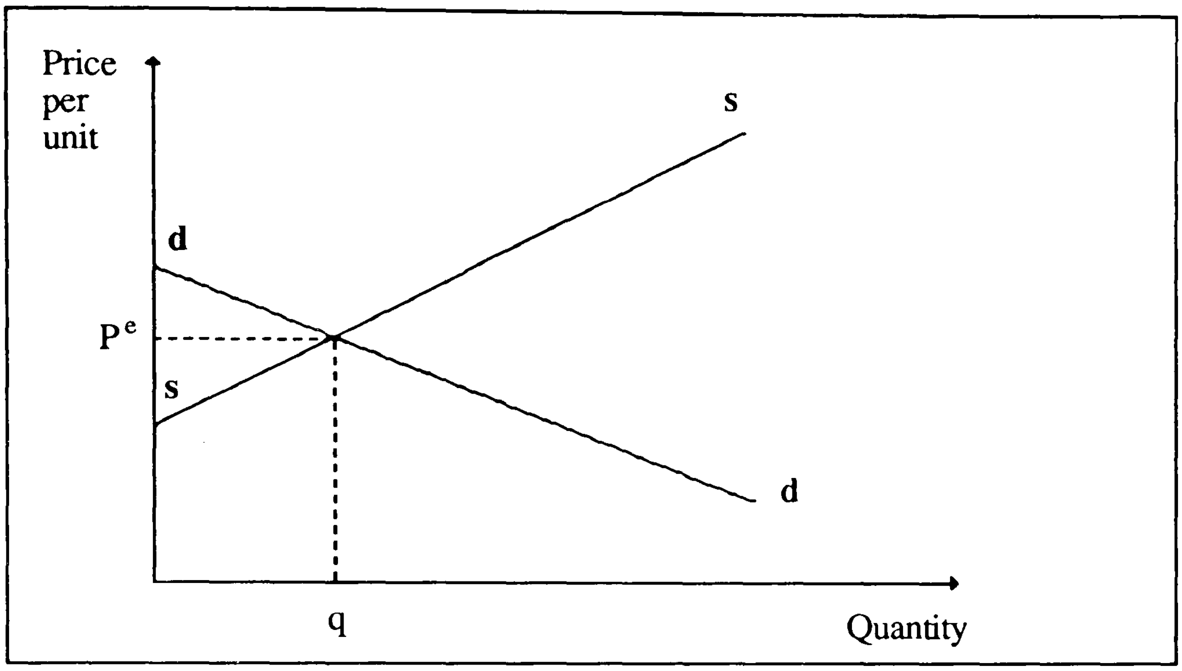
> "Transactions are the mechanism by which the allocation of land among individuals achieves equilibrium, so that the owners of land are content to hold that land". (p.70)

Let us now examine this mechanism more closely in terms of the *flow* concept of the demand and supply for transactions of land. The 'supply of transactions' during a given period, (*i.e.* the number of units of land that owners wish to sell in a particular period), will depend on the extent of the misallocation of land amongst owners in the market. The transactions supply schedule will thus comprise reservation prices only and *ceteris paribus*, the higher the price, the more land will be offered for sale. Thus the transaction supply curve ss will have a positive gradient as depicted in Figure III.2. The quantity of land that owners collectively wish to sell at any given price will be determined by the number of owners whose valuation of land is less than that given price.

'Transaction demand' can be thought of in a similar way, in that, it represents the valuations of agents in the market that wish to purchase land at given prices. Clearly, the distinction between this and stock demand lies in the fact that the latter represents valuations of all individuals whereas transaction demand only comprises the valuations of those agents who actually wish to buy land at that price, *i.e.* offer prices of prospective purchasers. *Ceteris paribus*, individuals will wish to purchase a greater quantity of land the lower its current market price and hence the transaction demand curve is defined with a negative slope as **dd** in Figure III.2. The quantity of land that prospective purchasers will wish to buy during any period will be determined by the number of valuations of prospective owners equal or greater than the current market price.

Using the more familiar flow concept of demand and supply, it is evident that both price and the volume of trade in equilibrium may be determined. Providing that it is borne in mind that the flow functions represent the demand and supply curves for land sales and not the stock of land, no confusion between the two need arise.

Figure III.2 : Transactions at Equilibrium



Let us now investigate the link between the stock and flow concepts. As will be seen later in Figures III. 3 and III. 4, each pair of curves intersect at the same equilibrium price level. This is not merely coincidental but rather a logical implication of their construction. To demonstrate this, assume that at time t, there are n agents in a land market, each possessing an initial stock of land Q_{it} (this being zero for the potential entrant) for $i = 1, \ldots, n$. Each agent also has a downward sloping demand curve in relation to price, P_t, for the ownership of land. This demand curve is $D_{it} = D_{it}(P_t)$ for $i = 1, \ldots, n$. The equilibrium price of land, P^e_t, reflects the intersection of the aggregate (stock) demand curve for land with the perfectly inelastic stock supply curve:

$$\sum_{i=1}^{n} D_{it}(P_t^e) = \sum_{i=1}^{n} Q_{it} \qquad \text{(III.2)}$$

The condition for equilibrium is given by the basic present value rule, equation (III.1) although we will leave the derivation of this result to Section (vii). The amount of land that will be traded while maintaining equilibrium may be small or large. The market for land sales - the flow market - may be described by the demand and supply of transactions, *i.e.* the excess demand or excess supply curves of agents in relation to endowments. At a specified price $\tilde{P}_t$, assume that m agents (where, $m \leq n$) have *non-negative* excess demand[3];

3 Note that here, excess supply is simply the non positive excess demand, hence, *both* may exist at any one price.

$$ED_{it}(\tilde{P}_t) = D_{it}(\tilde{P}_t) - Q_{it} \geq 0, \text{ for } i = 1, \ldots, m$$

and the remaining n-m agents have *non-negative* excess supply;

$$ES_{it}(\tilde{P}_t) = Q_{it} - D_{it}(\tilde{P}_t) \geq 0, \text{ for } i = m+1, \ldots, n.$$

The m agents with a non-negative excess demand are potential purchasers of land; the remaining n-m are potential sellers of land. At lower prices, aggregate (non-negative) excess demand increases partly because the number of prospective purchasers can increase and partly because the demand for ownership increases. Conversely, aggregate (non-negative) excess supply diminishes with lower prices. The transactions demand curve is represented by the quantity of aggregate non-negative excess demand in relation to land price; the transactions supply curve is represented by the quantity of aggregate non-negative excess supply in relation to land price. At equilibrium price, P^e_t, the aggregate ED and ES curves intersect:

$$0 < \sum_{i=1}^{h} ED_{it}(P_t^e) = \sum_{i=h+1}^{n} ES_{it}(P_t^e) > 0 \tag{III.3}$$

where, h agents have non-negative excess demand and (n-h) agents have non-negative excess supply. To show that the stock and flow equilibria coincide consider (III.3) which implies,

$$0 < \sum_{i=1}^{h} D_{it}(P_t^e) - Q_{it} = \sum_{i=h+1}^{n} Q_{it} - D_{it}(P_t^e) > 0 \tag{III.4}$$

Rearranging (III.4) in terms of the stock of land yields,

$$\sum_{i=1}^{n} D_{it}(P_t^e) = \sum_{i=1}^{n} Q_{it} \tag{III.5}$$

which is identical to equation (III.2). Consequently, equilibrium price will be determined by the intersection of the supply and demand curves for the stock and for land sales. Given that the transaction curves provide an illustration of both equilibrium price and quantity traded, we may proceed without the explicit inclusion of the stock demand and supply functions, which become superfluous. Further, the volume of transactions at the equilibrium price depends on the disparities in the demand curves for ownership amongst the n agents and the distribution of initial endowments and not the level of the equilibrium price. As will be demonstrated in section III.(v), the level of price and trade in equilibrium are determined independently. The role of transactions is to transfer land from individuals placing a lower value on land to individuals placing a higher value on land, such that in equilibrium valuations by current owners of land are above valuations by prospective purchasers.

In passing it is noted that if we relax the assumptions of costless transaction and perfect mobility of land then these factors can block prospective trades between otherwise legitimate buyers and sellers, and hence affect the volume of transactions at any particular time. Transactions costs include: (a) the cost of searching for suitable land and verifying its attributes for prospective purchasers, and costs of negotiation for prospective sellers; (b) costs of implementing final contracts. Land immobility implies that potential buyers may not trade with potential vendors if they are in different locations. Consequently, the strict inequality in (III.3) will only hold for a subset of agents who, after consideration of transactions costs and location, actually trade land such that,

$$0 < \sum_{i=1}^{k} ED_{it}(P_t^e) = \sum_{i=1}^{g} ES_{it}(P_t^e) > 0$$

where, k agents (less than h) being purchasers of land, g agents [less than $(n\text{-}k)$] being vendors of land and there being $(n\text{-}g\text{-}k)$ agents who are content to hold the land they currently own.

(c) Equilibrium in Durable Asset Markets

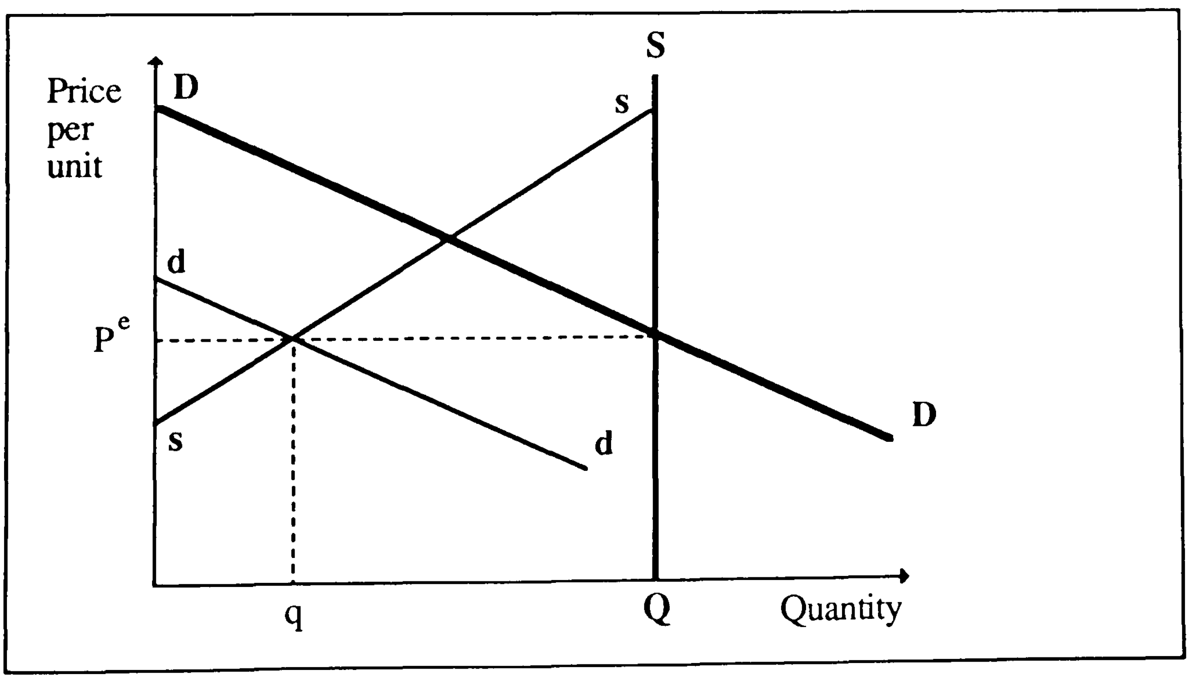
We can now proceed to marry the stock and transaction supply and demand together to illustrate what Clower (1954) called 'temporary' and 'stationary' equilibrium in a market for durable assets.[4] The stock demand and supply curves conveniently illustrate the equilibrium price at which *collectively* agents are willing to hold the stock of land. In other words, the *market* could be thought of as being in equilibrium, in that a price has been established at which agents are collectively willing to hold the stock of land. However, within the aggregate there may be agents that do not hold their equilibrium quantity (here, zero or one units of land) at that price. Where this is so, there will be current owners who wish to dispose of their holdings (their valuation of land is less than market price), and prospective owners wishing to purchase at that price (their valuation of land is greater than market price) and trade will occur between

4 To the extent that equilibrium normally implies a state in which there is no motivation to change, the identification of *two* distinct types of equilibrium is rather unfortunate. The terminolgy is upheld here for the simple reason that these two states were first explicitly recognised by Clower (1954) who coined the terminology. In essence the use of adjectives to describe an equilibrium reflects the fact that trade and price are determined independently for durable goods: temporary equilibrium refers to a state where price only is in equilibrium ; stable equilibrium refers to a state in which both trade and price are in equilibrium.

willing vendors and willing purchasers at the market equilibrium price. The market equilibrium simply requires that there exists the same number of individuals wishing to purchase land as there are current owners prepared to sell land at the equilibrium price. This is the temporary equilibrium described by Clower (1954) and is depicted in Figure III.3.

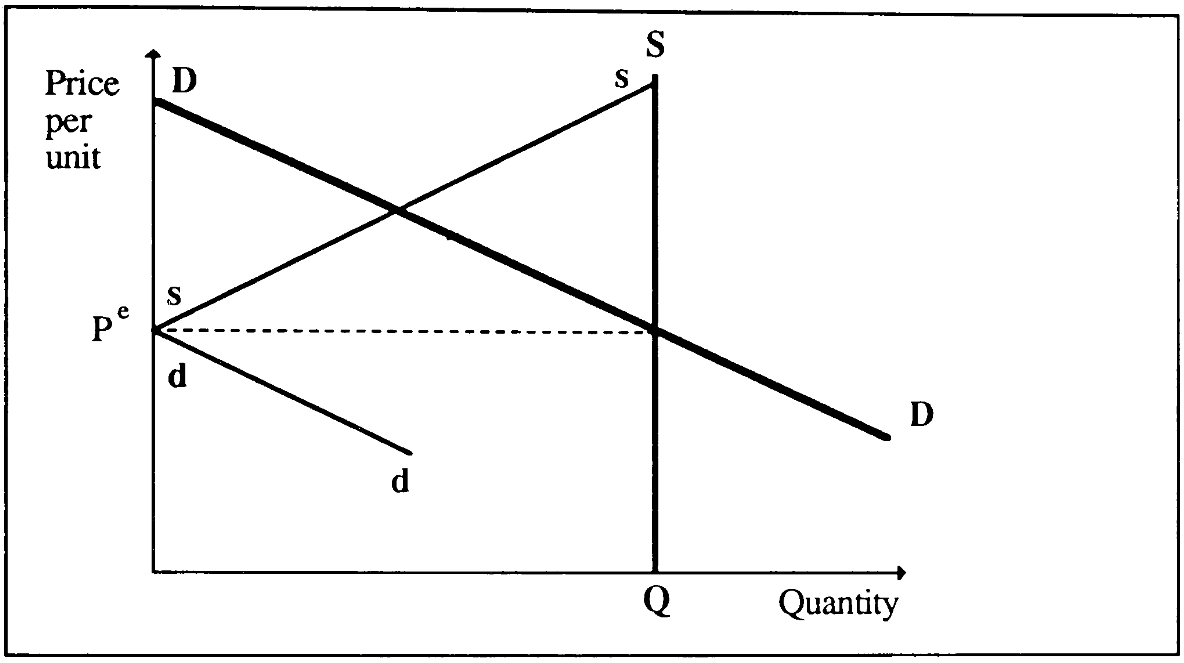
Note that this situation is characterised by a *disequilibrium allocation* of land at the market equilibrium price, P^e. More specifically, the extent of the misallocation is given by the number of transactions that occur in each period; here it is, q. Under the assumption that a valuation of land by each individual holds irrespective of whether that individual holds land or not, each transaction will entail that the reservation price of the vendor becomes his offer price as a prospective purchaser. Similarly, the offer price of the prospective purchaser will, after the transaction has gone through, become his reservation price as a land owner. With each successive sale the transaction demand and supply curves shift horizontally toward the price axis until there are no willing vendors or potential purchasers at the equilibrium price.

Figure III.3 : Temporary Equilibrium



Consequently, the transactions mechanism results in a situation where all reservation prices lie above all offer prices. At this equilibrium all owners of land are content to hold the land they own and hence no transactions take place. This is depicted in Figure III.4, and is the stable equilibrium to which Clower (1954) referred. The 'stability' of this equilibrium arises from the fact that in the absence of change to the valuation of each participant, the equilibrium price P^e will hold indefinitely and no further transactions will occur.

Figure III.4 : Stable Equilibrium



The transfer of ownership is the mechanism by which stable equilibrium is reached. In contrast to the relationship between price and quantity for non-durable goods, trade is independent of price, as the rate of transactions depends only on the extent of the misallocation of land among individuals at the equilibrium price and not the price itself. The role of transactions is therefore one of redistribution within the market, so that, not only are all individuals collectively willing to hold the stock at the equilibrium price, but that the stock is allocated among those individuals who have a positive demand for land at that price.

Two observations are worth noting at this point. First, bearing in mind that valuations are revised at the end of each market period, the price level is likely to fluctuate as information becomes available. Second, the result that the position of no-trade is indicative of equilibrium may at first sight appear perverse. Clearly however, this outcome hinges solely on the assumptions of the model, regarding information-processing and trade. When we admit market imperfection, time lags, and transactions costs it is clear that a stable equilibrium is an outcome confined solely to theoretical abstraction.

III.(iv) Price Determination in the Land Market

So far the analysis of price determination for a durable asset such as land has been cursory. However, we may glean useful insights into durable asset markets if we concentrate on the determination of price itself. We will initially focus attention on the transactions supply and demand functions using the analysis of Currie (1981, pp.87-89) and then tie it in with the demand and supply functions for the stock of land. To aid exposition the analysis begins with the simplest of cases and builds up to case where there is a large number of agents.

(a) Case 1

To begin, assume the market consists of one unit of land and two agents; a current owner and a prospective purchaser. A necessary condition for trade requires that the offer price of the prospective owner ($P_{o,1}$) must be at least as great as the reservation price of the current owner, ($P_{r,1}$). Providing $P_{o,1} > P_{r,1}$ trade will occur, yet, the precise level of the equilibrium price (P^e) is indeterminate, lying in the range, $P_{o,1} \geq P^e \geq P_{r,1}$ which Currie (1981) calls 'the core'. The precise level of equilibrium price obtained will depend on the relative bargaining strengths of the two agents[5]. Clearly, if the valuations of the two agents are exactly the same *i.e.* $P_{o,1} = P_{r,1}$ a determinate price is obtained, but in such circumstances it is unclear which of the two agents actually holds the land at any point in time. Here, trade is an ongoing phenomenon, ownership constantly switching between the two agents.

(b) Case 2

If we now introduce a third agent into the market - a prospective purchaser - with an offer price ($P_{o,2}$) such that, $P_{o,1} > P_{o,2} > P_{r,1}$ it is clear that it is impossible for him to enter into trade because any initial agreement between the current owner (*r,1*) and the new entrant (*o,2*) could be bettered by (*o,1*). However, the new entrant plays an important role in the market because his offer price narrows the range within which the equilibrium price can lie (*i.e.* he shrinks the core). Should trade between (*o,1*) and (*r,1*) occur at a price below $P_{o,2}$ then (*o,2*) could improve on it to (*r,1*)'s advantage. This implies that neither of the prospective purchasers could obtain the unit of land below $P_{o,2}$ as the other could always renegotiate a dominant contract with the current

5 Of course, as a co-operative game a determinate solution could be found, *i.e.* the Nash equilbirum, but the assumptions required for such a solution are restrictive and we need not detain ourselves with it as our primary interest is in the market composed of many agents.

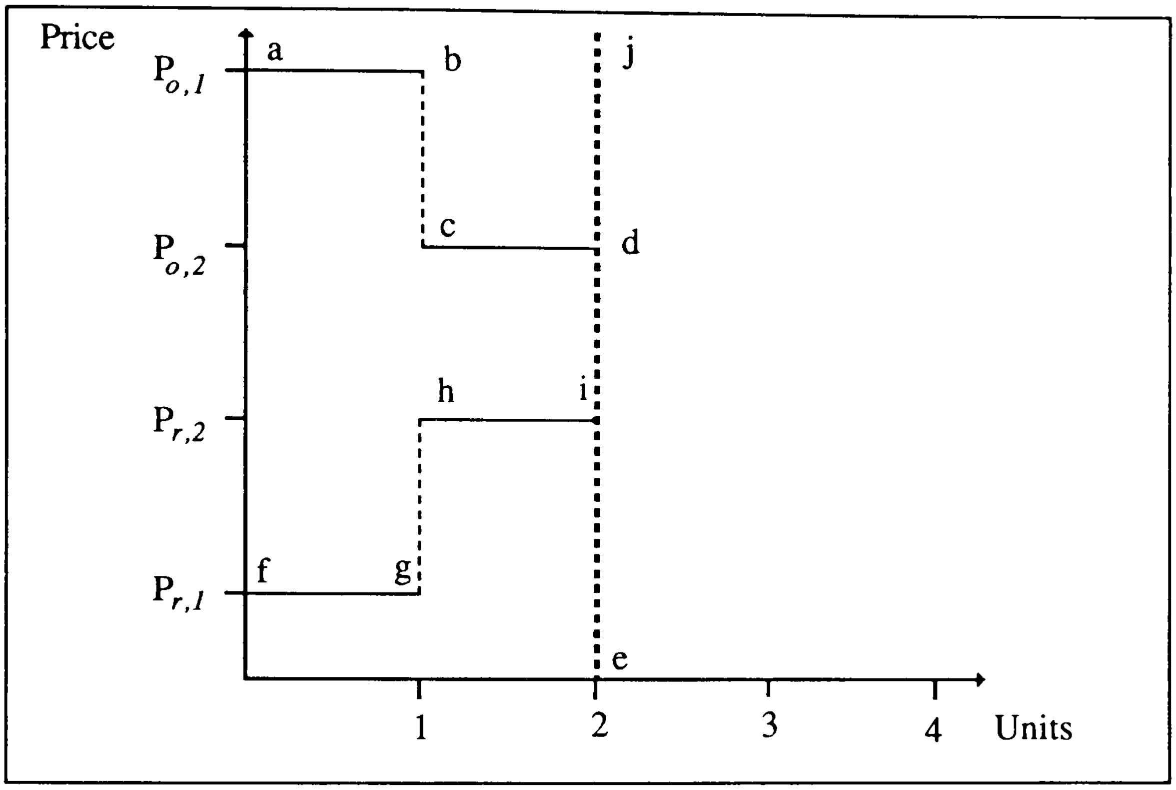
owner. Hence, the presence of (*o,2*) bids up market price and narrows the range within which the equilibrium price may lie. Given that $P_{o,1} > P_{o,2} > P_{r,1}$ then equilibrium price is indeterminate and lies in the core, $P_{o,1} \geq P^e \geq P_{o,2}$. In the case where $P_{o,1} = P_{o,2} > P_{r,1}$ equilibrium price is determinate (being equivalent to the offer prices of both prospective purchasers) but it is uncertain which of the prospective purchasers will obtain ownership at any particular point in time. Again trade will be an ongoing phenomenon.

(c) Case 3

Let us now consider a situation in which the stock of land comprises two homogenous units and four agents; two prospective purchasers and two current owners of land. With this example another feature of price determination emerges. Specifically, all units offered for sale will be traded at the *same* price, the equilibrium price. Suppose that the offer and reservation prices of the four agents are such that $P_{o,1} > P_{o,2} > P_{r,2} > P_{r,1}$. Because the lowest offer price ($P_{o,2}$) exceeds the highest reservation price ($P_{r,2}$) then *both* units, *i.e.* the entire land stock, will be traded. Each transaction will occur within the core set by $P_{o,2}$ and $P_{r,2}$ because at prices above $P_{o,2}$, (*o,2*) would not wish to purchase the second unit of land, and at prices below $P_{r,2}$, (*r,2*) would not wish to sell the second unit of land.

All units will be traded at one price since the prospective owner paying the higher price and the current owner receiving the lower price would renegotiate until both units of land were traded at the same price. This iterative bargaining process can be illustrated by the following. Given that agents valuations are such that, $P_{o,1} > P_{o,2} > P_{r,2} > P_{r,1}$ assume that (*o,1*) initially negotiates with (*r,2*) at a price between their respective offer and reservation prices, denoted P^*; and that (*o,2*) negotiates a trade with (*r,1*) at a price P^{**}, also between their respective offer and reservation prices, such that $P^* > P^{**}$ .Consequently, (*o,1*) and (*r,1*) have an incentive to negotiate a new deal because they are paying and receiving more and less respectively for a homogenous unit of land than the other agents in the market. As a result of cancelling their initial contracts they open up the entire market for renegotiation. Clearly, the motivation for recontracting will only cease when both units of land are sold at the same price. Hence, equilibrium price lies in the core set by $P_{r,2} \leq P^e \leq P_{o,2}$ This is more clearly seen in Figure III.5, which depicts the transactions supply and demand curves as step functions.

Figure III.5 : Determination of Equilibrium Price in a market comprising two owners and two prospective purchasers



The transaction demand curve is the function joining the points (abcde) and the transactions supply curve is that represented by the points (fghij). Notice that the intersection of the transactions functions occurs at 2 units and equilibrium price lies between $P_{r,2}$ and $P_{o,2}$ as explained above.[6] Appendix III.A examines the possible price-quantity outcomes in the four agent model and categorizes them according to whether the stable equilibrium explained above is attainable.

(d) Case 4

Using these principles we may now examine the case where there is a large number of agents and hence continuous functions (such as those used at the beginning of this chapter) may be used as legitimate approximations of the step functions drawn in the preceding cases. Assume that there are *m* prospective owners and *n* owners of land in the market, (which by definition, consists of *n* homogenous units of land). Denoting

6 Although the stock supply and demand functions have not been explicitly drawn in Figure 5 it should be clear that the stock supply curve is represented by the dotted line (ej) and the demand curve for the stock in this case would correspond to the transaction demand curve and would then continue as the mirror image of the transactions supply curve (the mirror being placed in the ej plane).

$P_{r,i}$ as the reservation price of the i^{th} owner (i = 1, 2, . . . n) and $P_{o,j}$ as the offer price of the j^{th} prospective purchaser (j = 1, 2, . . . m) we can define the transactions demand and supply curves respectively as a ranking such that:

$$P_{o,1} \geq P_{o,2} \geq \cdots \geq P_{o,m}$$
$$P_{r,1} \leq P_{r,2} \leq \cdots \leq P_{r,n}$$

If it is further assumed that $P_{o,1} > P_{r,1}$ then there exists a misallocation of land among agents which will motivate trade. Following similar lines to those set out above, all transactions will occur at the same equilibrium price. Assuming k units are traded to rectify this misallocation of land the general rule for obtaining the core within which equilibrium price must lie is given by,

$$\max\ (P_{r,k}, P_{o,k+1}) \leq P^e \leq \min\ (P_{o,k}, P_{r,k+1}) \qquad \text{(III.6)}$$

To see why this is so, it is convenient to return to a four agent market model defined by $P_{o,1} > P_{r,2} > P_{o,2} > P_{r,1}$. Substituting these values into (III.6) we have,

$$\max\ (P_{r,1}, P_{o,2}) \leq P^e \leq \min\ (P_{o,1}, P_{r,2})$$

$$P_{o,2} \leq P^e \leq P_{r,2}$$

This result is illustrated in Figure III.6 where the transaction demand curve is represented by the function (abcdef) and supply by (ghdcij).

The second element in each of the brackets either side of equation (III.6) is important because it limits the range in which the equilibrium price can lie. For example, if a third prospective purchaser is introduced into the market such that $P_{o,1} > P_{r,2} > P_{o,2} > P_{o,3} > P_{r,1}$ a single unit continues to be traded, but the size of the core has been reduced. Referring to Figure III.7 which illustrates this model, the transaction supply function is unchanged at (ghdcij) and the demand for transactions is represented by the function (abdeff'f").

The core is now bounded by $P_{r,2}$ and $P_{o,2}$ and has been reduced by the vertical distance (ef), which represents the difference between the new entrant's offer price and that which previously defined the lower bound of the core. In an analogous fashion we can also reduce the core by introducing a third current owner of land (*i.e.* enlarging the land stock) providing the new owner has a reservation price that lies somewhere in the core set by the five agent model.

Figure III.6 : Equilibrium Price Determination With Two Owners and Two Prospective Purchasers

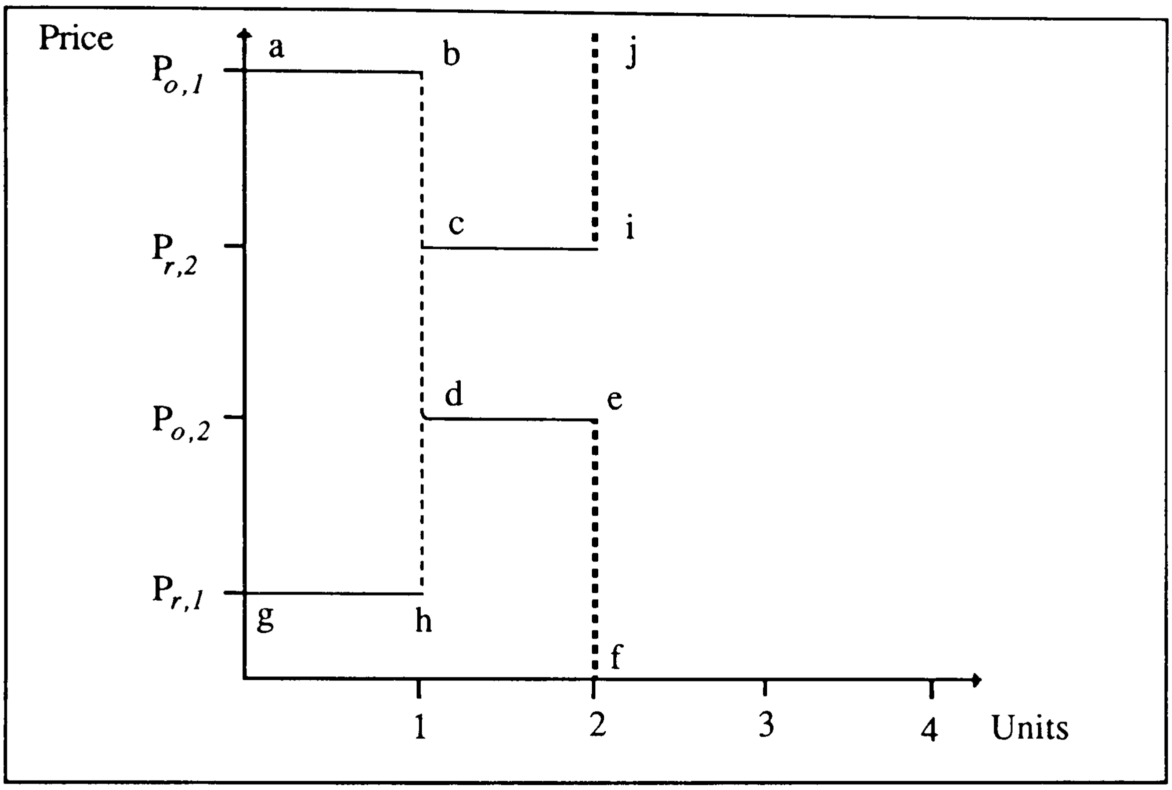
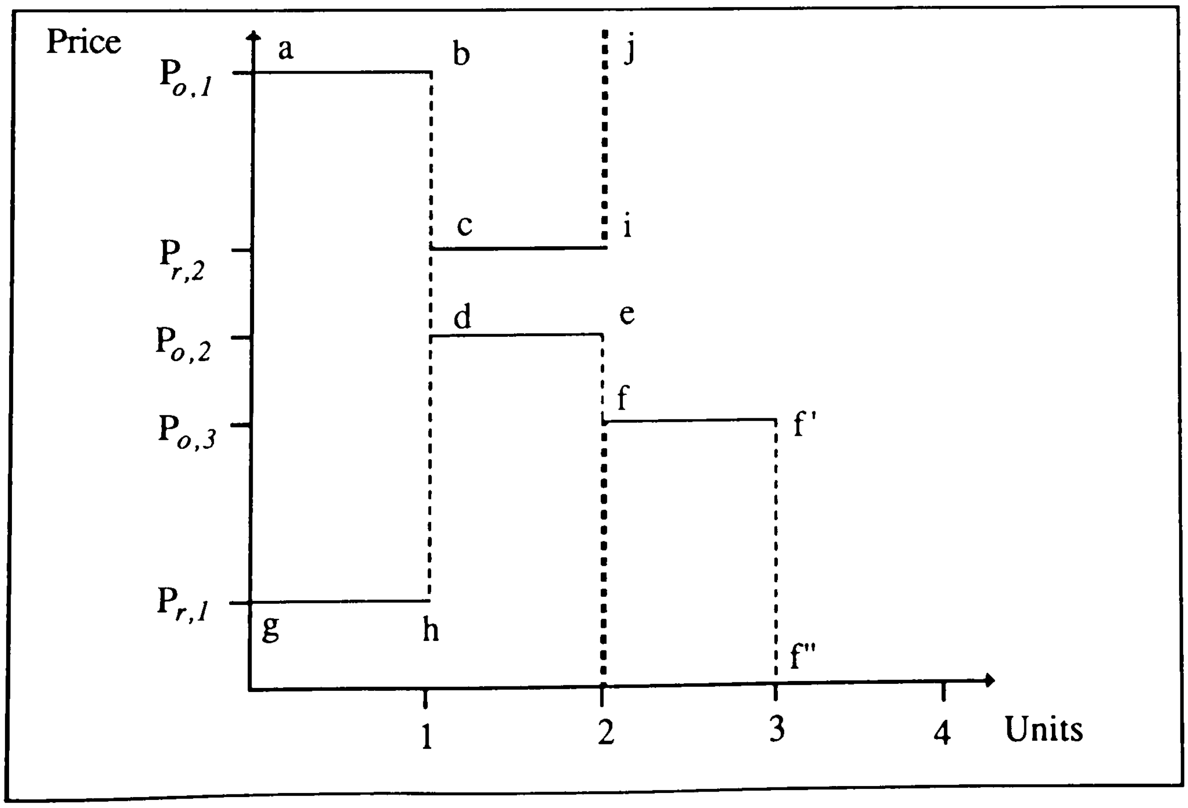


Figure III.7 : Price Determination With Two Owners and Three Prospective Purchasers



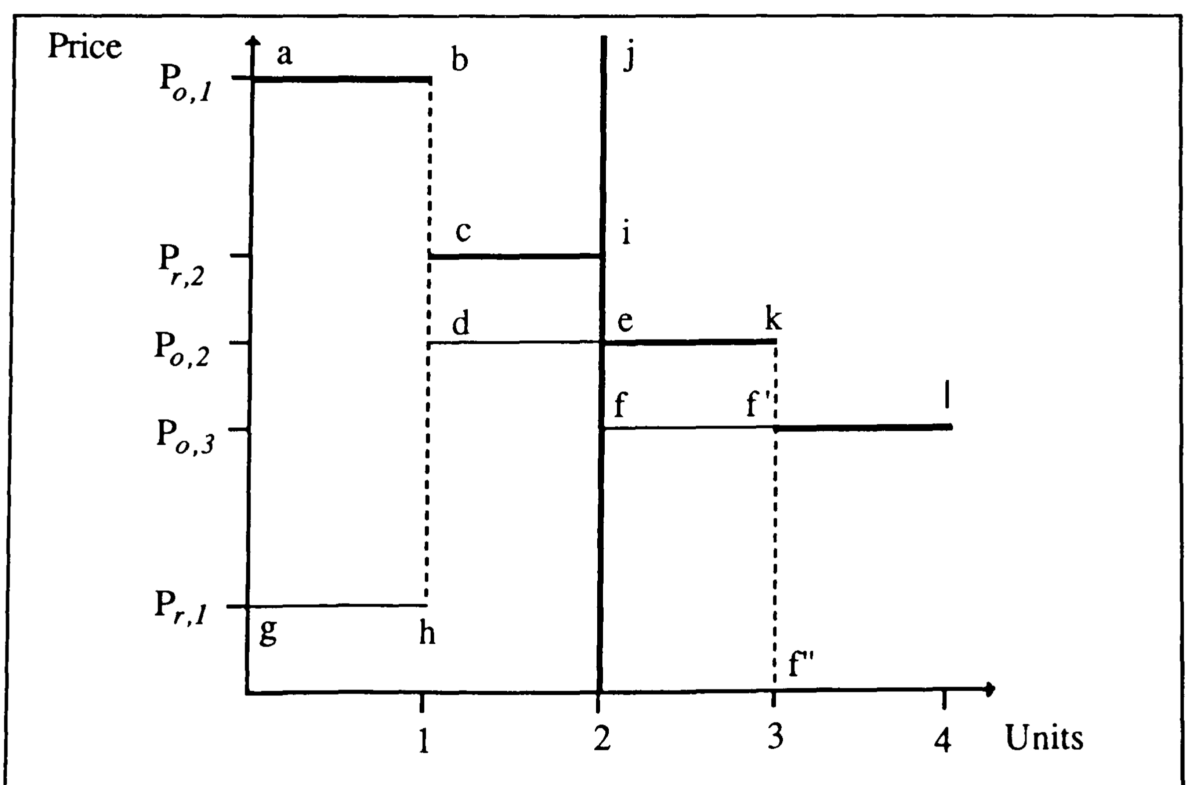
Returning to transactions in the n by m agent case we can now formulate a general rule for the determination of the number of transactions. As stated previously, the process of trade is the mechanism by which individual agents obtain their optimal allocation of land. Trade achieves this by transferring ownership of land from willing vendors at the equilibrium price to willing purchasers at that price. Where all reservation prices are greater than all offer prices there is no trade as all owners are content to hold land by definition. Letting (o, j) be the prospective purchaser with the j^{th} highest offer price and (r, i) be the current owner with the i^{th} lowest reservation price then a general formula for the number of transactions k occurring in a market consisting of n units is given by,

$$k = \min\left[\sum_{j=1}^{m}(o,j) \geq P_u^e, \sum_{i=1}^{n}(r,i) \leq P_l^e\right] \tag{III.7}$$

where P_u^e and P_l^e are the upper and lower limits of the core respectively. Should the equilibrium price be determinate then these limits will naturally coincide and P^e may be legitimately substituted for either in equation (III.7).

We may now link this analysis up with the demand and supply curves for the stock of land. This is shown in Figure III.8 which reproduces the five agent model of Figure III.7 and superimposes stock demand and supply.

Figure III.8 : Stock and Flow Step Functions in a Five Agent Model



Again, the demand and supply functions for transactions are given by (abdefff'') and (ghdcij) respectively and the stock supply curve is represented by the vertical line (jf) and the stock demand curve by (abciekl). As demonstrated earlier both sets of functions intersect to give the same equilibrium price, here the core is $P_{o,2} \leq P^e \leq P_{r,2}$.

An important result to emerge from this analysis is that, in a market consisting of n units the core in which equilibrium price must lie is defined by the n^{th} and the $n + 1^{th}$ lowest valuations, irrespective of whether the valuations are from prospective purchasers or vendors of land. This point is of some consequence for it clears up an ambiguity present in Currie's (1981) analysis which implied that the equilibrium price is determined by the valuation of the prospective purchaser and the valuation of the current owner at the margin. Only after trade has occurred, *and a stable equilibrium attained* will the 'marginal' vendor and 'marginal' prospective purchaser determine the core and hence the range in which the equilibrium price will fall. Given that a stable equilibrium will rarely, if ever be attained this point is worthy of note. For further explanation of this point see Appendix III.A.

In passing it can also be noted that where there are a large number of agents it is likely that the core will diminish to the point where it holds no practical significance and the equilibrium price will be to all intents and purposes determinate. Moreover, in a market consisting of n units equilibrium price will be determinate providing that the n^{th} and $n + 1^{th}$ valuations are equivalent. This case is also illustrated in Appendix A.

In summary, this analysis demonstrates that the equilibrium price is that price at which agents in the market are willing to hold the entire stock. In terms of the stock demand and supply functions the core for a n unit market is defined by the n^{th} and the $n + 1^{th}$ highest valuations. In terms of the flow concept of transaction supply and demand the the core is described by the expression,

$$\max (P_{r,k}, P_{o,k+1}) \leq P^e \leq \min (P_{o,k}, P_{r,k+1})$$

where k units of land are traded to rectify the misallocation. Further, the number of transactions required to achieve a stable equilibrium is given by,

$$k = \min\left[\sum_{j=1}^{m}(\mathrm{o},j) \geq P_u^e, \sum_{i=1}^{n}(\mathrm{r},i) \leq P_l^e\right]$$

In addition, because k and n are independent we are able to state that there is no theoretical basis to suggest a causal link between the number of transactions and the level of the equilibrium price.

III.(v) Some Comparative Statics of the Model

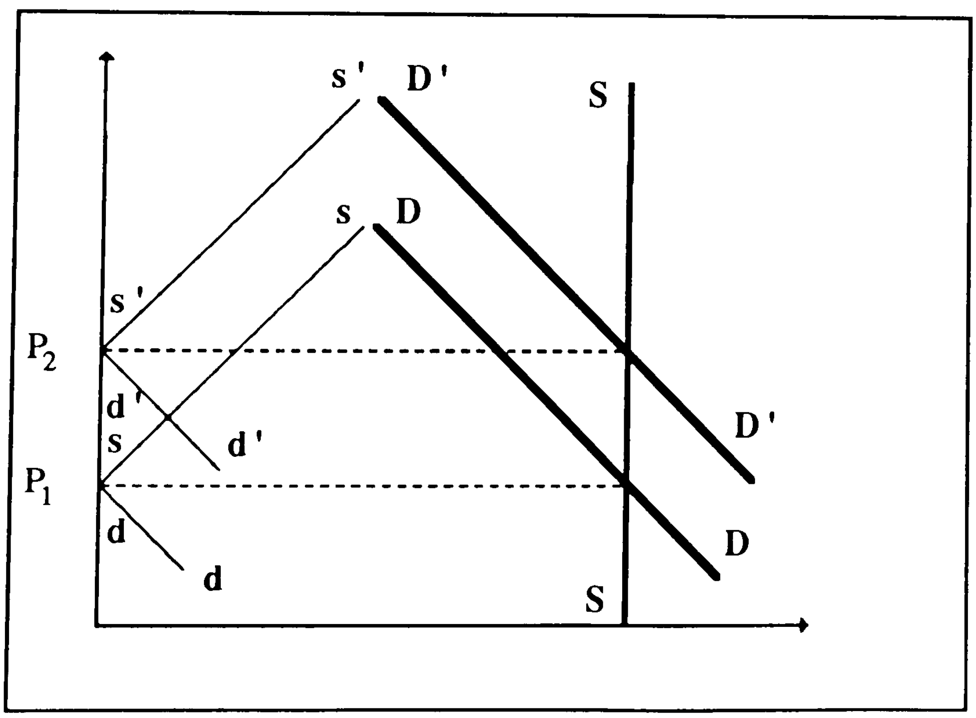
To underscore the independence of price determination and quantity traded in a market for a durable good it will be instructive to consider two comparative static propositions. Both cases are polar extremes, yet are the proper outcomes given the rather unusual conditions portrayed by each market. We will begin from a position of stable equilibrium, characterized by current owners who are all content to own the land they hold at the prevailing equilibrium price. Introducing particular stimuli into the model results in a market characterised by,

(a) a price change but no trade and,

(b) trade but no change in price.

To illustrate the outcome of the first proposition assume there is a sudden increase in farm product prices, all other factors remaining unchanged. Valuations of land by current owners and prospective purchasers rise inducing a vertical shift in the stock demand curve **DD** to **D'D'** in Figure III.9 reflecting the fact that land ownership is more profitable.

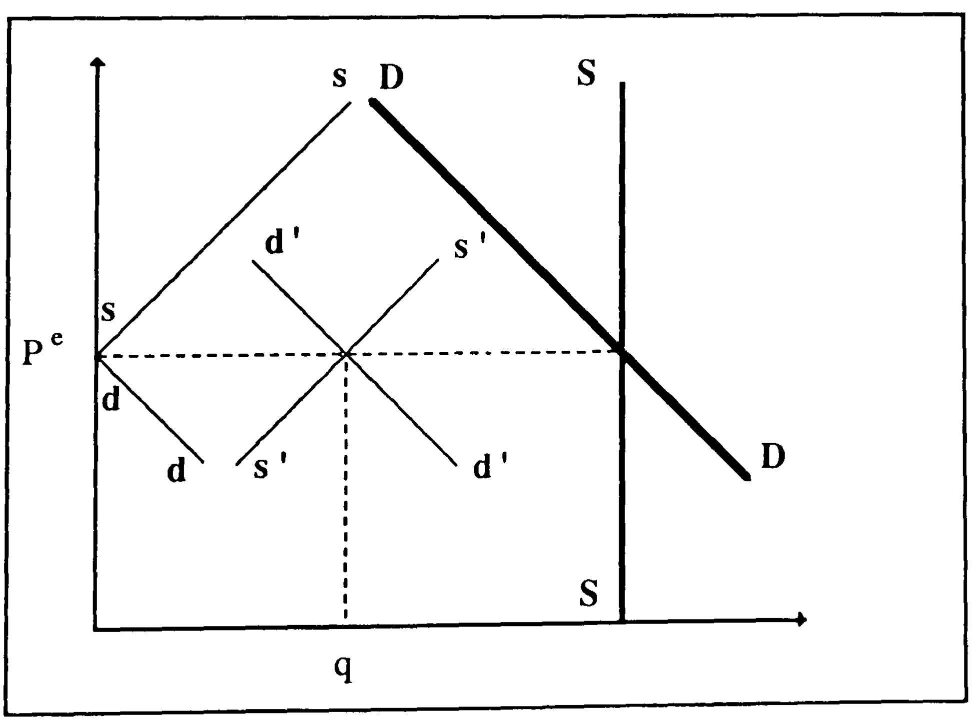
Figure III.9 : A Change in Land Price with no Trade



Provided that the initial product price rise is acted upon equally by all agents so that every valuation increases by the same amount, the demand and supply curves for transactions also shift vertically from **dd** and ss to **d'd'** and **s's'** respectively. Consequently, no trade is induced; all that occurs is a rise in land prices to P_2 to choke off the excess demand at the previous equilibrium price P_1. The change in land price from P_1 to P_2 does not motivate any trade as there has been no change in their relative valuations of owners and prospective purchasers. The owners of land at the initial equilibrium remain content to hold the land they own at P_2 and there is no motivation to trade.

In a similar manner, it is possible to conceive of an impetus to the market which motivates trade among individuals but does not change the demand for the land stock *per se*. Providing the information that causes trade to occur has an equal and opposite effect on prospective purchasers and current owners, no pressure on price will have been generated, yet the entire market could conceivably change hands given a sufficient disturbance to valuations. Providing that the n^{th} and $n + 1^{th}$ valuations remain unchanged in a market of n homogenous units, so will equilibrium price. Figure III.10 depicts a situation where q units are traded at the same equilibrium price P^e.

Figure III.10 : Transactions With no Change in Land Price



Here, there is a horizontal shift in the transactions supply and demand curves, (to s's' and **d'd'**) indicating that the fall in reservation prices is matched identically with a rise in offer prices and hence the stock demand curve does not change. *Ceteris paribus*, once trade has taken place to rectify the misallocation the market will be restored to stable equilibrium where all owners are content to hold the land they currently own at the prevailing market price, P^e.

III.(vi) A Numerical Example of The Land Market Model

This example illustrates the determination of price and trade and the role of transactions in the operation of the land market, along the lines described in the previous sections. For simplicity, it is additionally assumed that;

i) The land stock is fixed in supply at 10 units.

ii)There are 15 valuations for these units of land; 10 reservation prices of current owners and 5 offer prices made by prospective purchasers of land.

Different valuations of land in this elementary model do not arise from differences in land quality or location (all units of land are homogenous), but due to the [subjective] expectations of each individual concerning future levels of rent, psychic utility and discount rates. The 15 hypothetical valuations are presented in Table III.1 and graphed as supply and demand curves for transactions and the stock in Figure III.11.

Table III.1: Net Present Valuations of Land by All Individuals in the Market

Units of Land	Reservation Prices of Landowners	Offer Prices of Potential Purchasers
1	300	310
2	320	290
3	340	270
4	360	250
5	380	230
6	400	
7	420	
8	440	
9	460	
10	480	

From these rankings of reservation and offer prices the equilibrium price lies within the core given by,

$$\max(P_{r,k}, P_{o,k+1}) \leq P^e \leq \min(P_{o,k}, P_{r,k+1})$$
$$P_{r,k} \leq P^e \leq P_{o,k}$$
$$300 \leq P^e \leq 310$$

which are the tenth and eleventh lowest valuations by definition. Furthermore, the number of transactions required to attain a stable equilibrium is given by

$$k = \min\left[\sum_{j=1}^{m}(o,j) \geq P_u^e, \sum_{i=1}^{n}(r,i) \leq P_l^e\right]$$
$$k = 1$$

Figure III.11 illustrates the temporary equilibrium of this market : the supply and demand curves for transactions intersecting at a price between 300 and 310 which corresponds to that given by the tenth and eleventh lowest valuation on the stock demand curve and one unit is traded as shown by the intersection of **dd** and ss.

Following the transaction the lowest reservation price becomes 310 and the highest offer price is 300 and consequently, all reservation prices exceed all offer prices and in the absence of new information, no further trade will take place. The market is in a state of stable equilibrium in which all owners of land are content to hold the stock of land at the equilibrium price. This situation is illustrated in Figure III.12.

Figure III.11: Temporary Equilibrium in the Land Market

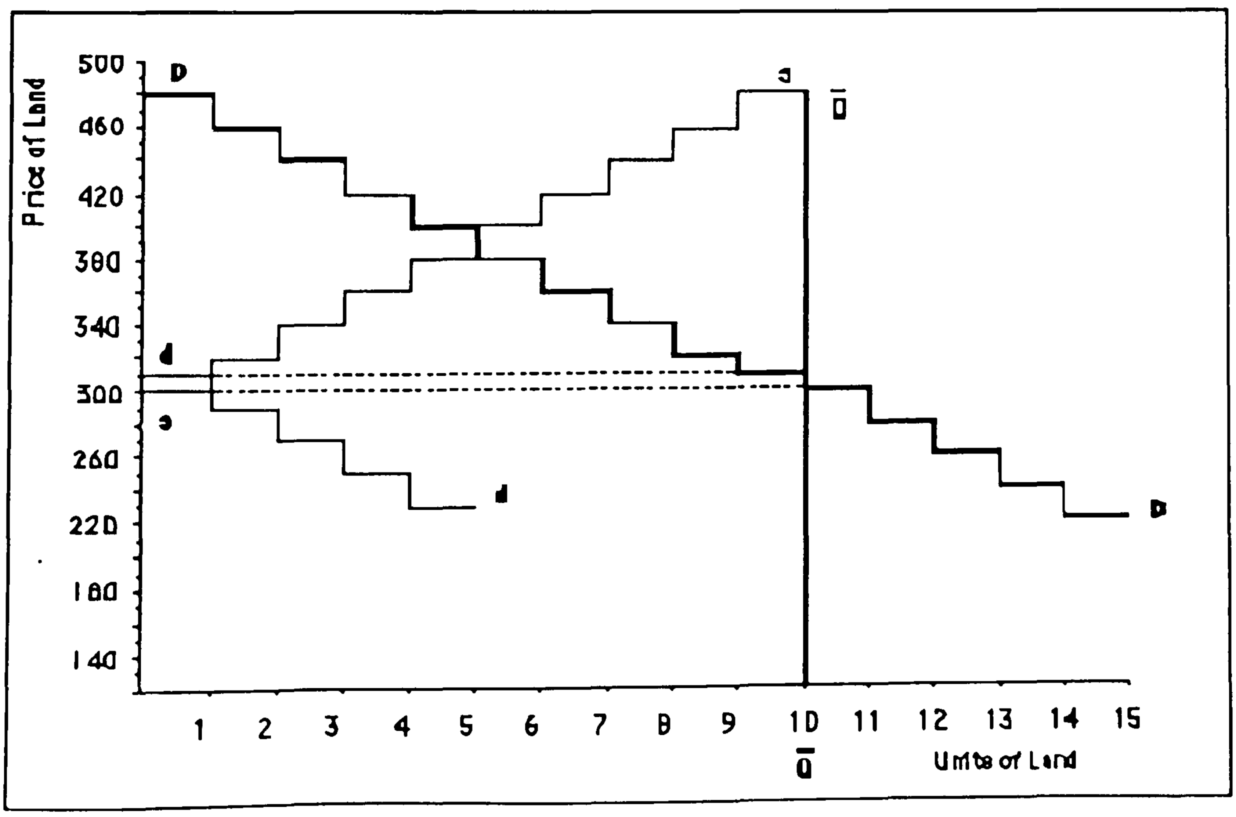
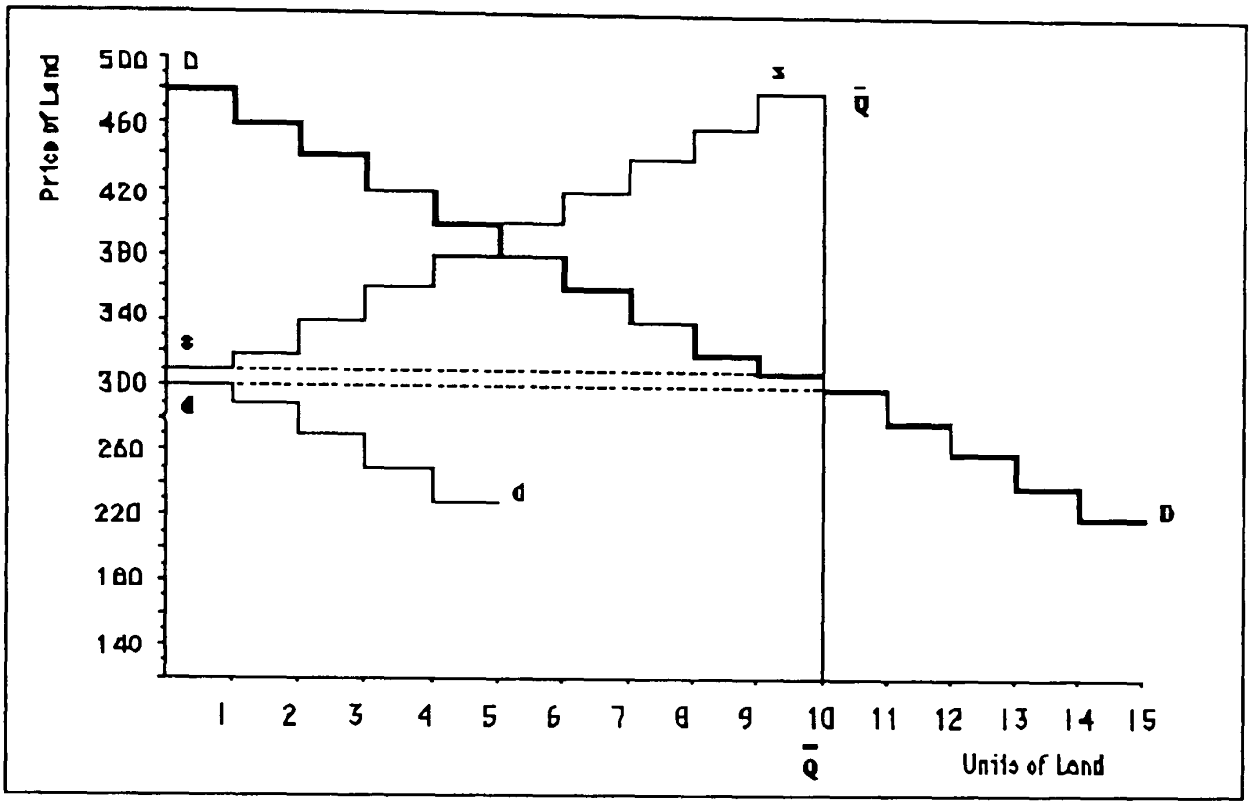


Figure III.12: Stable Equilibrium in the Land Market



III.(vii) Reduced Form Expressions of Land Price Determination

We may now formulate a market based asset pricing equation, consistent with the analysis of the previous sections, that may be used to estimate land prices in the empirical chapters that follow. Recall that each participant in the market, whether he be a current owner or prospective purchaser, is assumed to base his valuation of land according to the present value rule given by equation (III.1), that is,

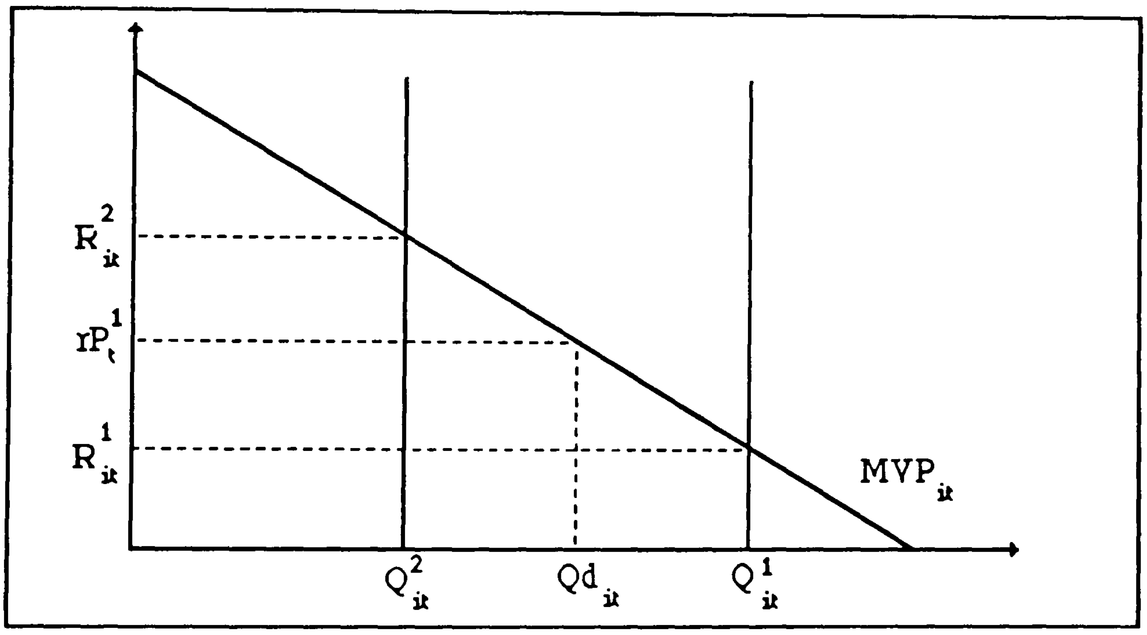
$$P_t = \delta \sum_{j=0}^{\infty} \delta^j \mathrm{E}_t\left[R_{t+j}\right] \qquad \text{(III.1)}$$

where P_t is an agent's valuation computed at the beginning of time t; δ is the discounting constant, defined as $(1/1+r)$ where r is the agent's rate of discount defined by the market rate of interest, E_t is the agent's expectation conditional upon information available at the beginning of time period t and R_t the net returns to land ownership comprising both pecuniary and non-pecuniary returns in period t. Equation (III.1) prices land according to market fundamentals, in that it asserts that changes in land prices are attributable to new information concerning the returns to land ownership . Assuming that net returns and the discount rate remain at their present level in perpetuity, then it can easily be shown that (III.1) collapses to[7]

$$P_t = \frac{R_t}{r} \qquad \text{(III.8)}$$

Equation (III.8) is a simple pricing rule employed by each participant and may be used to derive the reduced form price equation of land price determination in the land market as a whole. As an introduction let us look at the behaviour of the representative agent. Assume that at time t, there are n agents in the land market, each possessing an initial stock of land Q_{it} (this being zero for the potential entrant) for $i = 1, \ldots, n$. Assume that the i^{th} participant has a marginal value product (MVP) curve for land given by Figure III.13 which determines the marginal return he receives from owning additional units of land.

Figure III.13 : The Marginal Value Product Curve of the i^{th} Participant



Consequently, the MVP curve defines the i^{th} participant's demand curve for land which is downward sloping since it is assumed that there exists diminishing marginal returns to his managerial skills as a landowner. The marginal value product of owning a unit of land in year t will be the return he obtains from owning the land, R_t. Approximating the MVP curve with a linear form over the relevent range it may be expressed as,

$$R_{it} = a_{0i} - a_{1i} Q_{it} \qquad \text{(III.9)}$$

where a_{0i} is the intercept and a_{1i} is its slope.

7 See Chapter IV Section II, for a derivation of the present value of an annuity.

The alternative to land ownership is investment in the financial capital market. The annual return obtained from investing a sum of P_t is thus rP_t and this return represents the opportunity cost to the i^{th} individual of land purchase. In order to assess his optimal allocation of land at any given price of land (P_t), the i^{th} participant will compare the return he could obtain from investing P_t in land (R_t) with the return on the alternative investment, (rP_t). If R_t from a unit of land exceeds rP_t then land purchase is profitable and he will desire to own that land. If R_t is less than rP_t it will not be profitable to own that unit of land and the participant will not desire ownership. Consequnetly, the i^{th} participant will desire to own land until the returns on his marginal unit of land is equivalent to rP_t, *i.e.*,

$$rP_t = a_{0i} - a_{1i} Qd_{it} \qquad \text{(III.10)}$$

and $Qd_{it}$is the i^{th} participants optimal allocation of land at a price P_t.

Rewriting equations (III.9) and (III.10) in terms of actual and desired quantities of land gives,

$$Q_{it} = \frac{(a_{0i} - R_{it})}{a_{1i}} \qquad \text{(III.11)}$$

$$Qd_{it} = \frac{(a_{0i} - rP_t)}{a_{1i}} \qquad \text{(III.12)}$$

In equilibrium actual and desired quanities of land held by the i^{th} participant will coincide, hence equating (III.11) and (III.12) and solving for P_t yields the present value rule given by (III.8). This result is not surprsing since it was assumed that each participant uses (III.8) as a basis for land valuation. Note however, that when this holds for all *n* participants then we have a stable equilibrium referred to in the previous section and no trade will occur since all participants will be content to own the land they hold.

Whether the i^{th} participant enters the land market as a potential purchaser or vendor of land at P_t will depend on his initial endowment Q_{it}. Consider the situation depicted in Figure III.13. Should his initial endowment be Q_{it}^1 then he is only obtaining a return of R_{it}^1 on the marginal unit he owns and thus will enter the market as a vendor of land wishing to sell (Q_{it}^1 - Qd_{it}) units of land at P_t. Conversely, if the participant currently owns Q_{it}^2 units of land on which the marginal return accruing to him is R_{it}^2 he will enter the market as a purchaser of land wishing to buy an additional (Qd_{it} - Q_{it}^2) units of land. Clearly, if this individual is a potential entrant he will enter the market to buy Qd_{it} units of land.

Whilst the situation of no-trade is sufficent to obtain the equilibrium price, it is not necessary, and in any practical sense, not relevant, since trade is an ongoing phenomenon. As stated in Section (ii) if an individual has a demand curve for land, $D_{it} = D_{it}(P_t)$ for $i = 1, \ldots, n$ then the equilibrium price is merely that which allocates the stock of land among the n participants irrespective of whether they are content to hold the land they currently own. Reproducing the equation presented earlier, the equilibrium price is simply that which satisfies the condition,

$$\sum_{i=1}^{n} D_{it}(P_t^e) = \sum_{i=1}^{n} Q_{it} \qquad \text{(III.2)}$$

By implication, at a disequilibrium price then,

$$\sum_{i=1}^{n} D_{it}(P_t) - \sum_{i=1}^{n} Q_{it} = \sum_{i=1}^{n} Z_{it} \qquad \text{(III.13)}$$

is a non-zero quantity at that price. If $\sum_{i=1}^{n} Z_{it} > 0$ then there are more participants in the market wishing to purchase the stock of land at that price than there is avaliable land and hence competition by prospective purchasers bids up the market price. Conversely, where $\sum_{i=1}^{n} Z_{it} < 0$ there is an insufficient number of participants wishing to hold the stock and competition among current land owners exerts a downward pressure on price to stimulate demand.

Noting that $Qd_{it} = D_{it}(P_t)$ we may substitute the right hand side of equations (III.11) and (III.12) into (III.2) to yield,

$$\sum_{i=1}^{n} \frac{(a_{0i} - rP_t)}{a_{1i}} = \sum_{i=1}^{n} \frac{(a_{0i} - R_{it})}{a_{1i}} \qquad \text{(III.14)}$$

To obtain the equilibrium price that satisfies (III.2) we simply solve (III.14) for P_t. Dividing through by n and cancelling gives the reduced form of the market,

$$P_t^e = \frac{\bar{R}}{r} \qquad \text{(III.15)}$$

so that equilibrium price is defined by the average return from land ownership divided by the market interest rate.

A number of points are now worthy of comment. First, it has been demonstrated that short-run equilibrium market prices may be modelled by a single present value equation. This reduced form representation obviates the need to employ a simultaneous equations approach, which *a priori* will encounter problems of identification since, as we have shown, factors that affect vendors of land are exactly those that affect potential purchasers. Second, these results echo those presented in section (ii) in that the level of transactions is independent of equilibrium price determination, transactions merely being the process by which land is reallocated amongst market participants at the equilibrium price, rather than determining the equilibrium price itself. Third, if there is disequilibrium in the market then equation (III.15) may be adjusted to account for it. Substituting the expressions for an individual's actual and desired quantity of land{(III.11) and (III.12)} into the disequilibrium representation of the market, equation (III.13), gives,

$$\sum_{i=1}^{n}\frac{(a_{0i}-rP_t)}{a_{1i}}-\sum_{i=1}^{n}\frac{(a_{0i}-R_{it})}{a_{1i}}=\sum_{i=1}^{n}Z_{it} \qquad \text{(III.16)}$$

Solving (III.16) for equilibrium price yields the expression,

$$P_t^e=\frac{\bar{R}}{r}-\frac{\bar{a}_1\bar{Z}_t}{r} \qquad \text{(III.17)}$$

where $\bar{Z}_t$ is the average difference between actual and desired quantities of land across all participants. Hence, $\bar{a}_1\bar{Z}_t$ /r represents that price that must be added to the market price existing in time t to achieve equilibrium levels. Since $\bar{Z}_t$ is the *average* difference between actual and desired endowments trade may still occur in equilibrium as participants reallocate land subject to their *individual* preferences.

III.(viii) Concluding remarks

This chapter has served to explore the micro-economic foundations of price determination in capital asset markets. The analysis presented here unifies the research of Currie (1981) and Harvey (1974), demonstrating the equivalence of equilibrium price in stock and flow representations of the market and developing formulae to determine the price and number of transactions that obtain in a market where all reservation and offer prices are known. Whilst such a situation is purely hypothetical it nevertheless provides a valid platform on which the empirical modelling of land prices may proceed. Whilst Harvey (1974) first identified the distinction between stock and flow in the land market, and the independence of transactions and prices, his initial insight has been extended here and three classes of market stability identified. The distinction between stock and flow is an important one for it suggests that trade can have no explanatory role in the determination of land prices. Yet, as we shall descover in Chapter V, this has not been recognised in the econometric modelling of UK land prices. Finally, it has been demonstrated that a simple capital asset pricing model represents the reduced form of the market for short-run equilibrium price determination. This provides a convenient basis for the empirical models of land prices that follow.

Appendix III.A
Determination of Equilbrium Price and Transactions in the Four Agent Model.

The following analysis develops the work presented earlier in this chapter on the various price-trade outcomes in a model comprising two prospective purchasers and two current owners of the land stock (*i.e.* $n = 2$). The assumptions discussed earlier are germaine to this analysis also. Here, price and trade determination are examined under eight market scenarios. Each of these eight outcomes fall conveniently into one of three categories according to their market 'stability'. Specifically, a *stable market* is one where, *ceteris paribus*, no trade occurs ($k = 0$) *i.e.* all owners of land are content to hold the land they own at the prevailing equilibrium price. A *potentially stable market* is one which is rendered stable after a finite number of transactions have taken place ($k > 0$). Such a market, is equivalent to Clower's (1954) notion of 'temporary' equilibrium. In an *unstable market* the motivation to trade does not cease, and *ceteris paribus*, trade is an ongoing phenonmenon. Let us now consider the possibilities of the two-by-two agent model in detail.

1. A Stable Market

In a stable market all reservation prices lie everywhere above all offer prices *i.e.* $P_{r,2} > P_{r,1} > P_{o,1} > P_{o,2}$. Consequently, in the absence of new information affecting agents' valuations it is clear that there is no motivation to trade, so $k = 0$.

Equilibrium price in a stable market is confined to the range set by the reservation price and offer price at the margin: the core is bounded from above by the lowest reservation price and from below by the highest offer price, *i.e.*,

$$\max (P_{r,k}, P_{o,k+1}) \leq P^e \leq \min (P_{o,k}, P_{r,k+1})$$
$$P_{r,1} > P^e > P_{o,1}$$

This is depicted by the step functions in Figure III.A1.

2. A Potentially Stable Market

In this type of market, stability is obtained by a finite number of transactions. Trade results in a reallocation of the land stock so that all reservation prices exceed all offer prices. Figures III.A2, III.A3, and III.A4 illustrate the possible markets in which this may occur. Consider the market defined by $P_{o,1} > P_{r,2} > P_{o,2} > P_{r,1}$. As with any market, equilibrium price lies in a core set by the valuations of the n^{th} and $n+1^{th}$ highest valuations; here the second and third highest valuations. One transaction is necessary to return the market to a stable condition as may be seen in Figure III.A2.

Figure III.A1 : A Stable Market

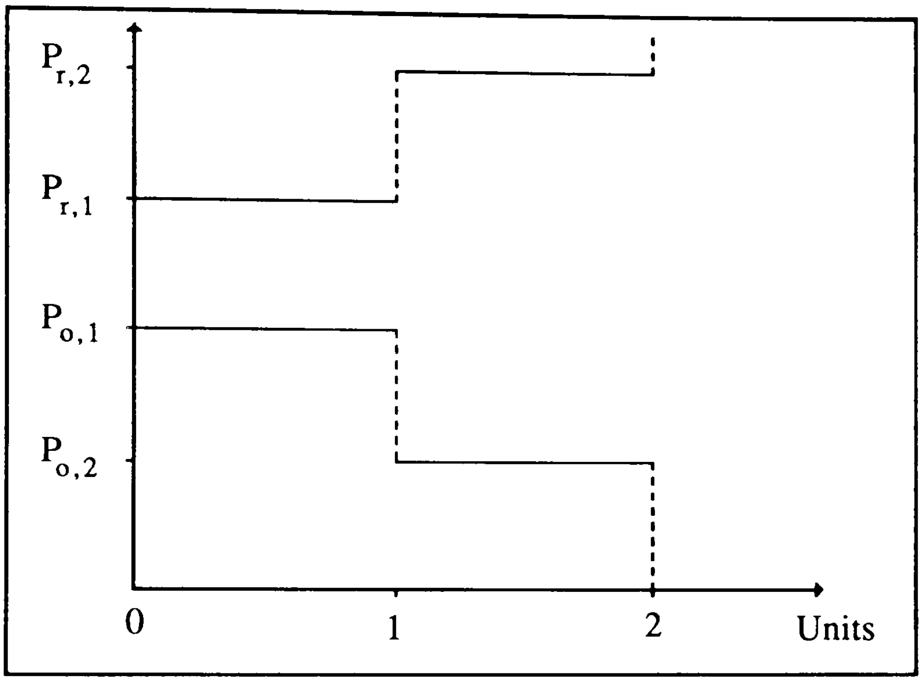
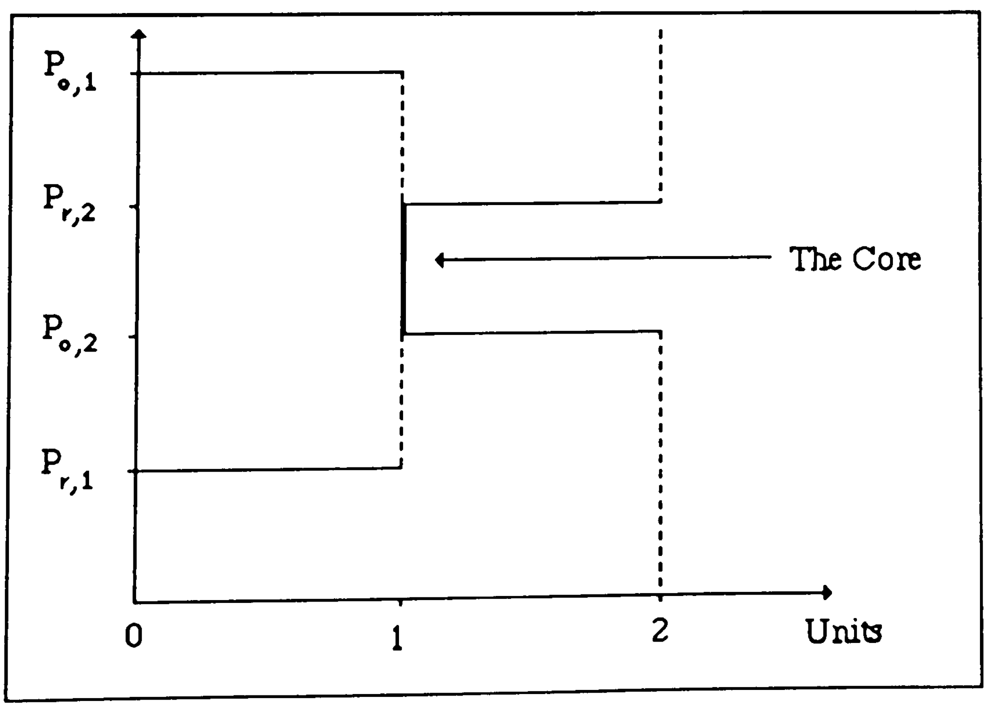


Figure III.A2 : A Potentially Stable Market with One Transaction



Specifically, given that the core is set by

$$P_{r,2} > P^e > P_{o,2}$$

the number of transactions is,

$$k = \min\left[\sum_{j=1}^{m}(o,j) \geq P_u^e, \sum_{i=1}^{n}(r,i) \leq P_l^e\right]$$

$$k = 1$$

Note here that the marginal reservation and offer price define the equilibrium price but that this is not generally the case in a market in which trade is occurring. For example consider Figure III.A3 which depicts the market defined by $P_{o,1} > P_{r,2} > P_{r,1} > P_{o,2}$. Here, one unit is traded to rectify the disparity in offer and reservation prices at the equilibrium price set by the core : $P_{r,1} > P^e > P_{r,2}$. Due to the fact that the two reservation prices lie between the two offer prices, it is not the valuations of the marginal owner and prospective purchaser that defines the core but the two reservation prices.[8]

As discussed in the main part of the chapter equilibrium price is determined by the agents with the n^{th} and $n + 1^{th}$ highest valuation of land and not the valuation of the marginal prospective purchaser and marginal current owner. However, after trade has occured the n^{th} and $n + 1^{th}$ highest valuations will be those corresponding to the marginal reservation and offer prices respectively. This demonstrates that we can only state that equilibrium price is determined by the prospective purchaser and current owner at the margin *after trade has occurred*, or more exactly, when the equilibrium is a stable one. This may evaporate the ambiguity present in Currie's (1981) account of price determination.

The market depicted by Figure III.A4 is such that all offer prices exceed all reservation prices, $P_{o,1} > P_{o,2} > P_{r,2} > P_{r,1}$ and thus both units of land are traded at the equilibrium price within the core given by, $P_{o,2} > P^e > P_{r,2}$. In all these cases trade returns the markets to that shown in Figure III.A1, wherein all reservation prices exceed all offer prices, and hence no motivation for trade exists *ceteris paribus*.

8 In a situation where the offer prices lie between the resevation prices the offer prices would define the core.

Figure III.A3 : A Potentially Stable Market with One Transaction

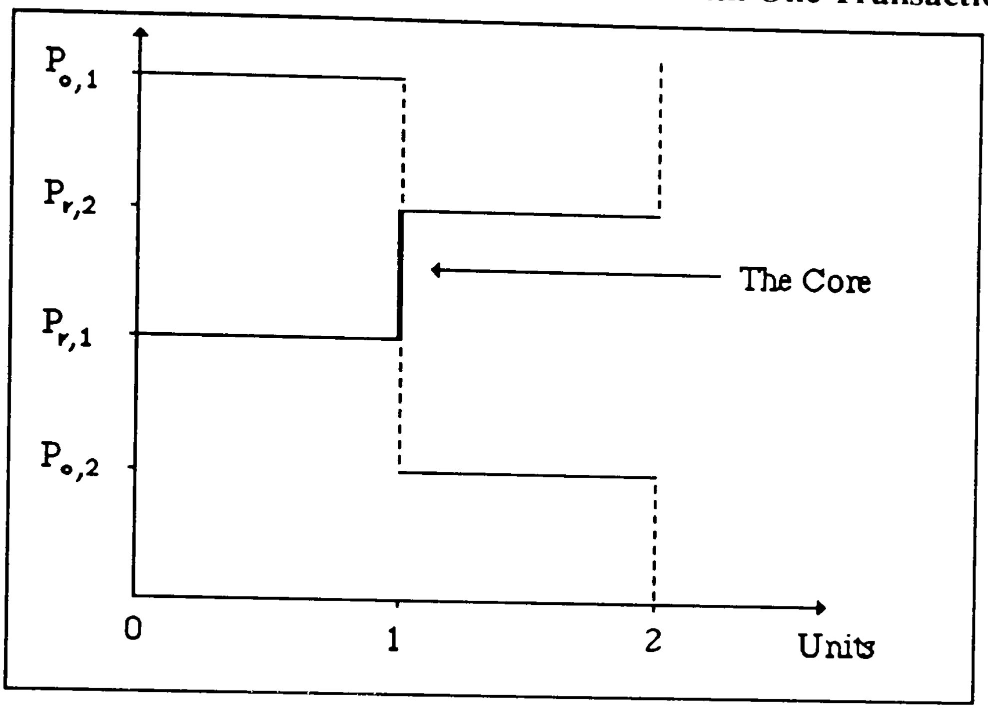
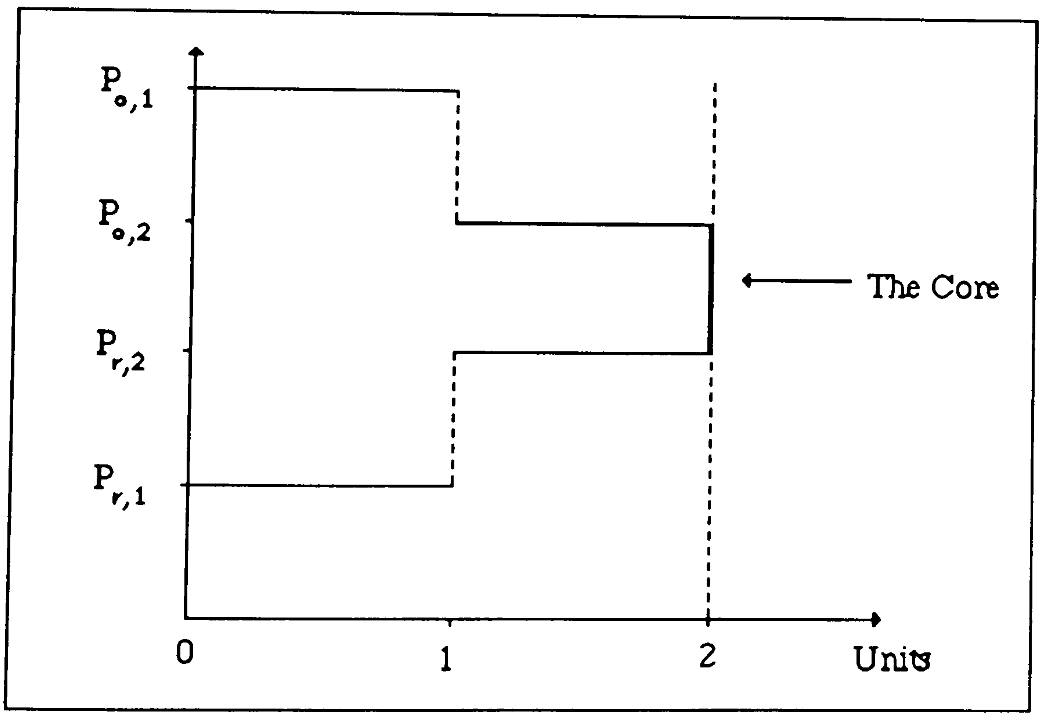


Figure III.A4 : A Potentially Stable Market with Two Transactions



3. An Unstable Market

It is possible to identify four market scenarios which are characterized by instability, in that *ceteris paribus*, trade never ceases. In each case the stability depicted by Figure III.A1 is never obtained despite the occurence of trade. Instability arises due to the equality of the valuations at the margin. Hence, *ceteris paribus* trade will be an ongoing process in any market in which the n^{th} and $n + 1^{th}$ valuations are equivalent. Whilst equality renders both the quantity of units traded and equilibrium price determinate some form of indeterminancy is always present. Here, the indeterminacy manifests itself as perpetual trading, in that we cannot identify which of the two agents holds ownership of the unit at any point in time.

In the cases that follow Figures III.A5 and III.A6 depict markets in which only one unit is traded continually, Figures III.A7 and III.A8 markets where (in the absence of new information) both units of land are continually traded. Figure III.A5 illustrates a market defined by $P_{r,2} > P_{r,1} = P_{o,1} > P_{o,2}$. Given that one transaction occurs ($k = 1$) the determinate equilibrium price is,

$$\max(P_{r,k}, P_{o,k+1}) \leq P^e \leq \min(P_{o,k}, P_{r,k+1})$$
$$P_{r,1} = P^e = P_{o,1}$$

Figure III.A5 : An Unstable Market with One Transaction

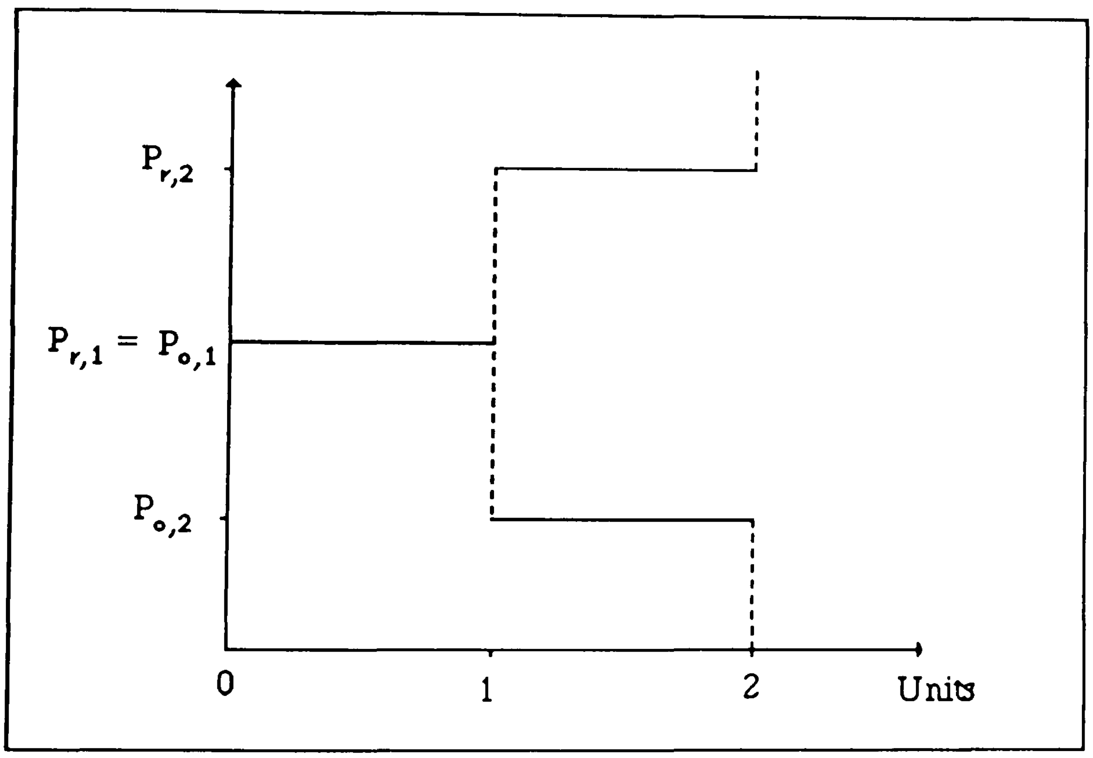


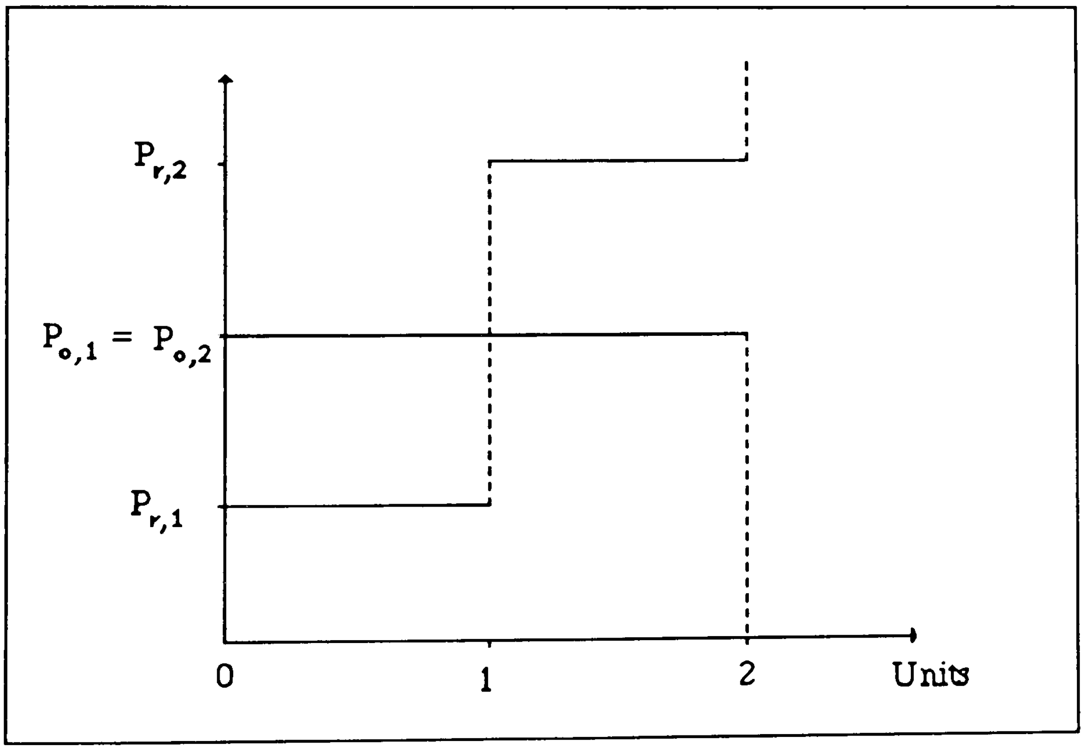
Figure III.A6 illustrates a market defined by $P_{r,2} > P_{o,1} = P_{o,2} > P_{r,1}$. At the determinate equilibrium price of $P_{o,1} = P^e = P_{o,2}$ the number of transactions is,

$$k = \min\left[\sum_{j=1}^{m}(o,j) \geq P_u^e, \sum_{i=1}^{n}(r,i) \leq P_l^e\right]$$
$$k = 1$$

Note here that after the initial trade has taken place the market is transformed but still does not obtain stability. Specifically, the market reduces to that represented by Figure III.A5, *ceteris paribus*.[9]

In Figures III.A7 and III.A8 both units of land are traded in the first instance. In Figure III.A7, which characterizes a market defined by $P_{o,1} > P_{o,2} = P_{r,2} > P_{r,1}$ equilibrium price is $P_{o,2} = P^e = P_{r,2}$ and the initial trade results in a market that is transformed to that shown in Figure III.A5, where one unit only is traded continuously in the absence of further information affecting valuations of agents. In a market where all reservation prices and offer prices are identical ($P_{o,1} = P_{o,2} = P_{r,1} = P_{r,2}$) such as that shown in Figure III.A8 no such transformation occurs and two units are traded continuously at the equilibrium price.

Figure III.A6 : An Unstable Market with One Transaction



9 We can also concieve of the analogous case in which the supply curve was perfectly elastic (rather than demand as shown in the text) so that $P_{o,1} > P_{r,1} = P_{r,2} > P_{o,2}$ In a similar fashion, one unit is traded at a determinate equilibrium price $P_{r,1} = P^e = P_{r,2}$and the market reduces to that depicted in Figure III.A5 also.

Figure III.A7 : An Unstable Market with Two Transactions

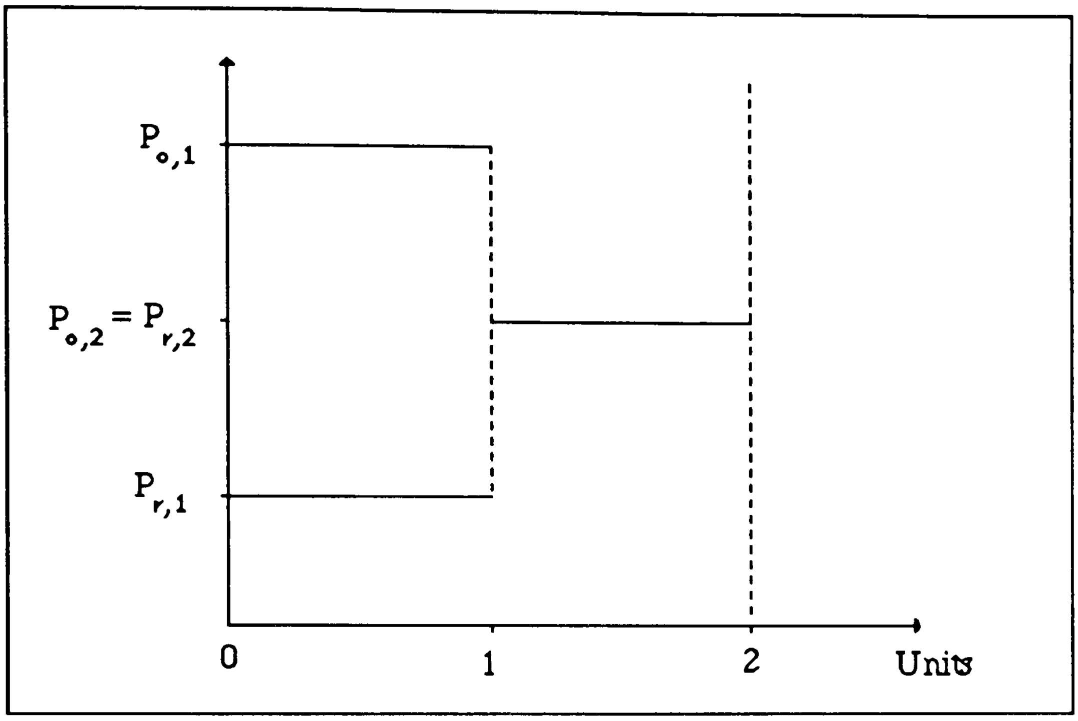
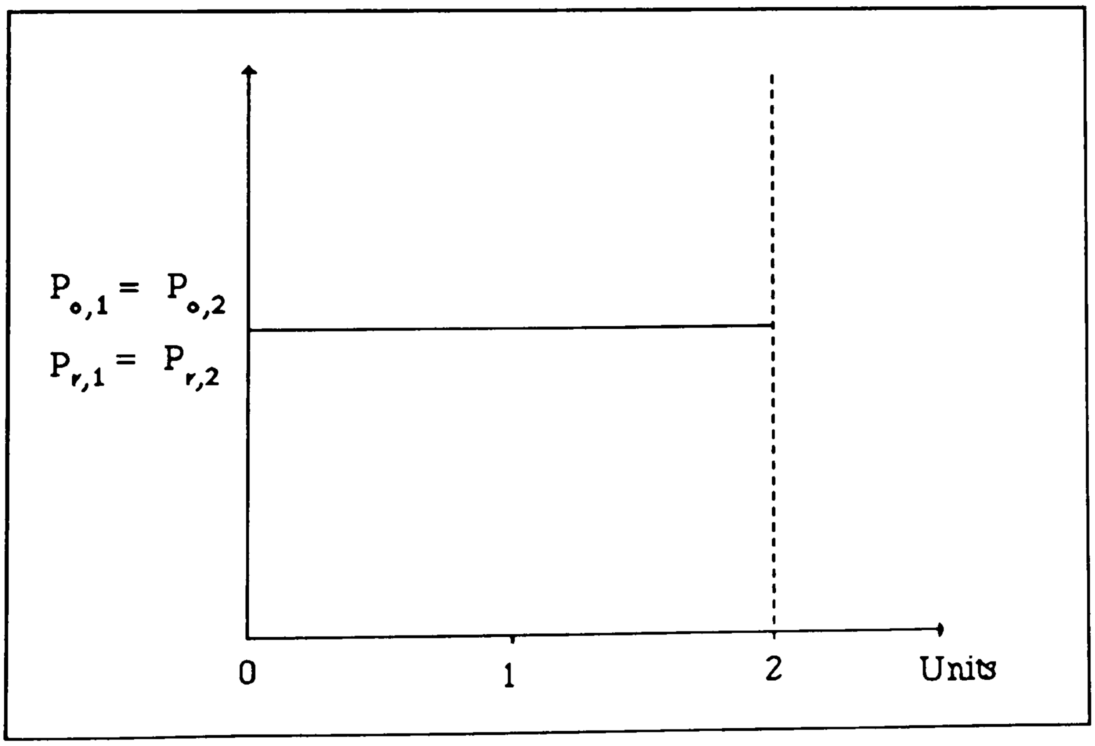


Figure III.A8 : An Unstable Market with Two Transactions



Chapter IV
Present Value Methods of Asset Valuation

IV.(i) Introduction

The examination of price determination in the last chapter suggested that the market price of a capital asset could be conveniently modelled using a single present value equation. However, in that Chapter little justification was given for the use of present value methods in asset valuation. Here, the origins, behaviour and implications of present value models are explored theoretically and empirically using relevant data for England and Wales. The present value approach to modelling is then extended with an examination of the role of expectations in asset valuations.

This Chapter is organised along the following lines. We begin in Section (ii) by focussing attention on the theoretical link between asset returns and asset prices, as embodied by the present value hypothesis and some simple specifications of the present value hypothesis are derived and their implications examined. Despite their obvious simplicity, present value models exhibit much of the behaviour that one observes in a time series of asset price, and a small simulation exercise is presented to evidence this view. In Section (iii) the discussion turns to the problem of defining the term 'returns' in the farmland context. A number of different measures have been employed in previous studies of land prices and a brief evaluation of the merits of each is warranted prior to any empirical analysis. Section (iv) is dedicated to the investigation of the role of expectations in price determination. Given that participants in the market must form some impression of the future regarding the stream of future returns to land in order to arrive at a current valuation, one may suggest that expectations play an integral role in capital asset pricing models. Three expectation mechanisms, namely adaptive naive and rational, are incorporated into the present value model and their applicability evaluated using empirical data. In Section (v) a number of ancillary issues are considered such as disequilibrium pricing, the opportunity cost of farmland and simultaneous modelling of the tenanted and vacant possession sectors. The Chapter draws to a close with some concluding remarks in Section (vi).

IV.(ii) The Present Value Hypothesis

Whilst there are obvious similarities in the acquisition of goods bought for consumption and investment, in that both are purchased at a single point in time and yield some 'satisfaction' to the purchaser, the two types of good are inherently different. For example, the act of consumption liberates an immediate utility to the consumer, but involves destruction of the good. In contrast, investment goods yield a return that may accrue over many periods, in the limit, perpetuity, and are thus 'destroyed' only gradually, or perhaps not at all. Agricultural land is a case in point since it may be used in perpetuity without destroying the inherent qualities from which returns are derived. Clearly, capital assets have an inter-temporal dimension which has logical implications for the pricing of such assets. Because all economic decisions which are inter-temporal need to be compared with the utility derived from not investing, all inter-temporal decisions ultimately collapse to questions about consumption.

An integral part of reducing all investment choices to an equivalent amount of current consumption is the assessment of the time value of money - the interest (discount) rate - since there is an opportunity cost to consumption (investment). Interest rates are universally positive reflecting two underlying influences;

(a) the productivity of economic assets and,

(b) the time preference of consumption.

With reference to the first point, the postponement of consumption in the current period allows an enhanced level of consumption in some later period. For example, we may consume a quantity of wheat grains now or plant them to yield a future crop of grain larger than the original quantity of seeds. Second, deferral of consumption implies a cost in terms of postponed utility, so that another reason for positive interest rates is that individuals have a preference to consume now rather than later.

One method that attempts to translate a stream of future income into an equivalent sum of money available for current consumption, (having taken account of the time value of money), is that suggested by present value theory. For the purpose of this introductory exposition the following points are assumed, although some will be relaxed later.

1. The opportunity cost or time preference of money is exogenous and determined in the (external) economy by market forces.
2. This opportunity cost of money is unique so that there is a single rate of interest at any point in time which may be used in any discounting or compounding exercise.
3. The interest rate is non-stochastic, entailing it is known with certainty in all time periods so that should the interest rate change, the timing and extent of the change is known to all in the market with certainty. To simplify the analysis further it is assumed that the interest rate is constant over all relevant time horizons.
4. The process of discounting and compounding occur discretely, say annually for

simplicity.[1]

5. The interest rate is determined in a perfect capital market characterised by perfect information, zero transaction costs and unlimited access to financial capital at the prevailing rate of interest.

6. Over all relevant time horizons the general price level is constant entailing zero inflation.

(a) A Simple Capital Asset Pricing Model

In order to introduce the present value models used later it will be useful to recapitulate some fundamentals of compounding and discounting. Because of positive rates of interest, future sums (whether in terms of actual commodities, utility or financial spending power) will always be greater than present values. Investing a principal (V) now at an annual rate of interest (r) will yield a future sum (S_t) of $V(1+r)$ at the end of this year; and a future sum, $(1+r)[V(1+r)] = V(1+r)^2$ by the end of the investment's second year. This discrete compounding exercise, given the assumptions stated above yields the familiar compound interest formula,

$$S_t = V(1+r)^n \qquad t = 1,2,\dots n. \qquad \text{(IV.1)}$$

In a similar manner we may obtain the present value of a sum received at some point in the future by discounting. Solving (1) for V, yields,

$$V = S_t(1+r)^{-n} \qquad t = 1,2,\dots n. \qquad \text{(IV.2)}$$

A frequently encountered discrete compounding situation is the constant annuity (installments) case, where the present value of a stream of constant annual payments (the annuity) over a number of years is sought. The present value of an annuity of £a per period at an interest rate of r over n years is given by,

$$A_{n,r} = a\left[\frac{1-(1+r)^{-n}}{r}\right] \qquad \text{(IV.3)}$$

Equation (IV.3) is derived by discounting the stream of periodic payments (a). Assuming that the first payment is made at the end of the first year then

$$A_{n,r} = \frac{a}{1+r} + \frac{a}{(1+r)^2} + \frac{a}{(1+r)^3} + \dots + \frac{a}{(1+r)^n} \qquad \text{(IV.4)}$$

Denoting $u = [1/(1+r)]$ equation (IV.4) may be rewritten as,

$$A_{n,r} = au + au^2 + au^3 + \dots + au^n \qquad \text{(IV.5)}$$

Multiplying (IV.5) by u and subtracting the result from (IV.5) gives,

1 For a discussion of present value methods in a continuous time framework see Copeland and Weston (1988), pp.851-855

$$A_{n,r} - uA_{n,r} = au - au^{n+1}$$

and thus,

$$A_{n,r} = \frac{au(1-u^n)}{1-u} \qquad \text{(IV.6)}$$

Substituting back for u in (IV.6) yields,

$$A_{n,r} = \frac{a\left[\frac{1}{1+r}\right]\left[1-(1+r)^{-n}\right]}{\left[1-\frac{1}{1+r}\right]}$$

$$= \frac{a\left[1-(1+r)^{-n}\right]}{(1+r)\left[\frac{1+r-1}{1+r}\right]}$$

$$= a\left[\frac{1-(1+r)^{-n}}{r}\right]$$

which is identical to (IV.3). In the application of present value theory to land values it will be convenient to consider the case where the asset yields a (constant) return *in perpetuity* in which case (IV.3) simplifies to

$$\lim_{n \to \infty} A_{n,r} = \frac{a}{r} \qquad \text{(IV.7)}$$

since $r > 0$ and thus in the limit $(1+r)^{-n}$ tends to zero. Consequently, within the framework outlined above, the present value of an infinite stream of constant payments is given by (IV.7).

(b) A Growth Model of Asset Pricing

Whilst it may be appropriate in certain cases to assume that the annuity does not grow through time it is possible to introduce a fixed rate of annuity growth into the model which collapses to a simple equation in the limiting case. As it may be more realistic in some circumstances to assume that asset returns are growing over time, we may incorporate this earnings growth as follows. Let the growth rate of asset returns be a constant g and let a_0 be the current return on the asset of interest. At the end of the first year the anticipated return will therefore be $a_1 = a_0(1 + g)$ and the expected return at the end of the second year is $a_2 = [a_0(1 + g)](1 + g) = (1 + g)^2\, a_0$. Assuming that this rate of growth (g) continues for n years at an interest rate of (r) then the present value of a growth annuity ($A_{n,r,g}$) is,

$$A_{n,r,g} = \frac{a_1}{1+r} + \frac{a_2}{(1+r)^2} + \frac{a_3}{(1+r)^3} + \ldots + \frac{a_n}{(1+r)^n}$$

$$= \frac{a_0(1+g)}{1+r} + \frac{a_0(1+g)^2}{(1+r)^2} + \frac{a_0(1+g)^3}{(1+r)^3} + \ldots + \frac{a_0(1+g)^n}{(1+r)^n} \quad \text{(IV.8)}$$

By letting $u = (1+g)/(1+r)$ equation (IV.8) can be rewritten as

$$A_{n,r,g} = a_0 u + a_0 u^2 + a_0 u^3 + \ldots a_0 u^n$$

$$= u a_0 \left(1 + u + u^2 + \ldots + u^{n-1}\right) \quad \text{(IV.9)}$$

Multiplying (IV.9) by u, subtracting the result from (IV.9) and rearranging yields,

$$A_{n,r,g} = \frac{u a_0 (1-u^n)}{1-u} \quad \text{(IV.10)}$$

Substituting for u in (IV.10) and noting that $a_1 = a_0(1+g)$ we obtain,

$$A_{n,r,g} = \frac{a_1\left[1-\left(\frac{1+g}{1+r}\right)^n\right]}{r-g} \quad \text{(IV.11)}$$

Conditional upon the rate of annuity growth being less than the rate of interest in each and every time period, then the limiting case of (IV.11) [*i.e.* where the number of annuity payments are infinite] collapses to,

$$\lim_{n\to\infty} A_{n,r,g} = \frac{a_1}{r-g} \quad \text{(IV.12)}$$

since,

$$\lim_{n\to\infty}\left(\frac{1+g}{1+r}\right)^n = 0, \qquad \text{iff} \quad g < r$$

Consequently, in circumstances where the rate of returns growth is less than the discount rate, equation (IV.12) describes the formation of an asset's present value.

(c) Some Observations on the Capital Asset Pricing Models

Despite the simplicity of these present value models a number of interesting results emerge in their application to land price modelling. For the time being we will not define formally the mechanism by which expectations of future returns are generated, but simply assume that at any point in time t current returns are known with certainty and this determines all future returns, as with the annuity models discussed above. Using the notation of earlier chapters, where P_t and R_t correspond to land price and annual net return respectively, the equations (IV.7) and (IV.12) may be rewritten as,

$$P_t = C R_t^{\beta} \qquad \text{where } C = 1/r \qquad \text{(IV.7')}$$

$$P_t = D R_t^{\beta} \qquad \text{where } D = 1/r{-}g \qquad \text{(IV.12')}$$

From equations (IV.7) and (IV.12) it is clear that the exponent β in (IV.7') and (IV.12') is unity. Interestingly, β is the coefficient of elasticity, so that each of these valuation models imply unit elasticity of returns to land prices, hence a 1% increase (decrease) in net returns from land ownership results in a 1% increase (decrease) in land values.[2]

Turning to equation (IV.7') in which returns are constant over all time horizons, it is useful to note that the ratio of asset returns to asset value (R/P) defines the capitalization rate (C) from which we may derive the rate at which financial capital is discounted in the agricultural sector, *i.e.* the opportunity cost of capital invested in farmland, r. Under the assumptions outlined at the start, this rate of return required from capital used in agriculture should be equivalent to the rate of return available from investments in other sectors of the economy. Consequently, if the market rate of interest in the economy is 5 per cent then the relationship implied by (IV.7') suggests that land prices sell at 20 times the annual return on land, *i.e.* the capitalization rate (C) of annual returns into land values is,

$$C = \frac{1}{0.05} = 20$$

Changes in expected annual returns influence land values through the unit elasticity coefficient; changes in the opportunity cost of capital feed through into land prices via the capitalization rate. Should land prices be high (low) relative to the returns accruing to landowners, this implies that the capitalization rate is also high (low). This in turn means that the opportunity cost of agricultural capital is necessarily low (high).

If we now introduce expectations of growing annual returns in to the asset pricing model as in (IV.12') it is easy to show that the discount rate in agriculture may differ from that prevailing in other sectors of the economy, as defined by the market rate of interest on capital. If it is assumed that the market rate remains at 5 per cent and that participants in the land market have an expectation of growing returns of the order of 3 per cent per annum, *i.e.* $g = 0.03$, then from (IV.12') it can be seen that the opportunity cost of capital for land capital is now only 2 per cent. Hence, despite borrowing capital for land purchase at the market rate of 5 per cent, owners of farmland

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2 Elasticity is calculated as $(dP/dR)(R/P)$. So, differentiating (IV.7') for example, with respect to R yields,

$$(dP/dR) = \beta C R^{\beta-1}$$

Noting that $P = CR^{\beta}$ we may rewrite the elasticity formula as,

$$\{(\beta C R^{\beta-1})/(CR^{\beta})\}R = \beta(1/R)R$$
$$= \beta$$

will be content to receive an annual yield of only 2 per cent because they will receive the remaining 3 per cent in the form of real capital appreciation given that the elasticity of asset returns to asset value is unity.

There are two implications that arise from this simple analysis. The first is that in the presence of expected returns growth, discount rates in agriculture may be lower than in other sectors of the economy. Second, land values may therefore be much higher than one may expect given the market rate of interest. In the example above, investors seeking a total return on their investment in farmland of 5 per cent will price the asset to yield an income return of only 2 per cent so that the asset will sell at 50 times earnings, *i.e.*the capitalization rate (D) of returns into land values is,

$$D = \frac{1}{0.05 - 0.03} = 50$$

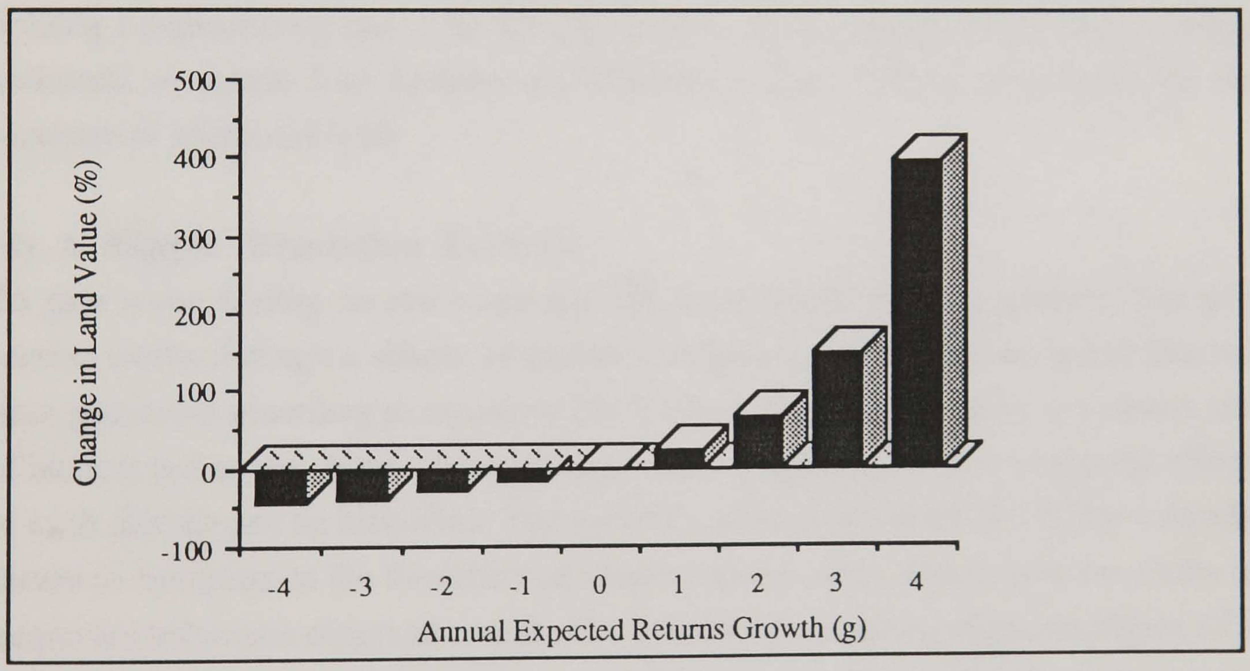
Furthermore, this analysis suggests that land prices may be highly volatile when expectations of future returns are revised in light of new information. In this example, a sudden upward revision of expected income growth from zero to 3 per cent growth by land market participants increases the capitalization rate from 20 to 50 resulting in a 250 per cent rise in land prices. The initial revision of expectations thus bestows enormous capital gains for those agents actually holding land when participants in the market perceive persistent returns growth. Windfall gains are exaggerated further if the rate of growth rises from a non-zero base. For example, if the expected growth in returns rises from say 3 to 4 percent in our model then the capitalization rate leaps from 50 to 100 and land prices rise by an additional 200 per cent *ceteris paribus*.

However, intuition and historical evidence suggest that expectations of returns growth cannot continue forever. Indeed, capital losses seem inevitable; writing in 1983 Melichar (1984) notes,

> "Back when savings accounts were paying 3 per cent interest, a favorite mathematical exercise was to calculate the present value of $1 invested in year 1 A.D. at 3 per cent interest compounded quarterly. The Answer is now about $55,000,000,000,000,000,000,000,000, or slightly more than the present value of the entire Earth plus a few other minor planets and a solar system or two. . . Obviously, wealth is continually being destroyed aswell as created." p.5

Should negative returns growth be expected, the capitalization rate falls and the pricing mechanism of equation (IV.12') is set in reverse, leading to falling asset values, although due to the arithmetic of the present value formula at realistic rates of real interest, the expectation of negative rates of growth *from a stable base* (*i.e.* the no growth situation, where $g = 0$) do not lead to such enormous changes (in absolute or percentage terms) as do positive growth rates.[3] For example, when expectations first change from stable to falling annual returns, of say 3 per cent, the opportunity cost of capital in agriculture rises from the market rate of 5 per cent to 8 per cent forcing the capitalization rate down from 20 to 12.5 resulting in an immediate drop in land prices of some 37.5 per cent. Should returns contraction accelerate further from say 3 to 4 per cent the capitalization rate drops from 12.5 to 11.1 and land prices fall a further 12.6 per cent. The response of asset prices to both positive and negative growth rates from a stable base are illustrated in Figure IV.1, where g = -4, -3, . . 3, 4. The diagram clearly illustrates the exponential growth in the change in asset values from the stable returns situation when g is positive and a more gradual decline when negative rates of growth are assumed in the model.

Figure IV.1 : Percentage Changes in Asset Values under Positive and Negative Rates of Growth



However, the asymmetry of the response to positive and negative growth rates is misleading for it implies that asset prices according to (IV.12') are precluded from the 'free-fall' occasionally observed in the land market. However, should land prices have been ascending rapidly, a slowdown or reversal of expectations of returns growth will cause the price of the asset to plummet. For example if at time zero, returns to land are stable at £10 per unit and the opportunity cost of capital is 5 per cent then land price is calculated as,

3 Note that Melichar's (1984) assertion that negative growth rates have an equally powerful effect on asset values (as postive ones) is only true if expected returns have previously been growing.

$$200 = \frac{1}{0.05} 10$$

If a 3 percent growth in returns is suddenly anticipated, then *ceteris paribus* land price in the following period will immediately rise to,

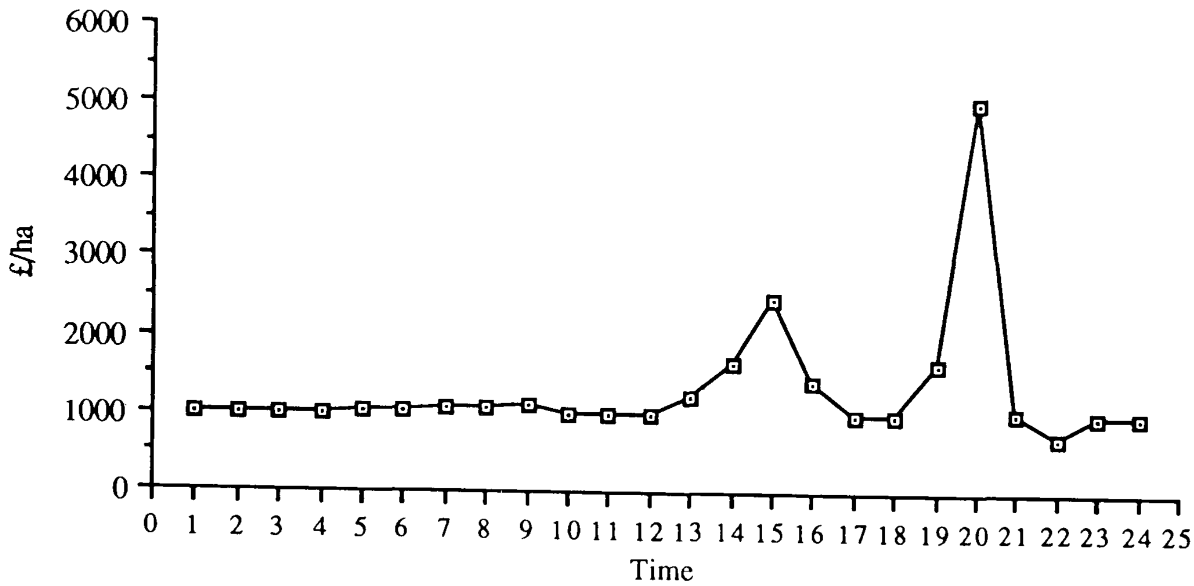
$$500 = \frac{1}{0.05 - 0.03} 10$$

Should the expectation of income growth be unwarranted, so that expectations are revised downward in the next period, say to zero, land prices will return to their initial value of £200. In this respect, the mechanism of (IV.12') is equally powerful in reverse. Thus, given *positive rates of returns growth* a downward revision in expected returns growth creates the momentum for equally large capital losses as capital gains. Consequently, when land is perceived by market participants to be a growth stock capital gains may be vast for those owners wishing to sell, but as soon as the rate of growth slows down,land prices fall dramatically. The ramifications of this volatility are numerous. Clearly, those owners who bought land on a rising market may well be holding a depreciating asset. The situation becomes more critical if the land is used as collateral to secure loan-finance, particularly so if the money is invested for the purchase of additional land.

(d) A Simple Simulation Exercise

To gain some feeling for the outcomes that these simple models produce, this sub-section works through a simple 24 period simulation exercise of land prices that has been generated according to equations (IV.7') and (IV.12'). Changes to the market rate of interest and expectations are superimposed in a sequential fashion so that the effects of each change can be identified. The stylized portrayal of events that follows merely serves to demonstrate the flexibility of these simple models, which have the ability to mimic the behaviour observed empirically. The land price series, plotted in Figure IV.2 is calculated from the information contained in Table IV.1. The changes that are imposed and the resulting effect on land prices is explained in a story-board format below.

Figure IV.2 : A Plot of the Land Price Simulation



Period 1 - 4 : Initial conditions

The initial conditions are that the market rate of interest is 5%, current returns are £50 per hectare and no growth in returns is expected. Consequently, the capitalisation rate is, 1/0.05 = 20 and thus land price is £1,000 per hectare

Period 5 - 9 : Unexpected growth in returns

Returns grow by £1 per hectare per period so that by period 9 rents have increased by 10%. Since there is unit elasticity between returns and land prices, this means that land prices grow proportionately over this period. At period 9 land prices are also thus 10% higher at £1,100.

Period 10 : Unexpected fall in returns

Returns unexpectedly fall by 10% and initiate an immediate 10% fall in land prices, back to £1,000.

Table IV.1 : A Simulation of Land Prices

Time	Rents	Cap. rate	Land price	Time	Rent	Cap. rate	Land price
1	50	20	1000	13	50	25	1250
2	50	20	1000	14	50	33	1667
3	50	20	1000	15	50	50	2500
4	50	20	1000	16	50	29	1429
5	51	20	1020	17	50	20	1000
6	52	20	1040	18	50	20	1000
7	53	20	1060	19	50	33	1667
8	54	20	1080	20	51	100	5100
9	55	20	1100	21	51	20	1020
10	50	20	1000	22	51	14	729
11	50	20	1000	23	50	20	1000
12	50	20	1000	24	50	20	1000

Period 11 - 12 : A period of stability

No change in either the market interest rate, returns or expectations, hence the capitalisation rate and land price remain constant.

Period 13 -15 : Falling market interest rates

The exogenously determined interest rate falls by 1% per time period. In period 13 the discount rate in the economy falls to 4% inducing the capitalisation rate to rise to 1/0.04 = 25. Consequently, land price rises to £1,250. In period 14 the discount rate falls to 3% entailing a rise in the capitalisation rate to 1/0.03 = 33, and land prices rise to £1,667 accordingly. In period 15 the interest rates fall to 2%, the capitalisation rate becomes 1/0.02 = 50 and land price climbs to £2500.

Period 16 -17 : The interest rate resumes it's original level

In period 16 the interest rate rises to 3.5% entailing the capitalisation rate falls to 1/0.035 = 29 and land price falls accordingly to £1,429. In period 17 interest rates rise further to 5% and land price returns to its original level of £1,000.

Period 18 : Brief calm

No change and land prices remain constant.

Period 19 : Expectation of returns growth

There is an expectation of returns growth that is assumed to continue forever. Rents are assumed to grow at 2% per year hence the capitalisation rate is 1/(0.05-0.02) = 33 and land prices rise to £1667.

Period 20 : Returns growth fuels expectations

The expectation of rent has materialised and rents rise to £51. This however fuels expectations regarding future growth in rents and expectations are revised upwards to 4% yielding a capitalisation rate of 1/(0.05-0.04) = 100 and land prices surge to £5100 per hectare.

Period 21 : The bubble bursts

The growth in returns is not realised and rent remains constant at £51. Expectations of future rent rises are no longer held and and the capitalisation rate falls to 1/0.05 = 20. Land prices decline sharply to £1020.

Period 22 : A Decline in returns is expected

Due to exogenous factors returns are expected to fall in perpetuity by 2%. The opportunity cost of financial capital in the land market now rises above the market determined interest rate and the capitalisation rate falls to 1/(0.05+0.02) = 14. Land prices drop slightly to £729.

Period 23-24 :Expectations stabilise

The expectation of falling returns is realised and rents now decline to 50. Expectations of further rent decline is not anticipated and the capitalisation rate returns to 1/0/05 = 20 and land price is £1000 per hectare.

We will resume the discussion of these present value models in Section (iv), and elaborate on their specification. However, before we do so it will be appropriate to examine what is meant by the returns to landownership. In the preceding discussion little has been said about what actually constitutes the return that owners of land receive and how it may be paid, and a number of issues emerge when this question is examined.

IV.(iii) The Returns to Land Ownership

Whilst in practice there may be a whole host of factors that determine the 'net return' to landownership, it should be clear that the return will critically depend upon the use to which the land is put. Land desired for its recreational value will yield a return to the owner that bears little relation to that accruing to owners of land where the land is employed for residence, hobby farming or indeed, agriculture. If it is reasonable to assume that land is demanded as a factor of agricultural production then the gross return accruing to landowners represents a payment for the right to use the 'land' as a medium for the production of crops and livestock[4]. In a setting characterised by two mutually exclusive groups comprising landowners and farmers, then the return to landownership is the payment from farmers to landowners *i.e.* agricultural rent. Given competition for land, then the actual level of rent paid will be determined by those factors influencing the profitability of the production process, such as input prices, output prices, managerial ability and the rate of technological change. Whilst we will not examine rent determination in any detail in this thesis, it is implicitly assumed here that the returns to landownership, as measured by farm rents, are market determined by the factors affecting the profitability of farming.[5]

Historically, the form of the rental payment has been in terms of labour services, farm output or cash; although we can legitimately dismiss the former as being an artefact of feudal agriculture. Whilst it is customary in many parts of the world for the rent (or part of it) to be paid in kind, with farm produce, as in the share-tenancy arrangement, such a practice has not been common in England and Wales, where the cash rent tenancy has dominated all other forms of rental payment. Moreover, rents in England and Wales have typically been fixed sums, agreed in advance of the harvest, based on some

4 Here, the term 'land' may be interpreted in its widest sense so to include farm buildings, roads and the farmhouse; in essence all the basic infrastrucutre that makes it possible to farm the land.

5 The interested reader is referred to Chapter IV of Harvey (1974) for a neoclassical derivation of rent determination.

average measure of historical profitability of the land, and paid at the end of the farming year.

(a) The Rental Contract

The precise details of the leasing arrangement between the landowner and farmer will typically be stipulated in a formal agreement negotiated by the two parties involved, called the rental contract. Whilst the form the contract actually takes will vary, it is typically the obligation of the landowner to maintain the farm infrastructure and pay for any improvements to it, such as field drainage and modernisation of farm buildings. In return the cultivator agrees to pay a specified level of *ex ante* rent and supplies all the working capital such as livestock, machinery, hired labour feed and seeds. In order to derive a measure of the net return to landownership it is necessary to deduct the landowner's expenses in maintaining the land, such as outgoings on improvements and the taxes payable on the gross income.

In a setting characterised by owner-occupiers one individual performs the functions and thus receives the rewards of both landowner and cultivator. Because the owner-occupier cannot obviate the obligations and rewards of landowner or farmer there appears no justification to treat land held by owner-occupiers any differently to land held in the tenanted sector. Whilst differences between tenant farmers and owner-occupiers may exist, particularly their respective wealth (and the implications this may have in imperfect capital markets), in general such differences should have a negligible effect on the determination of rent. Although the 'latent' rent of the owner-occupier is internalised and thus less visible, it must still exist as the services which rent is a payment for, have not disappeared.

(b) Empirical Measures of Returns to Land

(i) Net farm income

Despite the seemingly straightforward definition of cash rent and the empirical availability of such series, researchers in the UK and USA have frequently used the 'net farm income' of operators as a proxy for the returns to land ownership instead.[6] The explanation typically given to account for this approach centres on the predominance of owner-occupation as a mode of land tenure, so that net farm income represents the return to owner-occupiers and by association, their land. By using operators net farm income, (which had been relatively stagnant in the US during the

6 See for example Herdt and Cochrane (1966), Tweeten and Martin (1966), Duncan (1977) and Traill. (1979).

1960s) to measure earnings from assets (which incidentally had risen commensurately with land prices) researchers made an important error regarding the recipient of net farm income. Net farm income, as defined in official statistics actually represents the total return to the farmers' labour, management and working capital, such as machinery and livestock purchase and not the return of capital invested in land.[7] As a measure of the return to land, net farm income is therefore clearly inappropriate to the extent that its choice as a land income measure seems quite puzzling in retrospect.

However, use of net farm income as the return to land was reinforced, albeit ironically, by the 'seeming paradox' (Scofield 1957) of rising land prices in the face of stagnant or declining net farm income that have been observed in the US and UK since the Second World War. The solution of this paradox represented an exciting avenue of enquiry, yet such was the familiarity with farm incomes in this context that, rather than query the legitimacy of the empirical measure of returns to land used, attention was diffused into rather peripheral issues. A clutch of papers were published that investigated the influence of issues such as the emergence of non-agricultural demand for farmland, technological change and farm structure, as possible explanations for land price trends.[8] With hindsight, the solution to the paradox seems almost trivial and the investigations into the peripheral areas a diversion that threw empirical research off the 'right track' temporarily, yet arose simply out of confusing returns to land and returns to farming. Nevertheless, dissent was apparent from a number of quarters and new measures of returns were developed in order to overcome the problems of farm income and a declining tenanted sector.

(ii) Imputed Returns to landownership

A number of empirical studies conducted in the US used a residual income to measure returns to land and was obtained by deducting costs from gross farm income.[9] However, the residual income measure is likely to be defective due to empirical and conceptual problems. As stated by Alston (1986),

> 'This (residual) measure incorrectly treats land as the residual claimant for agricultural production and suffers from severe measurement problems, particularly relating to imputing costs for capital equipment and management'. p. 5,

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7 Indeed, net farming income as defined in official statistics explicitly excludes the return to land paid in the form of rent.

8 See *inter alia* Chryst (1965), Clery and Wood (1965), Herdt and Cochrane (1966), Tweeten and Martin (1966) and Reynolds and Timmons (1969)

9 See for example Hauschen and Herr (1980), Dobbins *et. al.* (1981) and Melichar (1979), Phipps (1984).

A conceptual problem is that residual income is a return to entrepreneurship not land,

> 'This distinction is particularly clear in the land rental market where the landowner obtains rent, contracted in advance, and the land-user claims any pure profit from the land. The same distinction should apply whether the landowner rents the land to himself or to someone else.' Alston (1986) p.5.

An additional conceptual problem concerns the use of a residual measure in a world characterised by uncertainty. If we admit the presence of uncertainty in yields and prices and an aversion to risk on behalf of land owners then it is intuitively clear that an *ex ante* fixed cash rent will be different to that implied by the *ex post* residual measure of returns. As Robison *et al.* (1985) suggest,

> ' . . . the tenant bears all the risk inherent in the farming operation, the cash rent then is considered a certainty equivalent income for the use of land.' p. 795.

These defects are compounded by empirical evidence suggesting that cash rents are a more accurate measure of farming returns to land than residual measures. Having computed a residual income measure Scofield (1965) compares the series to rents, and is able to conclude that,

> "Cash rents for farms provide a more direct measure of the returns realized by landowners than do the imputed returns"

More recently, the majority of land price models published in the US have used cash rents as a measure of farm returns and have generally inferred a stable relationship between the two, particularly so in areas that are predominantly agricultural.[10] *Ex ante* cash rents are also favoured from a conceptual point of view due to the fact that the rental payments are akin to the measure of 'returns' used in the capital asset pricing framework, and as such lend well to the construction of capital asset type models from which most modern land price models emanate.

(c) Other Considerations

Whilst it is generally accepted that farm rents provide a reasonably good estimate of the returns to land ownership where the demand for land is agricultural, this should not imply the redundancy of other factors in the determination of land prices. Motives for land purchase will be site specific: in areas designated 'agricultural', non-farm demand for land may exert an almost negligible influence, but this clearly may not be the case where the geographical location of land makes it suitable for development, residence or

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10 See for example Burt (1986) and Tegene and Kuchler (1991).

amenity. More generally, land purchase may be motivated by tax liability, long term investment potential, speculation and inflation hedging. Whilst the importance of these factors is largely an empirical question, which will be addressed in subsequent chapters, there still remains a problem which is more difficult to solve. This concerns the presence and magnitude of any non-pecuniary returns to land, a factor which commercial land agents and commentators of land market trends are only too keen to emphasise. Indeed, seldom does a description of the UK land market not include a reference to the 'nebulous attractions of landownership'. Whether this utility stems from social prestige, heritage, the ownership culture, or some other factor, it is difficult to identify, as indeed is whether participants actually attach a monetary value to it: the influence of psychic utility may well be a myth that vanishes in the hard light of the auction room. Notwithstanding its potential importance, in the absence of an empirical measure of this utility there is little chance of resolving the issue in a time series framework, although evidence from cross-sectional survey data may well throw some light on this subject and research currently in train at the University of Cambridge attempts to do this.

In summary, it is probably clear that no ideal measure of the returns to ownership currently exists or indeed may be computed from raw data in the future given the diversity of uses to which land may be put and the measurement errors involved in computation. Of all the measures considered here, cash rents appear to offer the most attractions and given that long historical time series exist, it is cash rents that will be used in the empirical analysis that follows. Whilst the bulk of the empirical modelling appears in later chapters, in the remainder of this chapter we investigate the implications of expectations formation in the capital asset pricing model, at the theoretical and empirical levels.

IV.(v) An Expectations Augmented Present Value Framework

In Chapter III it was demonstrated how the present value hypothesis may represent the reduced form equation for short-run equilibrium price determination in a capital asset market. Here, we demonstrate how the present value rule may be elaborated to include various types of expectations mechanism that lead to instructive abstractions about the behaviour of the market. *A priori*, one may suspect that expectations play a crucial role in determining agents' valuations, due to the longevity of the asset and the considerable sums required in order to secure acquisition of land. However, the form of expectation mechanism that characterises price formation in the land market has not been previously explored at either the theoretical or empirical levels. To address this issue, three competing specifications are developed that reflect adaptive, naive and rational expectation mechanisms. Each specification is logically deduced from a common present value hypothesis and then tested for empirical validity using data on average land prices and rents from England and Wales.

To recap, the notation is as follows,

E_t : expectations operator at time t. This is a conditional expectation given the information available to agents in the land market at time t.

N_t : average nominal price of land traded in England and Wales (£/ha) at the beginning of year t.

Y_t : average nominal (cash) rent (£/ha) negotiated in year t.

F_t : index of the GDP deflator in year t.

f_t : rate of inflation in year t.

$$= \left[\frac{F_{t+1}}{F_t}\right] - 1$$

P_t : real price of land (£/ha) at the beginning of year t.

$$= \frac{N_t}{F_t}$$

R_t : real return to land (£/ha) in year t.

$$= \frac{Y_t}{F_t(1+f_t)}$$

r : (assumed) constant real discount rate.

δ : discounting constant.

$$= \frac{1}{(1+r)}$$

The real discount rate represents the marginal rate of substitution between present and future consumption of the representative agent involved in the land market. A constant rate may seem unduly restrictive but it may be argued that due to the long-term nature of land purchase, participants are most likely to use a single rate to discount future earnings.[11] More importantly, imperfections in the capital market may prevent equality between the real discount rate and the opportunity cost of capital. In this light it is perhaps simplest to regard the real discount rate as the rate of return required by landowners in equilibrium. Historically, the rate of return on land has tended to be 'low' although no empirical investigation at an aggregate level has attempted to quantify it.

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11 See Section IV.(vi) for more on this point.

In terms of the definitions set out above, strictly speaking, land prices should be dated at the beginning of year t and returns measured as the flow over year t. Similarly, the general price index should be dated at the beginning of the year and the inflation rate should represent the percentage change over the year. These conventions are employed in this section, although as explained later, data measurement problems prevent a neat carry-over into the empirical analysis.

(a) An Alternative Representation of the Present Value Hypothesis

In Chapter III it was demonstrated that the reduced form price equation of an equilibrium market model is,

$$P_t = \delta \sum_{j=0}^{\infty} \delta^j E_t\left[R_{t+j}\right] \qquad \text{(IV.13)}$$

Equation (IV.13) prices land according to market fundamentals. It embodies a decision rule which asserts that changes in the price of land are attributable to new information concerning the returns to land. A special case of equation (IV.13) is where expected future returns are a random walk: $E_t[R_{t+j}] = E_t[R_t]$ for all $j > 0$. If we combine this with naive expectations, (where $E_t[R_t] = R_{t-1}$), this implies that,

$$P_t = \frac{R_{t-1}}{r}$$

However it is informative to consider alternative formulations of the present value rule since if equation (IV.13) is used to form $E_t[P_{t+1}]$, and $\delta E_t[P_{t+1}]$ is subtracted from (IV.13), then we have,

$$P_t = \delta E_t[R_t + P_{t+1}] \qquad \text{(IV.14)}$$

Equation (IV.14) states that the real price of land at the beginning of t is equal to discounted expected real returns over t plus discounted expected real price at the beginning of $t+1$. As such, it allows for speculation in the land market. Indeed, the relationship between (IV.13) and (IV.14) is seen by considering the class of forward solutions to (IV.14) interpreted as a linear difference equation,[12]

$$P_t = \delta \sum_{j=0}^{\infty} \delta^j E_t[R_{t+j}] + \gamma_t \left(\frac{1}{\delta}\right)^t \qquad \text{(IV.15)}$$

where γ_t is any random process that obeys $E_t[\gamma_{t+1}] = \gamma_t$. What equation (IV.15) is asserting is that land price is the sum of a market fundamentals component, M_t and a speculative element S_t, *i.e.*,

$$P_t = M_t + S_t \qquad \text{(IV.16)}$$

where,

12 See Sargent (1987) p.95 for further explanation of this relationship.

$$M_t = \delta \sum_{j=0}^{\infty} \delta^j E_t[R_{t+j}]$$

is assumed to be a convergent sum and,

$$S_t = \gamma_t \left(\frac{1}{\delta}\right)^t$$

with the property that,

$$E_t[S_{t+1}] = (1+r)S_t$$

or,

$$S_{t+1} - (1+r)S_t = w_{t+1}$$

where, w_{t+1} is a random variable with the property that,

$$E_{t-j}[w_{t+1}] = 0 \quad \text{for all } j \geq 0.$$

Thus, equation (IV.16) permits a divergence between the prevailing market price and that determined by market fundamentals. In the land market, expected capital gains or losses independent of expected future returns to land are a possible candidate for a speculative element in determining land price and thus an equation in which speculation may be accommodated is rather appealing. Specifically, it may be suggested that equation (IV.14) embodying a one-period decision rule, is more applicable in empirical analysis than (IV.13) for three reasons. First, the unpredictability of the long term in the land market; second, that agents are unlikely to employ sophisticated expectations about the long term and, third, that arbitrage over time is difficult because of the low turnover in the land market, so that speculation cannot be ruled out.[13]

As a result equation (IV.14) will be used as the common basis of the present value hypothesis in the econometric modelling that follows and takes the form,

$$P_t = \delta E_t[R_t + P_{t+1}] + u_t \qquad \text{(IV.17)}$$

where u_t is a random error term. In order to render (IV.17) operational in the estimation of equilibrium prices, the mechanism driving expectations must be initially specified. The next sub-section derives three specifications of this model that correspond to adaptive, naive and rational expectations.

(b) Expectations Formation

Under adaptive expectations the relevant part of (IV.17) may be written as,

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13 Equation (IV.14) implies a weaker and thus more flexible present value rule than equation (IV.13) in the sense that whereas (IV.14) can be derived from (IV.13) the reverse is not true. See Chow (1988) for more on the relationship between these two specifications.

$$E_t[R_t + P_{t+1}] = \frac{\alpha(R_{t-1} + P_t) + v_t}{1 - (1-\alpha)L} \qquad \text{(IV.18)}$$

where, α is the expectations coefficient, $(0 < \alpha < 1)$

L is the lag operator

v_t is a random error term, uncorrelated with u_t.

Substituting (IV.18) into (IV.17) and re-arranging yields the following,

$$P_t = \frac{1}{1-\delta\alpha}(1-\alpha)P_{t-1} + \frac{\delta\alpha}{1-\delta\alpha}R_{t-1} + \frac{1}{1-\delta\alpha}(\delta v_t + u_t - (1-\alpha)u_{t-1}) \qquad \text{(IV.19)}$$

It may be useful to note here that when estimated by ordinary least squares, we will clearly only obtain a single estimate for each of the compound coefficients in (IV.19). The structural parameters (α and δ) that make the compound coefficients and about which we are primarily interested in, will then be derived following the initial estimation.

Naive expectations are a special case of (IV.19) where $\alpha = 1$. Consequently, in the presence of naive expectations equilibrium market price is given by

$$P_t = \frac{\delta}{1-\delta}(R_{t-1} + v_t) + \frac{u_t}{1-\delta}$$

i.e., the stochastic representation of the familiar present value model,

$$P_t = \frac{1}{r}R_{t-1} + \varepsilon_t \qquad \text{(IV.20)}$$

where, ε_t are serially uncorrelated.

Finally, a rational expectations model is considered. This representation is formed by noting that a rational expectations equilibrium in the land market requires that the expected percentage rate of return on land as an asset, stemming from expected capital gains and expected income flow, is equal to the (constant) real rate of discount,

$$\frac{E_t[P_{t+1}] - P_t + E_t[R_t]}{P_t} = r \qquad \text{(IV.21)}$$

Furthermore, under this version of rational expectations,

$$P_{t+1} - E_t[P_{t+1}] = e_{t+1}$$

where the e_{t+1} are serially uncorrelated. Consequently, using the expression in (IV.21), reducing the subscripts by one and rewriting gives,

$$P_t = \delta^{-1}P_{t-1} + e_t - E_{t-1}[R_{t-1}] \qquad \text{(IV.22)}$$

Further, assuming, as is usual in the rational expectations literature, that agents have the same knowledge that is available to the econometrician, then rents may be modelled by the extrapolative, weakly-rational predictive model,

$$R_t = \phi + \sum_{i=1}^{n} \beta_i R_{t-i} \qquad \text{(IV.23)}$$

Hence, $E_{t-1}[R_{t-1}]$ in (IV.22) can be replaced by the ordinary least squares (OLS) estimate of R_{t-1} from (IV.23), denoted $\hat{R}_{t-1}$ to yield,

$$P_t = \delta^{-1} P_{t-1} - \hat{R}_{t-1} + \eta_t \qquad \text{(IV.24)}$$

where η_t are also serially uncorrelated.

We have now derived the three competing specifications that may be tested with empirical data in the sections that follow. Although the series used here are discussed at some length in the Data Appendix, a brief summary and explanation is given here.

(c) The Data

Following the notation of the previous section we define,

P_t : real average price of all sales of agricultural land [£/hectare] traded in England and Wales in calendar year *t*.

WP_t : real average price of without possession (tenanted) land [£/hectare] traded in England and Wales in calendar year *t*.

VP_t : real average price of vacant-possession (owner-occupied) land [£/hectare] over 20 hectares traded in England and Wales in calendar year *t*.

R_t : average real cash rent of agricultural land [£/hectare] in England and Wales during calendar year *t*.

RN_t : real average cash rent of agricultural land [£/hectare] in England and Wales that has undergone a rent change during calendar year *t*, (*i.e.* average rent negotiated in year *t*).

F_t : index of G.D.P. deflator for U.K. as an average over calendar year *t*. Base year 1985.

D_t : dummy variable for E.E.C. entry. $D_t = 1$ for 1972 and 1973, $D_t = 0$ for all other years.

The data series P_t and R_t are available for the years 1946 -1987; WP_t, VP_t and RN_t for 1969 - 1987.Before the results of estimation are presented three points should be noted concerning the data.

(i) Due to the conventions used by the authorities, published statistics do not correspond perfectly with those specified in the theoretical model. For example, in theory P_t represents the average land price prevailing at the beginning of year *t*, whereas a datum for P_t is an average land price observed *during* year *t*. Similar problems exist in the rent and deflator series. Land sold with development potential is excluded from agricultural land price statistics, but the (residential/amenity) value of a smallholding may inflate average land prices (most notably for vacant-possession land) above its price based solely on agricultural earning potential. An attempt has been made to reduce this (upward) bias in the vacant-possession series by the exclusion of those sales below 20 hectares. In general, the market for tenanted land is unaffected by this factor and thus has not been adjusted. The 1946-87 time series has also been left unadjusted due to the fact that that sales by size and tenure were not recorded prior to 1969. In order to maintain a long and consistent time series suitable for estimation (and being content that such 'residential/amenity sales' exert a smaller effect in the 'all sales' land price) this series is also left unadjusted.

(ii) The land price series are derived from statistics reported by the Inland Revenue and are adjusted to take account of the delay that is observed between the date at which sales actually occur and the date at which they are reported to the Inland Revenue. Because this delay is generally believed to be about 9 months on average, sales of land reported during the 12 months ending 31st September in year t will more accurately reflect the sales, and hence market conditions generally, that took place in calendar year $t - 1$.

(iii) The commercial rent paid on tenanted land, (R_t), is used as the measure of the annual return to land for the 'all sales' series. R_t is the average rent *paid* in year t; because of legal provisions binding landlords to maintain the same rent for at least three years, only approximately one-third of rents included in this rent series will have been increased in any one year. This lag in rent adjustment will entail that the rent data will not be the most accurate indicator of rents negotiated in any particular year. As a proxy however, it is considered here to be a reasonable one, and one that allows a far larger sample for the purposes of estimation. However, for the two separate series of land prices (WP_t and VP_t) the rent variable RN_t is used and represents the average rent *negotiated* in the year in question.

(iv) Owing to accession to the E.E.C., agricultural land prices rose to extraordinarily high levels in 1972 and 1973 and a dummy variable has been included to account for the extra-ordinary events during those years. Concluding an article on land price movements during 1972 and 1973 Munton (1975), remarks,

> 'It is generally agreed, however, that prices were far in excess of those that could be justified on farming grounds alone and even, perhaps, in terms of long term property investment aswell.'

and that,

> '. . . land price movements in 1974 and 1975 reveal, as many auctioneers correctly predicted, the artificiality of prices in 1972 and 1973.' p.130.

From a statistical perspective the inclusion of a dummy variable is also warranted on the grounds that, in its absence, econometric results would be biased due to the unusually large weighting given to the estimated residuals in those two years and indeed preliminary regression results without a dummy variable support this inference.

(d) The Empirical Testing of Expectation Hypotheses

The theoretical derivations of the present value rule under adaptive (AE), naive (NE) and rational expectations (RE), equations (IV.19), (IV.20) and (IV.24) are estimated for the three land price series, P_t, VP_t, and WP_t at our disposal and the results are presented in Tables IV.2, IV.3 and IV.4 respectively. Turning to these tables it is evident that constant terms are redundant in most of the regressions, suggesting that the data are consonant with the theoretical derivations. Equation (IV.19) actually implies serial correlation in the empirical AE models. Rather than remedy the problem with an orthodox corrective procedure - which will typically assume a simple form of autocorrelation, usually AR(1) - an alternative method is employed which incorporates lagged OLS residuals (denoted e_{t-1} and e_{t-2}) as extra regressors. This latter approach is adopted as being more appropriate given the potentially complex nature of the error term of (IV.19). However, contrary to, (IV.20) and (IV.24) the empirical NE and RE models are also serially correlated and have been corrected in a similar manner.

As noted above in order to estimate the rational expectations formulation of the PV rule, a forecasting model for $E_t[R_{t-1}]$ in (IV.22), is required. Fitted values generated from third order polynomial distributed lag forecasting models are estimated for each rent series and are denoted $\hat{R}_t$ and $\hat{RN}_t$. Three diagnostic tests of model adequacy are presented in the tables : ω represents an assessment of a recursive Chow (1960) test for parameter stability. A cross (x) under this heading indicates a statistically significant difference between parameters estimated before and after the land price boom of the early 1970. The test statistics ψ and ζ indicate the presence of serial correlation and heteroscedasticity respectively, and are accompanied by 5% critical values (reported in bold type).

The results from the regressions comprising Tables IV.2, IV.3 and IV.4 may be summarised as follows. All estimated coefficients are significant at the 5% level and have signs consonant with *a priori* beliefs. Indeed, the adaptive and rational models appear to perform quite satisfactorily, having 'good' explanatory power ($\bar{R}^2$) and stable coefficients. The similarity in the performance of the two types of model is not surprising since they only differ in the rent series that is actually used. Whereas the adaptive models use actual rents, the rational model employs the forecasted rent series from equation (IV.22). However, since it is the interest in the underlying structural parameters that is motivating this investigation, the similarity in the statistical performance of the two types of models reported in the tables does not imply that land prices are generated both rational and adaptive expectation mechanisms. The interpretation of the ordinary least squares estimates is left to the next section where the applicability of each hypothesis is evaluated.

Table IV.2. :Regression Models for the All Sales Land Price Series (P_t) for the Three Expectations Hypotheses.

Regressors							Diagnostics				Equation
C	P_{t-1}	R_{t-1}	$\hat{R}_{t-1}$	D_t	e_{t-1}	e_{t-2}	$\bar{R}^2$	ω	ψ	ζ	
Adaptive Model											
	0.580	+17.689		+1935.2	+0.640		0.95		3.08	2.27	(IV.25a)
	(9.69)	(6.40)		(9.32)	(4.46)				**4.96**	**4.60**	
Naive Model[14]											
-948.3		+ 56.98		+2879.5	+0.807			x	0.27	1.87	(IV.25b)
(-5.47)		(17.36)		(5.89)	(3.09)				**4.13**	**4.10**	
Rational Model											
	+0.623		+16.100	+1790.5	+0.842	-0.356	0.95		0.02	1.73	(IV.25c)
	(9.58)		(5.35)	(8.45)	(5.10)	(-1.97)			**4.17**	**4.13**	

The statistical results from the NE models are less satisfactory however. Equation (IV.25b) which estimates the all sales land price series under naive expectations has a significant constant, contrary to the theoretical derivation in (IV.20) and exhibits unstable coefficients over the sample period. It should also be noted that virtually all models are augmented with lagged residuals to adjust for serial correlation. Whilst this

14 Note that model (IV.25b) is estimated with an intercept, contrary to the theoretical derivation of (IV.20). This empirical model is also heteroscedastic and consequently a simple weighting procedure is employed to obtain homoscedastic residuals. Due to this transformation, the R^2 statistic gives misleading results and has not been reported. Intercepts and weighted least squares were not necessary in models (IV.26b), or (IV.27b) supporting equation (IV.20).

is expected in the AE case it runs contrary to the theoretical derivations of NE and RE, described by (IV.20) and (IV.24). Although serial correlation may simply represent a nuisance inherent in the data it may also reflect a misspecification of the RE and NE (and even possibly the AE) models. Consequently, these preliminary results indicate that the NE models are generally inferior to their AE equivalents, and that there is little formal evidence favouring either the AE or RE specification.

Table IV.3 : Regression Models for the Vacant Possession Land Price Series (VP_t) for the Three Expectations Hypotheses.

	Regressors					Diagnostics				Eq. No.
VP_{t-1}	RN_{t-1}	$\hat{RN}_{t-1}$	D_t	e_{t-1}	e_{t-2}	$\bar{R}^2$	ω	ψ	ζ	
Adaptive Model										
0.385	+25.787		+2002.8	+0.704		0.73		2.20	2.60	(IV.26a)
(3.60)	(5.16)		(7.26)	(3.09)				**4.96**	**4.60**	
Naive Model										
	+41.632		+2726.9	+0.810		0.69		0.11	0.17	(IV.26b)
	(17.36)		(5.89)	(3.09)				**4.75**	**4.60**	
Rational Model										
+0.416		+27.417	+1917.6	+0.721		0.81		4.26	0.04	(IV.26c)
(3.88)		(4.88)	(6.72)	(3.05)				**4.96**	**4.67**	

Table IV.4. : Regression Models for the Without Possession Land Price Series (WP_t) for the Three Expectations Hypotheses.

	Regressors				Diagnostics				Eq. No.
WP_{t-1}	RN_{t-1}	$\hat{RN}_{t-1}$	D_t	e_{t-1}	$\bar{R}^2$	ω	ψ	ζ	
Adaptive Model									
0.500	+15.71		+2081.5		0.74		1.85	0.40	(IV.27a)
(3.92)	(3.78)		(6.03)				**4.60**	**4.49**	
Naive Model									
	+29.705		+2744.1	+0.703	0.70		0.61	0.05	(IV.27b)
	(20.98)		(7.10)	(3.27)			**4.60**	**4.49**	
Rational Model									
0.505		+15.583	+2043.6		0.73		2.67	0.29	(IV.27c)
(4.39)		(3.54)	(5.76)				**4.60**	**4.49**	

(e) Interpretation of the Coefficients

Having estimated the three land price series using the present value hypothesis under adaptive, naive and rational expectations, we now solve the OLS coefficients to obtain the structural parameters, *i.e.* the expectations coefficient (α) and the discounting constant (δ), from which the implied real rate of discount (r) may be derived.

(i) *The Adaptive Expectations Solution*

If we denote the coefficients on P_{t-1} and R_{t-1} in (IV.19) as a and b, then;

$$a = \frac{1}{1-\delta\alpha}(1-\alpha) \qquad \text{(IV.28)} \qquad \text{and} \qquad b = \frac{\delta\alpha}{1-\delta\alpha} \qquad \text{(IV.29)}$$

Noting that both a and b have a common term in $\delta\alpha$, then rearranging (IV.28) and (IV.29) gives,

$$\delta\alpha = \frac{a-1+\alpha}{a}$$
$$\delta\alpha = b - b\delta\alpha$$

from which we may solve for the structural parameters of interest, which gives,

$$\alpha = \frac{ab}{1+b} - a + 1 \qquad \text{(IV.30)} \qquad \text{and} \qquad \delta = \frac{b}{\alpha(1+b)} \qquad \text{(IV.31)}$$

Recalling that $\delta = 1/(1+r)$, the real rate of discount, r is simply $(1/\delta) - 1$. Hence using the estimates of a and b from the OLS regressions (IV.25a), (IV.26a) and (IV.27a), the estimated structural parameters for the three land price series are:

(a) The 'all sales' land price series, P_t ; $\hat{\alpha} = 0.969$, $\hat{\delta} = 0.977$ and $\hat{r} = 2.38\%$

(b) The vacant-possession series, VP_t ; $\hat{\alpha} = 0.986$, $\hat{\delta} = 0.976$ and $\hat{r} = 2.42\%$

(c) The tenanted land price series, WP_t ; $\hat{\alpha} = 0.972$, $\hat{\delta} = 0.966$ and $\hat{r} = 2.91\%$

The real discount rate $\hat{r}$ implied by these models seems plausible lying between 2 - 3% and as we can interpret $\hat{r}$ as being the real rate of return required on average by land market participants, the estimates accord quite well with the widely held belief that returns on land are traditionally low. Focussing now on the expectations coefficient ($\hat{\alpha}$) whilst we do not have any priors concerning its empirical value it is interesting that in all three AE models the expectations coefficient is almost unity. Since a value of α of exactly unity would imply that expectations are revised naively, it is instructive to determine whether the empirical results of the AE model actually imply naive expectations. However, as the structural parameters have been derived indirectly, [from the OLS estimates of a and b in (IV.25a), (IV.26a) and (IV.27a)] it is not possible to obtain their standard errors directly, which could then be employed in standard hypothesis testing. It seems however, that we could test the hypothesis, H_0: $\alpha = 1$ against H_1: $\alpha < 1$ by two other approaches, namely; estimate the standard errors of the structural parameters of (IV.19) using non-linear least squares, or alternatively evaluate the legitimacy of results we would obtain if $\alpha = 1$, actually existed. Although this latter approach is somewhat unorthodox it demonstrates quite clearly what we wish to know. To implement this 'test', we begin by multiplying (IV.30) by (1+b) so that ,

$$\alpha = \frac{ab - a(1+b) + (1+b)}{1+b}$$

which after cancelling leaves,

$$\alpha - 1 = \frac{-a}{1+b} \qquad \text{(IV.32)}$$

Now, if we assume that $b \geq 0$ in (IV.32), then $(\alpha - 1) \leq 0$, if and only if $-a \leq 0$, *i.e.* $a \geq 0$. It follows therefore that $(\alpha - 1) < 0$ if and only if $a > 0$. Consequently, on the assumption that $b \geq 0$, we may test the hypothesis, H_0: $\alpha = 1$ against H_1: $\alpha < 1$ in the structural model by testing, H_0: $a = 0$ against H_1: $a > 0$ in the empirical models. This assumption is reasonable since b is the coefficient relating rents to land prices and as such is positive and statistically different from zero. Using a one-tailed t test, the null hypothesis (that H_0: $a = 0$) is rejected for all three models, inferring that, because $a > 0$ in the empirical models [(IV.25a), (IV.26a) and(IV.27a)] then α cannot equal unity in the structural model (IV.19). In other words, the AE models estimated here do not imply naive expectations of land price formation.[15]

(ii) *The Naive Expectations Solution*

Since the expectations coefficient is unity by assumption under naive expectations attention here focuses on the required rate of return. The theoretical interpretation of the coefficient on R_{t-1} in the NE model (IV.20) is simply $1/r$. Consequently, under NE, the real rate of discount, ($\hat{r}$) implied by equations (IV.25b), (IV.26b) and (IV.27b) is estimated at, 1.75% for the all sales series, 2.40% for the vacant-possession land series and 3.37% for the tenanted land price series. Interestingly these estimates correspond quite closely with those obtained using the adaptive expectations model.

15 As a matter of interest, hypothesis testing using the estimated standard errors from non-linear least squares also arrives at this conclusion.

(iii) *The Rational Expectations Solution*

When expectations are revised rationally, the coefficient on P_{t-1} in (IV.24) represents $1/\delta$. With a positive real rate of discount, this coefficient should exceed unity. However, the coefficients of the rational expectations models estimated in (IV.25c), (IV.26c) and (IV.27c) are all less than unity, implying *negative* real rates of discount. The estimated real rate of discount, ($\hat{r}$) is −37.74% for the all sales series; −58.45% for the vacant-possession land price series and -49.5% for the tenanted series.[16] Further evidence that the RE hypothesis is inconsistent with the data is suggested by the coefficient on the rent variable in each empirical model. From (IV.24) this coefficient should be -1, yet the estimates obtained in equations (IV.25c), (IV.26c) and (IV.27c) are positive and 5.68, 3.78 and 5.06 standard errors away from minus unity respectively. It thus appears that, within the PV framework, the data refute this version of the RE hypothesis. Furthermore, given that the AE empirical models do not infer naive expectations formation, yet have higher explanatory power and stable coefficients, it seems reasonable to simply use the AE models in further investigation.

IV.(vi) Some Ancillary Issues

Before we depart from this preliminary econometric investigation there are a number of related issues that seem appropriate to tackle here. The first relates to the possibility of disequilibrium pricing in the land market; the second, concerns the opportunity cost of capital and finally we investigate the simultaneous modelling of land prices in the tenanted and vacant possession sectors of the market.

(a) Disequilibrium Pricing

The possibility of disequilibrium pricing was introduced in Chapter III in connection with the derivation of the reduced form price equation where it was suggested that disequilibrium could be identified by the presence of an additional term in the present value equation representing excess/insufficient demand for the stock of land. Since data on the quantity of land offered for sale and desired in any year is not available, it is not possible to test directly the statistical significance of such a variable if included in the present value price equation. However, it is possible to test for the presence of disequilibrium pricing if we tackle the problem from the viewpoint of price adjustment. Disequilibrium would imply that price does not fully adjust to the equilibrating value in

16 To test the possibility of positive real discount rates it could be assumed arbitrarily that $r = 0.02$ and test the hypothesis that, $H_0 : 1/\delta = 1.02$ against the alternative that $H_1 : 1/\delta < 1.02$. Using a one-tailed t test, statistics calculated from all three RE models reject the null hypothesis, confirming the results in the text.

a particular year so that with $P_t < P_t^e$ there is excess stock demand and quantity rationing simultaneously in the transactions market; or with $P_t > P_t^e$ there is excess stock supply with agents unable to sell land in the transactions market. Viewed in this light then disequilibrium will manifest itself as some form of price stickiness. An *ad hoc* procedure for examining price stickiness is via the partial-adjustment model (Bowden 1978):

$$P_t - P_{t-1} = \lambda(P_t^e - P_{t-1}) + u_t \qquad \text{(IV.33)}$$

where P_t^e is the market equilibrating price specified in Section IV.(v) and λ is the adjustment coefficient, such that $0 < \lambda < 1$. Incorporating (IV.33) into the AE theoretical model (IV.19) yields,

$$P_t = \frac{1-\lambda+1-\alpha}{1-\lambda\alpha\delta}P_{t-1} - \frac{(1-\lambda)(1-\alpha)}{1-\lambda\alpha\delta}P_{t-2} + \frac{\lambda\alpha\delta}{1-\lambda\alpha\delta}R_{t-1} + \frac{1}{1-\lambda\alpha\delta}(\lambda\delta v_t + u_t - (1-\alpha)u_{t-1}) \qquad \text{(IV.34)}$$

Now, if price stickiness is observed in the land market then, λ represents the proportion of the adjustment to equilibrium actually achieved in the market. Thus, if λ assumes the value of 1 there is complete adjustment to equilibrium in a single period. There appear to be two approaches that one could use to test for sticky prices. First, (IV.34) could be estimated by non-linear least squares and a hypothesis test conducted on the estimate of λ. From a practical point of view, it may be preferable to adopt a simpler approach using ordinary least squares since , if $\lambda = 1$ then the compound coefficient on P_{t-2} will be zero. Hence, we may test the hypothesis that, $H_0 : \lambda = 1$ against $H_1 : \lambda < 1$, by a straightforward one tailed t test on the coefficient on P_{t-2} in the OLS regression of, $P_t = f\{P_{t-1}, P_{t-2}, R_{t-1}\}$.

Estimation of this OLS regression for each of the three land price series yields equations in which the second lag of price is not statistically significant from zero. Consequently, this implies that $\lambda = 1$ and thus the adjustment to equilibrium land prices is complete, not partial in the tenanted, vacant possession and aggregate land markets.[17]

(b) The Opportunity Cost of Capital

The basic PV model of Section (v) assumed a constant real rate of discount as postulated by standard neoclassical theory. Further support for the use of a near constant real rate of interest is provided by Burt (1986), who states,

---

17 Applying non-linear least squares to (IV.34) yields estimates of the structural parameters, α, δ and λ. In each of the land price models λ was not significantly different from one, confirming the results shown in the text.

'With the long term investment characteristics of farm land and the sizeable transactions costs involved, market participants are apt to use an estimated long run equilibrium rate of interest in the classic capitalisation formula to approximate land values'. p.12

However, it is possible that the opportunity cost of capital may have a short run influence on market prices. The possible influence of both the real and the nominal opportunity cost of capital is investigated as follows. First, let $X_t = 1 / (1 + \bar{r}_t)$ where $\bar{r}_t$ is the real opportunity cost of farmland capital in year t. The basic present value rule given by (IV.17) may be modified to include this variable,

$$P_t = \delta E_t[R_t + P_{t+1}] + \beta(X_t - \delta) + u_t \qquad \text{(IV.35)}$$

so that $\bar{r}_t > r$, implies that $X_t < \delta$ and a real opportunity cost of capital above the discount rate depresses land price. Second, it may be that nominal rather than real interest rates have a *short run* influence on land prices via cash flow considerations. Let i_t be the nominal rate of interest, then (IV.17) may be modified,

$$P_t = \delta E_t[R_t + P_{t+1}] - \theta \Delta i_t + u_t \qquad \text{(IV.36)}$$

so that rising (falling) nominal interest rates can have a short-run depressing (stimulating) effect on land price but no permanent effect. Incorporating the adaptive expectations model (IV.19) in (IV.35) yields an equation of the form,

$$P_t = -\frac{\beta\alpha\delta}{1-\delta\alpha} + \frac{(1-\alpha)}{1-\delta\alpha}P_{t-1} + \frac{\delta\alpha}{1-\delta\alpha}R_{t-1} + \frac{\beta}{1-\delta\alpha}\Delta X_t + \frac{\beta\alpha}{1-\delta\alpha}X_{t-1}$$
$$+ \frac{1}{1-\alpha\delta}(\delta v_t + u_t - (1-\alpha)u_{t-1}) \qquad \text{(IV.37)}$$

Now, if the real opportunity cost of farmland has no discernible effect within this framework then $\beta = 0$ and (IV.37) collapses to the original AE model, equation (IV.19). For each of the three land price series, we estimate,

$$P_t = f\{\, b_0, b_1P_{t-1}, b_2R_{t-1}, b_3X_{t-1}, b_4\Delta X_{t-1}, b_5D_t \,\}$$

using OLS, where b_0 is a constant term.[18] To test the null hypothesis that $\beta = 0$ in the structural model, (IV.37), a restricted regression is estimated for each land price series in which $\beta = 0$ is imposed. Hence, testing the null that $\beta = 0$ in the structural model is equivalent to implementing an F statistic using the empirical models based on the null hypothesis that,

H_0: $b_0 = b_3 = b_4 = 0$ against

H_1: $b_0 \neq b_3 \neq b_4 \neq 0$,

18 Note that ΔX_{t-1} and X_{t-2} are employed not ΔX_t and X_{t-1}. This is due to the fact that X_t represents the real opportunity cost of farmland during time period t, and is thus unobservable at the beginning of t.

The test statistic generated for each land price series is unable to reject the zero restrictions imposed under the null hypothesis, implying that β is not significantly different from zero in the structural model (IV.37). Consequently, the real opportunity cost of farmland does not have a statistically significant effect on agricultural land price formation in this instance.

To test whether nominal interest rates (i_t) affect farmland the adaptive expectations model is incorporated into equation (IV.36) to give a structural model of the form,

$$P_t = \frac{(1-\alpha)}{(1-\delta\alpha)}P_{t-1} + \frac{\delta\alpha}{(1-\delta\alpha)}R_{t-1} - \frac{\theta}{(1-\delta\alpha)}\Delta i_t + \frac{(1-\alpha)\theta}{(1-\delta\alpha)}\Delta i_{t-1} + \frac{1}{1-\alpha\delta}(\delta v_t + u_t - (1-\alpha)u_{t-1}) \quad \text{(IV.38)}$$

Note that if nominal interest rates have no discernible effect on farmland values, $\theta = 0$ in (IV.38), and that equation reduces to the standard PV expression, (IV.19). In an analogous fashion to the above, one may test whether $\theta = 0$ in (IV.38), by applying OLS to a model where[19]

$$P_t = f\{\ b_1P_{t-1},\ b_2R_{t-1},\ b_3\Delta i_{t-1},\ b_4\Delta i_{t-2},\ b_5D_t\ \}$$

and test the hypotheses that H_0: $b_3 = b_4 = 0$ against H_1:$b_3 \neq b_4 \neq 0$ using an F test for the zero restrictions imposed under H_0.

The resulting test statistics imply that the zero restrictions imposed under the null are valid for the tenanted and vacant-possession markets, but not for the 'all-sales' data series.[20] As a result it appears that nominal interest rates affect the all sales series but neither vacant possession or tenanted land prices. One plausible explanation for this rather anomalous result is that the acquisition of small farms (excluded from the VP_t series and relatively unimportant in the WP_t) is influenced strongly by the nominal rate of interest. As the all-sales series used here includes purchases of these smallholdings, (often bought as hobby farms, residence, or to amalgamate into a neighbouring farm) it may well be picking up this special form of demand, not present in either of the other series. Given the consistent rejection of nominal interest rates in the VP_t and WP_t models, which arguably use more pertinent information to estimate land prices, the results obtained for the all-sales series may be spurious or may depend upon non-agricultural demand. Furthermore the sign of the coefficients on the interest rate variables are contrary to the predictions of the theoretical model and thus cast some doubt over their apparent significance. Nevertheless, despite these somewhat unsatisfactory conclusions, estimates of the structural parameters derived from the

19 Again, note that Δi_{t-1} and Δi_{t-2} are employed not Δi_t and Δi_{t-1}.

20 Estimation of (IV.38) by non-linear least squares (using the three land price series) suggests the same conclusion.

interest rate augmented all-sales model are virtually identical to those obtained from (IV.25a), in that $\hat{\alpha} = 0.960$, $\hat{\delta} = 0.978$ and $\hat{r} = 2.30\%$.

(c) Seemingly Unrelated Regression Estimation (SURE)

Our final concern is with the existence of two closely related sub-markets - tenanted and vacant-possession - for farmland in England and Wales. As was noted in Chapter II the markets for vacant-possession and tenanted land are, in practice, quite distinct due to the security of tenure afforded to tenant farmers in law. Because sitting tenants have security of tenure, prospective owner-occupiers can only purchase land sold with vacant possession and thus a premium exists for this land. However, it seems reasonable to assume that the two markets respond in a similar way to features in the general economic environment affecting agriculture.

When modelled, the effects of common factors such as exogenous shocks and unquantifiable or omitted variables will be captured in the error term of each model. If the two markets actually do respond in similar ways, the error term of one model will be correlated with the error term of the other. Where this is so, there is said to be *contemporaneous correlation* in the set of seemingly unrelated regressions which can be exploited to aid parameter estimation if the equations are estimated jointly. More specifically, it can be shown that if the regressions are estimated jointly there exists a generalized least squares (GLS) estimator that provides more efficient (lower variance) parameter estimates than those obtained when each regression is estimated separately by OLS.[21] The SURE procedure uses this GLS estimator, and the degree of correlation between the two error terms may be described by a simple correlation coefficient (*corr*) such that,

$$corr = \frac{\text{cov}(\hat{\varepsilon}_1, \hat{\varepsilon}_2)}{\hat{\sigma}_{\varepsilon_1} \hat{\sigma}_{\varepsilon_2}}$$

where $\text{cov}(\hat{\varepsilon}_1, \hat{\varepsilon}_2)$ is the estimated covariance between the two error terms using SURE and $\hat{\sigma}_{\varepsilon_1} \hat{\sigma}_{\varepsilon_2}$ are their estimated standard errors. If no contemporaneous correlation is detected then the GLS estimates are identical to those in the OLS case. Here, *corr* = 0.287 implying an advantage in the estimation of these models by SURE. A formal asymptotic test suggested by Breusch and Pagan (1980), confirms this conclusion at the 5% significance level.[22] Applying the SURE procedure to the two

21 Intuitively, this is so because GLS makes use of the information contained in the two correlated error structures in estimation. See Judge *et al*. (1985) for a formal derivation of this result.

22 The Lagrange Multiplier (LM) test statistic follows a χ^2 distribution on one degree of freedom, if the null hypothesis of no contemporaneous correlation is true. A test statistic of 24.99 here

land price models yields,

$$VP_t = \underset{(4.96)}{0.441VP_{t-1}} + \underset{(5.55)}{22.168RN_{t-1}} + \underset{(8.54)}{20.69D_t} + \underset{(3.24)}{0.514e_{t-1}} \qquad \text{(IV.39)}$$

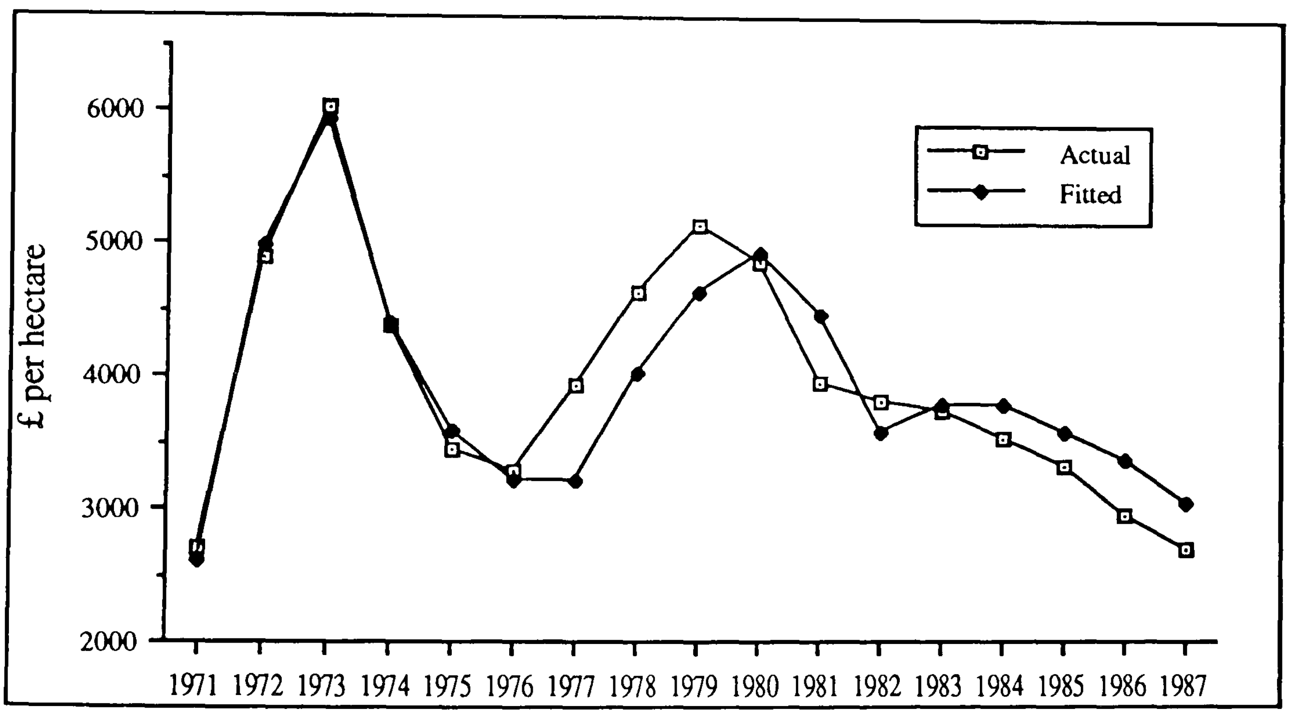
$\bar{R}^2$: 0.86

$$WP_t = \underset{(3.79)}{0.414WP_{t-1}} + \underset{(4.54)}{17.254RN_{t-1}} + \underset{(6.57)}{2093D_t} \qquad \text{(IV.40)}$$

$\bar{R}^2$: 0.77

Figures IV.3 and IV.4 graph the actual and fitted values from the models estimated using SURE.

Figure IV.3: Actual and fitted real prices of vacant possession land in England and Wales(1971-87).GDP deflator 1985 base year



Using (IV.39) and (IV.40) to derive estimates of the structural parameters, $\hat{\alpha}$,$\hat{\delta}$ and $\hat{r}$ yields;

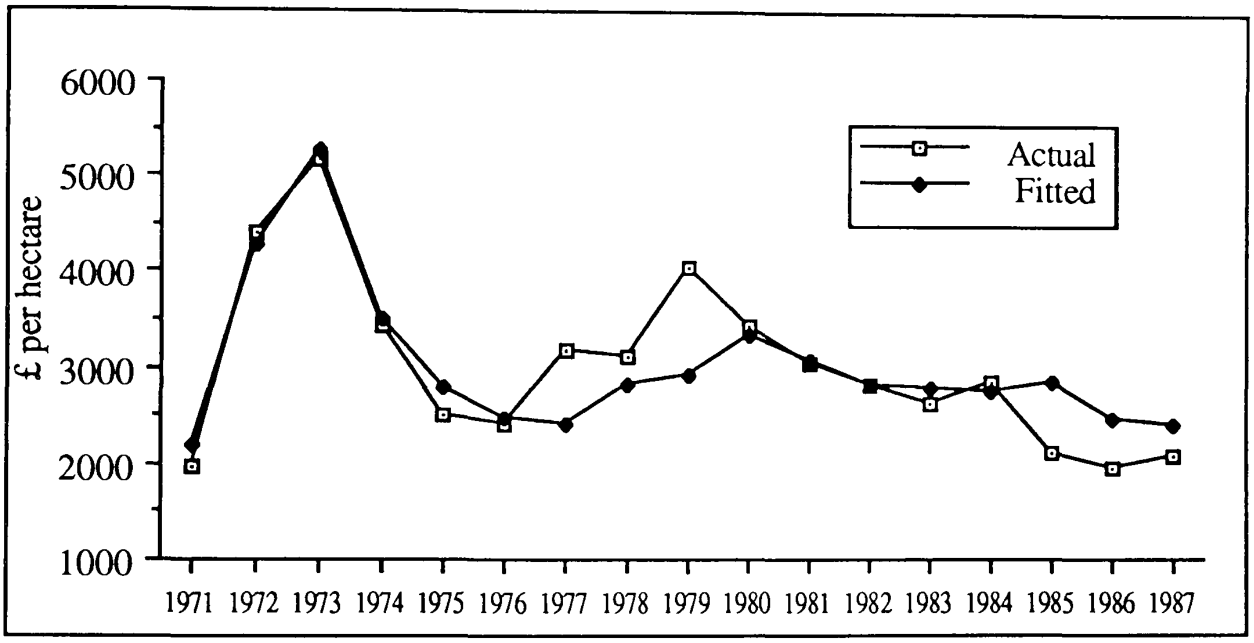
(i) for the vacant-possession series, VP_t ; $\hat{\alpha}$ = 0.981, $\hat{\delta}$ = 0.975 and $\hat{r}$ = 2.52%.

(ii) for the tenanted land price series, WP_t ; $\hat{\alpha}$ = 0.977, $\hat{\delta}$ = 0.967 and $\hat{r}$ = 3.37%

confirms the use of the SURE procedure which, incidentally, may be deduced from the higher explanatory power and improved significance of the SURE models. See p.247 of Breusch and Pagan (1980) for the construction of this test statistic.

Although these results are similar to those estimated using equations (IV.26a) and (IV.27a) SURE leads to slightly higher real rates of discount for each land price series. For comparison, it may be noted that Burt (1986) obtains an implied real discount rate of 4% when modelling land prices in the United States, whilst Chow (1988) estimates the real discount rate at 3.8% for US stock prices. The lower rate of discount on vacant-possession land is explained by the vacant-possession premium that separates the two sub-markets for agricultural land in the UK.

Figure IV.4 : Actual and fitted real prices of without possession land in England and Wales(1971-87). GDP deflator 1985 base year



IV.(vi) Some Concluding Comments

This Chapter has sought to build on the findings of Chapter III where it was established that the present value price equation represents the reduced form of a competitive market for a capital asset. The discussion has highlighted the merit of present value methods, in that such models have sound theoretical underpinnings and are capable of mimicking empirical price behaviour. Indeed, this type of capital asset pricing model offers many attractions to the applied economist, not least of which is its flexibility. The framework is a tractable one that allows expectations mechanisms to be incorporated at the theoretical level and tested empirically. Using annual data on cash rent and land prices the empirical results suggest that the process of farmland price determination is best characterised by adaptive learning, although naive expectations could be viewed as a reasonable approximation, given that most expectations coefficients were estimated at around 0.96. The version of rational expectations considered here is refuted by the data. The models also allow the implicit real rate of discount on land purchase to be derived and this is consistently estimated at around 3%, a figure which accords well with *a priori* beliefs. Finally, there is insufficient evidence to support the notion of disequilibrium pricing in the UK land market, and the data refute the presence of a statistically significant role for interest rates in the determination of agricultural land prices.

Chapter V
A Critique of Empirical Research : TheTraill (1979) Model

V.(i) Introduction

Of the extensive literature on land market research in the UK, there has only been one serious attempt to model land prices, that undertaken by Bruce Traill in 1979.[1] This Chapter seeks to evaluate the credibility of this model in light of the analysis of land price determination already presented. The model was heralded as a milestone in the modelling of UK land prices and the reticence of other workers to develop competitors after its publication may well reflect its percieved dominance, particularly since the model fitted so comfortably into the story of State support being capitalised into land values, a topical issue during the 1970s. However, close scrutiny of the model reveals some disquieting features which seriously question its validty. Whilst the concern about the capitalisation of agricultural support into land values and its repercussions remain generally undisputed, the empirical model and its theoretical underpinnings are rather suspect. Before we discuss the model in detail, a very brief review of the land price literature in the United States is given since much of the criticism directed at the early models of US land prices are also germane to the Traill model.

This Chapter comprises four Sections and an Appendix. Section (ii) offers a brief summary of the isues that have dominated the American literature on land prices. In Section (iii) the Traill (1979) land price model for the UK is examined in some depth and a number of criticisms are put forward to question the original model's apparent performance. Section (iii) reports results obtained from a re-estimation of Traill's model over an enlarged sample period and Section (iv) contains some concluding remarks. The Appendix details the statistical tests used to evalute the model's performance.

V.(ii) Recent Issues in the American Literature

The paucity of economteric work in the UK contrasts with the situation in the United States where a high 'propensity to regress' has created a large yet contradictory literature on landprice modelling. Herdt and Cochrane's (1966) article was the first of three papers published in the 1960s (Tweeten and Martin 1966, Reynolds and

1 Harvey (1974) estimated a simple linear regression of land prices on an index of imputed returns to land as part of his Ph.D. thesis. The 'model' has not been developed or published subsequently and is not considered here any further.

Timmons 1969) that sought to model U.S. land prices using a simultaneous equation system and net farm income. Klinefelter (1973) departed from this systems approach and used a single equation model, in which net farm income remained the major explanatory variable. Despite their satisfactory performance over the original sample a review paper by Pope *et al.*(1979) found that all these models performed poorly over extended samples and concluded that,

> '. . . if one is concerned with both the predictive ability and economic structure, additional research is needed to explain recent movements in farmland prices' p.115

The Pope *et al.* study encouraged research into single equation models of land values and the Duncan (1977) is one such example. However, like earlier models, Duncan incorporates a whole host of factors - including net farm income - into the estimating equation in an *ad-hoc* fashion, without any formal justification. Espel and Robison (1981) comment,

> 'Duncan, like many of his predecessors, simply hypothesizes correlations without exploring the behavioural link which causes the correlation' p.11.

Land price models developed subsequently, such as Hanschen and Herr (1980), and Dobbins *et al.* (1981) favour the use of imputed returns to land rather than offical net farm income statistics. However, these models focus on the demand for land, ignoring or mis-specifying the supply of land as the number of transactions. Furthermore, all these early models adopt what could be termed 'kitchen sink' econometric methodologies, in that the influence of a host of potential determinants is tested without any formal justification for their inclusion. Coupled with differences in specification and data, each model promotes a different set of variables as having an explanatory role. Espel and Robinson's (1981)conclude that,

> '(1) a carefully deduced land market model is needed; (2) this model must include both the supply and demand forces in determining land's prices; and (3) to evaluate such a model an appropriate model of income to land is needed' p.14.

The poor performance and structural inadequacies of these models has led to a large number of published articles in the 1980s, primarily in the *American Journal of Agricultural Economics*. Virtually all of the more recent models adopt some variant of a capital asset pricing model such as the present value hypothesis. Whilst these models initially used some imputed measure of returns to land, more latterly the use of cash rents has been more common. Nevertheless, the contradictory conclusions of published research in the States remains. Although a detailed discussion of the issues and methodologies germane to the US experience in recent years is beyond the scope of this analysis, the following description attempts to give a flavour of the debate.

At the close of the 1970s Reinsel and Reinsel (1979) argued that loose credit markets were responsible for the land price boom of recent years whereas Melichar (1979) believed that the root cause of the boom were capital gains and growing returns to land. Feldstein (1980) used a portfolio choice model to show that rapid inflation such as that which occured in the 1970s was an important force driving land prices. These papers and public discussion of their contents inspired a host of empirical land price studies which sought to pin down the determinants of farmland prices. For example Phipps (1984) obtained empirical results that suggested non-agricultural demand for farmland was of trivial importance, yet this finding was disputed by Robison *et al.* (1985) who argued that non-farm demand coupled with inflation played pivotal roles in the market.

However, evidence provided by Alston (1986) and Burt (1986) suggested that it was not inflation that was important but rental rates. Further contradictory evidence was obtained by Shalit and Schmitz (1982) who found that credit market constraints cause both a rapid price explosion when the collateral value of the assets was increasing and rapid price decline when the collateral value of assets declined. This contrasted starkly with Reinsel and Reinsel findings that the cause of the land price boom at the end of the 1970s was loose credit markets. As Just and Miranowski (1988) assert,

> '. . . many empirical studies use a relatively unstructured econometric approach in which spurious correlations with inappropriate variables or natural correlations with omitted variables can cause results to vary widely depending on model specification'
>
> p.2

Another reason to account for the discrepancies that have emerged is the number and type of data sets that have been used in estimation and hypothesis testing. Whereas in the UK it is only the aggregate time series that are sufficiently long enough to submit to an econometric investigation, in the US rent and land price series are constructed on a State basis, with the result that many 'rent' and 'land price' series abound. Regional variations in motivations for land purchase and differences in the composition and construction of the series do not help to clarify these issues. Of particular importance is the proximity to urban areas, since in some States the non-agricultural demand is widely recognised, yet in others it is barely discernible.

Despite the contradictory empirical evidence of these American models, a number of salient points do emerge that are of importance generally. Firstly, the final estimating equation ought to be derived from a sound theoretical base, that includes both the supply and demand sides of the market. Secondly, the use of transactions as a measure supply is inconsistent with theory and should thus be avoided. Third, it is apparent that land price models in the US have become increasingly parsimonious. Whilst this undoubtedly reflects the technical complexity of incorporating many different potential determinants into the theoretical framework, it does help reduce the likelihood of isolating spurious correlations, which plagued the US literature in the 1960s and 1970s. Since the adoption of parsimonious models is likely to cause problems caused by omitted variables diagnostic checking ought to play a central role in the modelling exercise. Finally, on an empirical note, the American literature implies that farm income or imputed measures of returns are poor indicators of the returns to land, and should be avoided if consistent rent series are available.

V.(iii) The Traill (1979) Land Price Model

A significant model of the land market in the UK was developed in the aftermath of the land price boom of the mid 1970s by Traill (1979).[2] The model represented a necessary requisite of a much broader study concerning the beneficiaries of agricultural price support policies.Traill's central thesis maintained that gains to farmers from price support policies would accrue in the short run only. Improved incomes would place an upward pressure on market rents and therefore land prices. This 'capitalization' of farm income growth (via rents) into land values entails that in the long run the benefits of price support policy accrue to current *owners* of agricultural land, not farmers. Moreover, high land prices and rents may be detrimental to those wishing to farm the land. In order to demonstrate this proposition Traill constructed a dynamic econometric model of farmland prices in England and Wales which simulated movements in land values during the 1950 to 1978 period.

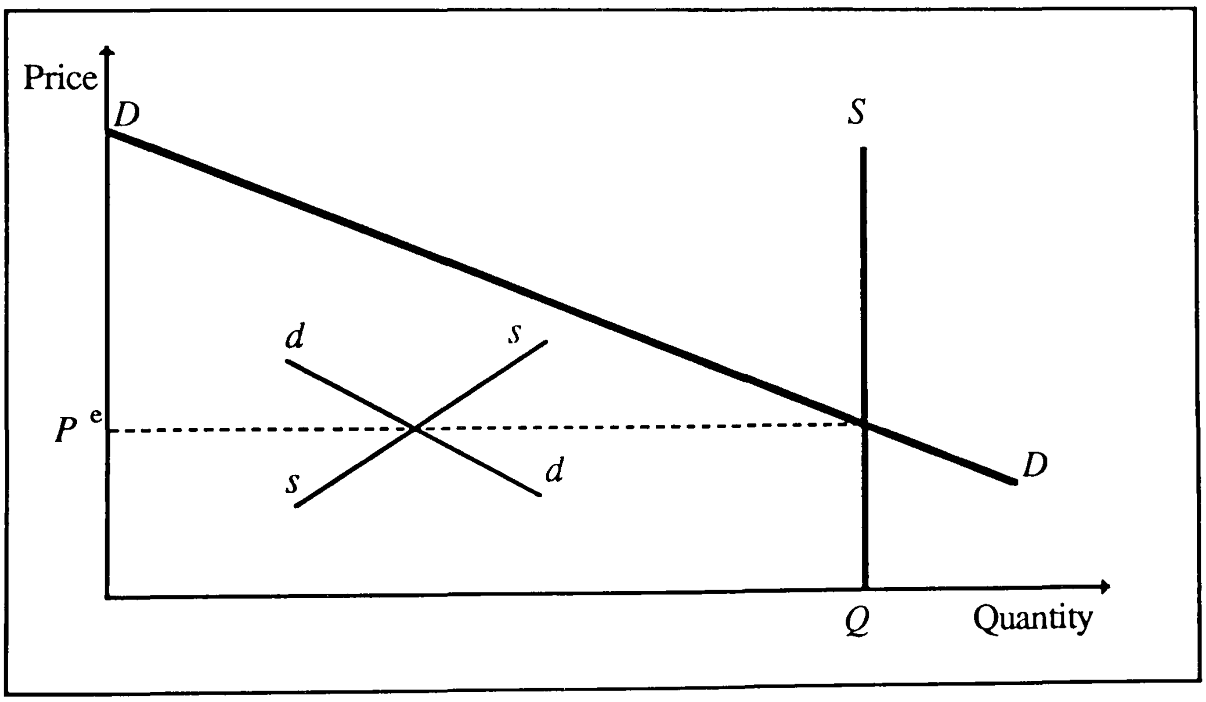
(a) The Theoretical Framework

Traill's model of land price determination is based loosely in the theoretical framework developed by Harvey (1974) and Currie (1976) that was discussed in some depth in Chapter III. To recap briefly, this approach depicts a competitive market for

2 Much of the discussion here relates to a more detailed explanation of the model that was published in 1980. See the references for details.

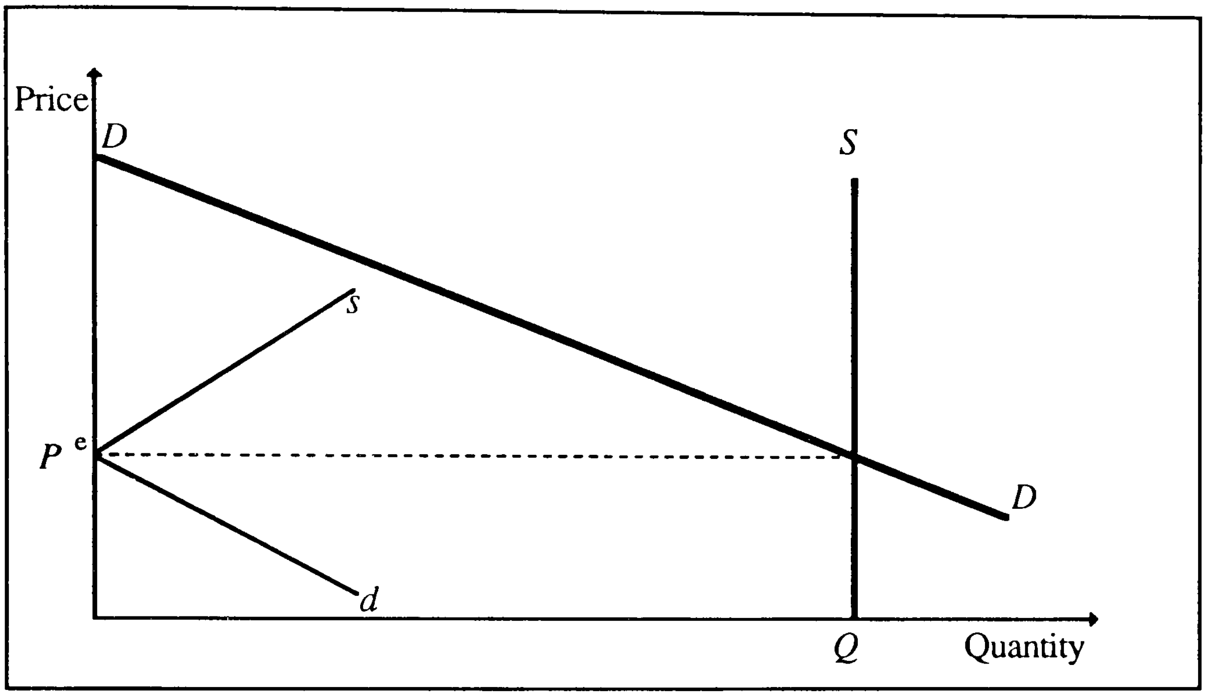
homogeneous units of agricultural land as shown in Figure V.1. *QS* represents the stock of agricultural land which is assumed to remain fixed at any point in time. The demand curve for the stock of land *DD* represents the total demand for agricultural land at a point in time and comprises the valuations of every individual in the land market, whether they be current owners or prospective owners of land. The valuation of each current owner represents his *reservation price*, that being the minimum value the owner would be prepared to sell land for. Conversely, each prospective owner has an *offer price*, which represents the maximum they are prepared to offer for a unit of land. By distinguishing between the valuations of these two types of agent it is possible to conceive supply and demand curves for land sales (*ss* and *dd* respectively); the former being the reservation prices of current owners ranked in ascending order and the latter being the offer prices of prospective purchasers ranked in descending order.

Figure V.1. Transactions in the Land Market



Assuming that a valuation of land by each individual holds irrespective of whether that individual holds land or not, (*i.e.* transactions are costless and agents are indifferent to location) each transaction will entail that the reservation price of the vendor becomes his offer price as a prospective purchaser. Similarly, the offer price of the prospective purchaser will, after the transaction has gone through, become his reservation price as a land owner. *Ceteris paribus*, at the equilibrium price P^e the transactions mechanism will entail that the market for land will converge on an equilibrium, wherein all offer prices lie everywhere below all reservation prices. At this equilibrium all owners of land are content to hold the land they own and hence no transactions take place. Figure V.2 depicts this situation.

Figure V.2 : Equilibrium in the Land Market



Although not explicitly stated in Traill's study it is the demand and supply curves *dd* and *ss* that Traill uses in order to estimate land prices. In addition Traill assumes that each individual bases his valuation of land upon the present value of a stream of future net benefits accruing from the ownership of land. Given that the unit of land is expected to be owned for *T* periods, at a constant opportunity cost, the expected net present value of land can be represented by the standard expression[3],

$$E_t\left[P_t\right] = \sum_{t=1}^{T-1} \frac{E_t\left[R_t\right]}{(1+r)^t} + \frac{E_t\left[P_T\right]}{(1+r)^{T-1}} \qquad \text{(V.1)}$$

where,

E_t = expectations operator conditional upon information available at time zero, (beginning of time t)

R_t = net return to landownership in period t, (accruing at the end of t),

3 This expression may be written as if the current owner had no intention at time 0 to sell at time *T*. Hence, in the limit,

$$E_t\left[P_t\right] = \sum_{t=1}^{\infty} \frac{E_t\left[R_t\right]}{(1+r)^t}$$

Note that the $E_t[P_T]$ in (1) simply represents the sum of the net returns to land ownership from time period *T* to ∞.

P_T = resale value of land at the beginning of time period T,
r = (constant) opportunity cost capital, where $t = 1, \ldots, T - 1$.

Whilst acknowledging that the potential influences on land values are manifold and include both pecuniary and non-pecuniary attractions to land ownership, Traill focuses on the 'profitability of farming', as represented by net farm income, as the major determinant of land prices. Given that a change in the profitability of farming will change both the maximum prices potential purchasers are willing to pay and the minimum prices that current landowners are willing to accept, land prices can also be expected to change by an amount equivalent to the *present value* of the increase in farming income received in perpetuity.

To clarify this statement consider a situation in which net farm income rises by £*A* per unit. Given that every individual in the land market maintains 'naive' expectations of the future at any one point in time, then a prospective purchaser of land may expect to receive the increase in net farm income every year, yet, will pay only once for the ownership of that unit. Hence, the increase in the price that the prospective purchaser is willing to pay for land as a consequence of the £*A* per unit increase in net farm income will naturally depend on the value that is attached to receiving £*A* per unit every year in perpetuity. Noting that, at a constant opportunity cost of capital (represented by the rate of interest r) the present value of receiving an annuity of £*A* per unit indefinitely can be shown to be A / r, then, a £1 increase in net farming income per unit, at an interest rate of 5%, may be expected to increase land prices by £20 per unit. It is in this way that increases in net farming income are said to be 'capitalized' into land values.

Following earlier studies, [Herdt and Cochrane (1966), Tweeten and Martin (1966)], Traill attempts to circumvent the problem of unobservable data by employing data on *transactions* to represent the quantity of land demanded and supplied at various prices. Consequently, the average prices observed will hence refer to 'equilibrium' prices since in order for transactions to take place quantity demanded and quantity supplied are equivalent by definition. By using this approach, the [unobservable] desired quantities depicted in supply and demand curves are replaced by the [observable] rate of transactions at various ('equilibrium') prices. However, this expedient introduces a theoretical inconsistency present in many of the earlier analyses. This concerns the 'relationship' between the number of transactions and equilibrium price. From the discussion in Chapter III it is clear that the level of transactions in any period is independent of price. A particular number of transactions may be associated with either a high or a low equilibrium price because transactions merely represent the mechanism whereby land is reallocated amongst individuals who have a positive demand for land at the prevailing market price. This degree of misallocation depends not on price but on the extent to which valuations of prospective purchasers exceed those of current land owners at the *prevailing equilibrium price* and statistical evidence presented in a recent paper by Wollmer (1988) implies that the area of land traded is independent of land price in England and Wales.

However, Traill (1980) accepts this 'transactions' specification of the model, evidencing its validity with casual observation of the plot between nominal land price and the level of transactions, which, over the 1945 to 1977 period clearly depicts a negative relationship. On the basis of this statistical correlation Traill (1980) suggests that the plot may be assumed to represent,

> '. . . some form of demand curve [for land].' p.17

and then concludes,

> 'This apparent discrepancy between theoretical and statistical results may be *explained* if we are prepared to make two assumptions about the nature of the demand and supply curves.'[4] p.17

These state that (i) the 'demand' curve is 'stable', and (ii) the supply curve is exogenous to the model, *i.e.* perfectly inelastic. The 'demand' curve will be stable if sales of land in any period do not discernably affect transactions in the following period(s). Consequently, the demand curve will no longer shift horizontally towards the price axis as a result of transactions, (as described in Figure V.2). In order for this to occur, one of two conditions must be met. The offer prices of actual purchasers of land in one period must either be replaced by equivalent offer prices of new prospective purchasers, (whether they be the valuations of new entrants or of the previous owners), or that the withdrawal of these prospective purchasers through actual sales has a negligible effect on demand for land[5]. Without prior knowledge of the number of individuals who are willing and able to purchase land at a particular point in time this assumption is untestable, yet it should be noted that both conditions sit uncomfortably beside the outcomes that one may reasonably expect.

4 *My emphasis.*

5 The reasoning advanced by Traill (1980) to account for a stable demand curve, i.e. 'a large number of potential purchasers' will, strictly speaking, only infer stability if actual sales are negligible. Only when there is perfect replacement of offer prices can stability be ensured.

The second assumption is however, rather more serious since a perfectly inelastic supply curve denotes that the quantity of land sold in any period is unaffected by the previous, current or expected future price of land. Whilst it is reasonable to accept that some land sales will be involuntary, (through bankruptcy, death or enforced retirement) the actual and expected price of land is likely to play a decisive role in the timing of voluntary sales of farmland, [particularly so since the emergence of the financial institutions, [see Nix *et al.* (1987)] for whom a vital motive for acquisition is inter-temporal asset appreciation]. Having considered these assumptions one may reasonably surmise that far from *explaining* the discrepancy between empirical observation and theory, the restrictions imposed establish conditions under which such a discrepancy is possible. Nevertheless, the adoption of these assumptions entails that the observed combinations of average land price and quantity traded can be plotted and the [statistical] relationship between these two variables estimated econometrically. The similarities of the Traill model and the early American attempts are thus apparent, in that in addition to the use of farm incomes, the model assumes a perfectly inelastic supply curve of reservation prices, and hence ignores this side of the market entailing that the price-transactions combinations that are observed are believed to specify the loci of a demand curve.

(b) Specification of the Empirical Model

So it is evident that Traill outlined an essentially demand orientated relationship between average price and total area of land traded. Other explanatory variables of land price determination have the effect of shifting the demand function up or down in a systematic fashion. Traill (1980) identifies the following as having an important and quantifiable affect on land prices.

(i) The current and expected profitability of farming (represented as net farming income and growth of net farm income),

(ii) The opportunity cost of capital, (measured by the Agricultural Mortgage Corporation loan rate),

(iii) The expected capital gains from land purchase, (proxied by land price changes in previous years) and,

(iv) A dummy variable for accession to the European Economic Community.

Note that all value-based data used in the estimation are expressed in current prices (*i.e.*nominal terms). Clearly, this will influence the estimation and quality of inference considerably as will be discussed later. The first two of these variables form an expression in the model which approximates to the first term in equation (V.1), in that, an increase in expected farming income or a decrease in the interest rate will increase the expected price of land.

The model also employs a variable to account for capital gains in agricultural land values [$CAPGAIN_t$]. In its most simple form, this variable may be interpreted as representing an attempt to 'explain' expected land price movements that are not strictly due to land's expected agricultural income earning potential, (and accounted for in the present value expression). Clearly, the inclusion of this variable represents a marked departure from the theoretical model outlined above, since, in that framework all returns to landownership, (pecuniary and 'non-pecuniary), are incorporated in the present value formula. Hence, this variable is a rather *ad hoc* addition to the model's specification. However, given that published figures of net farming income do not include any speculative element or encompass all the 'returns' that landownership bestows, a simple present value formulation, (using farming income) may well be inadequate as the sole determinant of land prices. Traill (1979) justifies the capital gains variable on the grounds that,

> '. . . some people may have expectations of land price changes that are inconsistent with their expectations of farm income growth'. p.219

Several authors have emphasized the importance of capital gains as a motivation in land acquisitions, particularly during inflationary periods. Moreover, it is suggested that the expectation of future capital gains is in itself prophetic,

> '. . . expectations of this nature tend to be self-fulfilling. If enough key people expect land prices to rise, they will do so. The fact that they do reinforces the expectations of future rises'. Currie (1976) p.308

This variable also represents the 'dynamic' element of the model: specifically, Traill hypothesizes that it is lagged land prices that form the basis of the expectations formation, and that these contribute to the determination of current land prices. Owing to the increased amplitude of land price movements after 1972 the definition of this variable was altered to reflect the apparent change in the way expectations in the land market were formed. Prior to 1972 a three period moving average of past changes in land prices was employed, although this was replaced by a one period change in land prices for years after 1972, reflecting the increased volatility of expectations concerning land prices.

Other factors which are often reported as being of potential importance in the determination of land prices, such as capital taxation, technological change and attitudes to risk were excluded from Traill's original model either because they were difficult to quantify or because their inclusion produced unfavourable statistical results.

Hence, the form of the estimated model can be summarized as,

$$P_t = f\,[T_t, PV_t, CAPGAIN_t, D_t\,]$$

where, P_t is price of land; T_t is number of transactions; PV_t is expected farming income in the current period; $CAPGAIN_t$ is expected capital gains in the current period; and D_t is a dummy variable.

(c) Estimation and Examination of the Model

The model was estimated using a weighted least squares procedure to correct for heteroscedasticity, under the assumption that the residual error variance is proportional to the magnitude of the variable PV_t. As a result of using this remedial procedure R^2 tends to be overstated, consequently, the correlation coefficient (r^2) is presented indicating the goodness of fit between actual and estimated land prices.

Equation V.2 of Table V.1 is the final form of the model estimated by Traill (1980)[6]. The statistical results indicate that the model simulates movements in land prices over the sample quite satisfactorily; r^2 suggests a high degree of correlation between fitted and actual land prices and the t statistics are all statistically significant at the 5 per cent level. Appropriate diagnostic tests performed on the regression for heteroskedasticity and autocorrelation do not indicate either of these econometric problems, however, there is considerable evidence of multicollinearity, a feature not noted in Traill (1980). Because of this, results of the two test procedures used are detailed in Appendix I. Although these tests are by no means conclusive, their results do indicate a statistically significant degree of correlation among the regressors in the land price model, particularly between PV_t and $AREASOLD_t$. This inference is not entirely surprising given the strong statistical correlation between the number of transactions ($AREASOLD_t$) and the price of land. Noting that, (in theory at least) the price of land is the present value of the discounted stream of net returns to land, and that this is approximated by the PV_t variable, then one may reasonably expect PV_t and $AREASOLD_t$ to also exhibit collinearity.

Another potential source of collinearity is Traill's use of variables valued at current

6 This model is a replication of the Traill (1980) equation. The coefficients of the Traill (1980) model are ; 60.04, 11.13, 0.83, -0.19, and 89.25 Differences that exist are assumed to represent rounding errors.

prices. Because inflation will tend to trend all value-based series in a similar fashion, not only will the use of nominal series increase the explanatory power of the regression as a whole, but it will also render the PV_t and $CAPGAIN_t$ variables collinear. Although the effect of inflation is of minor importance during the early part of the sample period, its trending effect will undoubtably become more serious, and hence represent a more disquieting aspect of the model during the high rates of inflation experienced in the mid 1970s. Because collinearity will tend to produce high standard errors and hence low t statistics, its presence will increase the likelihood of accepting a false null hypothesis and may thus lead the analyst to drop important variables on the basis of statistical insignificance. The fact that the coefficients in the model are all statistically significant, may lead one to assume that the deleterious effects of multicollinearity are irrelevant, in this instance. This however is not so, for the effects of multicollinearity may well have influenced the original specification of the model[7]. Hence, although this point is essentially conjectural, it should be noted that omission of important variables constitutes a specification error and may seriously bias the estimation of the remaining variables; over or under estimating their 'true' values.

In order to gain some insight into the explanatory power of the model it is worthwhile examining the precise specification of the variables used to determine land prices. Recall that the PV_t variable approximates to the first term in the present value expression (V.1) : the numerator is the product of current income and the expected growth in farming income and hence establishes an expected net farm income at the end of time period t. The denominator is simply an appropriate measure of the opportunity cost of capital by which future income should be discounted to obtain its present value. With an infinite time horizon, naive expectations of income growth and a constant rate of discount, (as depicted in the simple theoretical model), the formula collapses to,

$$\frac{E_t\left[R_t\right]}{r} \qquad \text{(V.6)}$$

which represents the present value of an annuity. Traill adopts a slightly different specification by disregarding this naive expectations hypothesis and substitutes it for one in which expected future farming income need not be constant. Although this

7 For example, certain variables that may be considered to be of some importance, such as technological change and a discounted version of the capital gains variable, (which were excluded from the final model on the grounds of insignificant t values and/or because they did not improve the explanatory power of the land price equation), may have been dropped from the model on the basis of such 'false' test statisitics.

formulation is more appealing, it entails the inclusion of only one expected future value into the computation of the present value expression, [as opposed to the infinite income stream depicted in equation (V.6) above]. This is a necessary restriction because for any year where the rate of farm income growth exceeds the opportunity cost of capital, the stream of expected future income will sum to infinity[8]. Thus, although PV_t is akin to the theoretical expression (V.6) it is not identical to it. However, the results do compare favourably with those produced with the theoretical model. Using mean interest rates and expected growth rates over the sample period, (7.8% and 6.5% respectively) and correcting for the the downward bias created by use of UK farming income figures (instead of England and Wales), the long run effect of a £1 per acre increase in UK farming income, (*ceteris paribus*), is an increase in average land price in England and Wales of £13.73. The equivalent figure derived from (V.6) is £12.82.

A further comment concerns the modelling of average land prices published by the Inland Revenue, for which there is a time lag between the date at which a transaction actually takes place and the year in which it is included in the statistics compiled by the authorities. Because this time-lag is generally believed to be approximately nine months in duration, the average land price reported by the Inland Revenue in the 12 months upto 31st September in calendar year t+1 will more accurately reflect the land prices prevailing in the 12 months upto 31st December in calendar year t. This lag does not present any major problems providing that data on the other variables are adjusted to accommodate for it. However, this adjustment is absent from the model estimated by Traill (1979, 1980) and hence the timing of the variables used is inappropriate.[9]

Table V.1 : Summary Regression Results of the Land Price Models

8 For a mathematical proof see Copeland and Weston (1988) pp.847-848.

9 This can be illustrated as follows. Noting that an expected net income received at the beginning of year t+1 has a present value (as is assumed here) equivalent to the discounted value of the product of current farm income (i.e. at the beginning of year t) and the expected rate of farm income growth between t and t+1, then, in order to use this expression to determine the average land price for the year t, a figure for net farming income at the beginning of year t is required. This will represent an initial farm income which when multiplied by the expected rate of growth will yield the expected future value in t+1. Given that farm income statistics for year t relate to the June_t - May_{t+1} year it will be inappropriate to use them in year t because land price data for year t (October_{t-1} - September_t) will actually reflect sales of land in the calendar year t-1. It would be more in the spirit of the present value framework to explain land prices published for the 12 months ending 31st September in year t, (which actually relate to the calendar year t-1), by the use farm income in the June_{t-2} - May_{t-1} year, instead of the June_{t-1} - May_t year employed in Traill (1979, 1980).

Estimated with 1945-77 Data Series

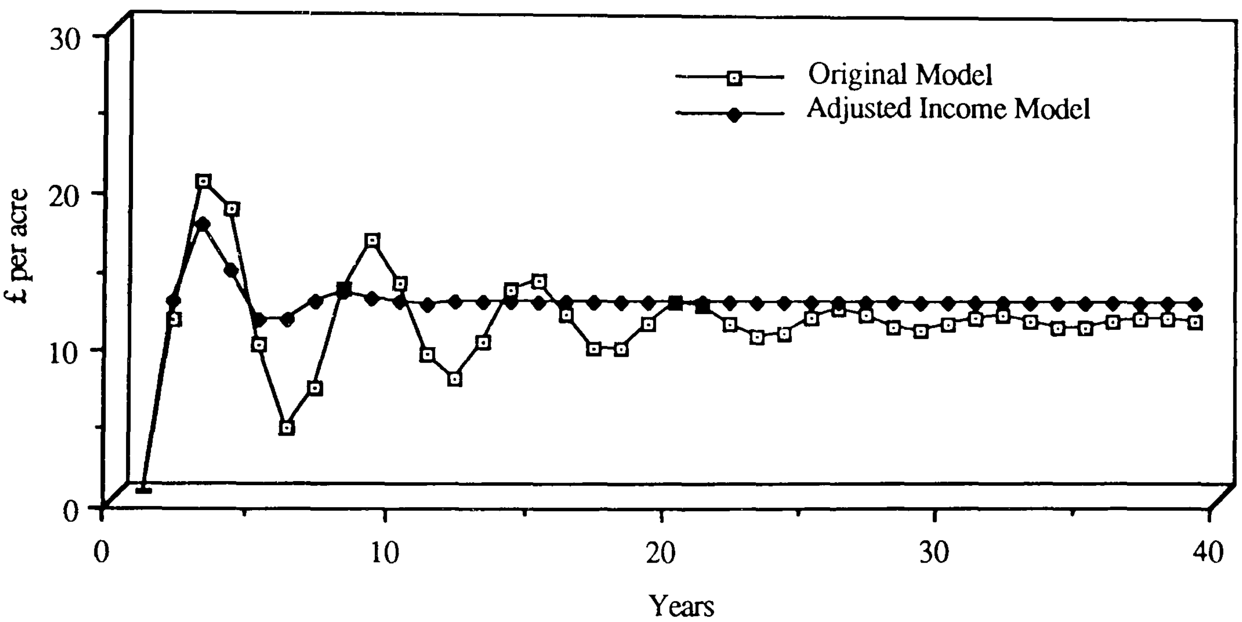
	Equation (V.2)	Equation (V.3)	Equation (V.4)	Equation (V.5)
	Nominal Terms		Real Terms	
	Original	Adjusted Income	Original	Income Adjusted
Constant	**60.20**	**103.64**	**130.39**	**145.20**
	(1.34)	(1.74)	(6.98)	(7.41)
PV_t	**11.12**	**12.38**	**3.19**	**1.57**
	(13.40)	(9.83)	(1.41)	(0.68)
$CAPGAIN_t$	**0.81**	**0.40**	**0.40**	**0.42**
	(4.96)	(1.94)	(2.37)	(2.41)
$AREASOLD_t$	**-0.19**	**-0.27**	**-0.15**	**-0.15**
	(-3.67)	(-3.96)	(-7.98)	(-7.61)
D_t	**85.21**	**137.33**	**39.67**	**44.35**
	(1.98)	(2.69)	(2.35)	(2.87)
Diagnostic Tests[10]				
r^2	0.97	0.94	0.82	0.80
Hetero'	Not Present	Present	Not Present	Present
Autocorr	Not Present	Present (negative)	Not Present	Not Present
Collinearity	Present	Present	Not Present	Not Present

All statistical tests conducted at the 5% significance level

10 Here, Hetero' denotes heteroscedasticity, Autocorr' denotes autocorrelation and Collinearity denotes multicollinearity. See Appendix I for details of these tests.

Re-estimating the model to account for this lag in land prices yields the results displayed in Table V.1 as Equation (V.3). The equation is somewhat inferior to Traill's original model in that the adjusted income model is subject to autocorrelation, heteroscedasticity and multicollinearity. The estimated coefficients however, are quite similar, with the exception of the coefficient on the capital gains variable : thus the importance of this adjustment relates to the dynamic properties of the model. Although both models are stable, in that they converge to equilibrium levels[11], the change in the value of the estimated coefficient will affect the 'transient' solution - the time-path to equilibrium. Figure V.3 illustrates the dynamic properties of the two models by simulating the effect of an increase in expected net farm income on predicted land prices in each model[12].

Figure V3 : The Dynamic Properties of Models (V.2) and (V.3)



Although the long run effect is quite similar in both models, (in that land prices stabilize at an equilibrium value about £12 per acre above the initial value), the magnitude and duration of the oscillations that characterize the path to equilibrium are quite different. The adjusted income model exhibits less pronounced oscillations and converges on an equilibrium value in around six years compared to around 35 years indicated by the original specification.

11 The condition for convergence in this instance is simply that the absolute value of the coefficient on $CAPGAIN_t$ be less than one.

12 In both models, the specification of the $CAPGAIN_t$ variable used to illustrate the time path is the one-period change in land prices *i.e.* that used by Traill for the years after 1972.

Although the inclusion of a variable for 'capital gains' may appear justifiable, the way in which the variable is constructed and employed in the model is not wholly satisfactory. Not only is the definition of the variable changed post 1972 in a rather *ad hoc* manner but more importantly, the specification of the variable itself in the estimating equation does not appear to be consistent with the theoretical framework; implying that the empirical model is misspecified. As an illustration, consider the following hypothesis of nominal land price formation in a present value framework:

$$N_t = \frac{1}{1+E_t\left[i_t\right]} E_t\left[X_t + N_{t+1}\right] \qquad \text{(V.7)}$$

where, N_t= nominal land price at the beginning of year t

X_t= nominal cash returns to land over year t accruing at the end of year t

i_t= nominal discount rate over year t.

Focussing on the income and capital gains terms, Traill's model may be described as

$$N_t = \lambda_1 \frac{E_t\left[X_t\right]}{1+E_t\left[i_t\right]} + \lambda_2 E_t\left[\Delta N_{t+1}\right] \qquad \text{(V.8)}$$

where $E_t[\Delta N_{t+1}] = E_t[N_{t+1}] - N_t$. Note that this corresponds to the post 1972 definition of $CAPGAIN_t$. A partial reconciliation between the present value rule (V.7) and the Traill model (V.8) can be achieved by rewriting (V.7) as[13]

$$N_t = \frac{1+E_t\left[i_t\right]}{E_t\left[i_t\right]}\left[\frac{E_t\left[X_t\right]}{1+E_t\left[i_t\right]}\right] + \frac{1}{1+E_t\left[i_t\right]} E_t\left[N_{t+1} - \frac{X_t}{i_t}\right] \qquad \text{(V.9)}$$

where $E_t[N_{t+1} - X_t/i_t]$ can be interpreted as the excess of expected price at t+1 over the present value of land according to its earning potential based on expected returns over period t. The term $E_t[N_{t+1}]$ reflects market fundamentals, in the sense that it incorporates expectations concerning future returns from land. However, it could also reflect any speculative element - capital gains or losses - unrelated to market fundamentals, allowing the land price to overshoot its long-run equilibrium value. In Traill's study, past capital gain is used to represent expected capital gain and this in turn might be loosely interpreted as a proxy for,

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13 This derivation utilizes

$$E_t\left[\frac{X_t}{(1+i_t)}\right] = E_t\left[\frac{i_t}{(1+i_t)}\frac{X_t}{i_t} + \frac{X_t}{i_t\,(1+i_t)} - \frac{X_t}{i_t\,(1+i_t)}\right]$$

$$= E_t\left[\frac{X_t}{i_t} - \frac{1}{(1+i_t)}\frac{X_t}{i_t}\right]$$

$$E_t\left[N_{t+1} - \frac{X_t}{i_t}\right]$$

However, the tie-up between Traill's empirical model (V.8) and the theoretical model (V.9) is incomplete for other reasons: specifically, the parameters λ_1 and λ_2 in (V.8) imply constant nominal interest rates in (V.9), whereas actual nominal interest rates changed markedly over Traill's data set.[14]

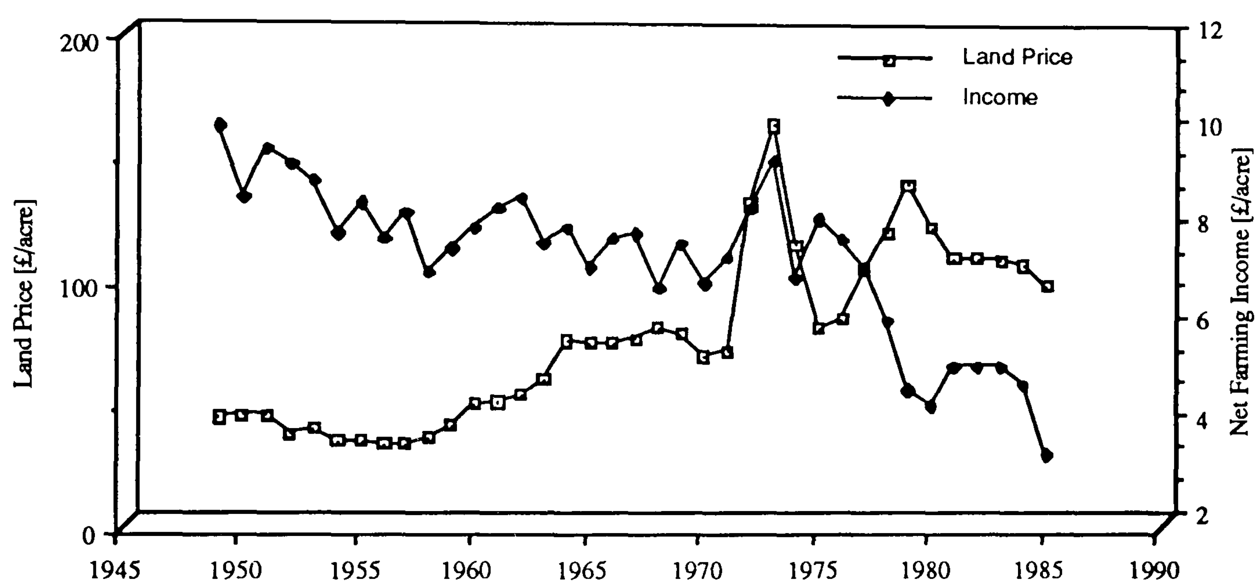
A further criticism concerns the use of net farming income as a measure of the return to land ownership. Clearly, under a pure landlord-tenant system of tenure the net return to land ownership (excluding any 'psychic utility' or non-pecuniary benefits) would simply be net rent. However, the prevalence of owner-occupation in the UK has led researchers in the past to disregard published rent figures and seek some other measure of the returns to holding agricultural land, which can then be used in a present value expression. However, figures published for farming income are far from satisfactory because they represent the return to labour and physical assets employed in production (such as machinery and livestock), and not the return to land itself. In fact, (as Traill acknowledges) farming income explicitly excludes the return to land and buildings paid in the form of rent. Thus, it is important to recognise that changes in farming income will only affect land prices to the extent that changes in farming income affect farm rent and its owner-occupied 'equivalent'. The distinction between the profitabilty of farming (as represented by farming income figures) and the profitability of land ownership is an important one, not least because there appears to be a weak *negative* correlation between farming income and land prices in real terms, as illustrated by Figure V.4.

Thus, given that as a measure of the returns to land ownership published figures for farming income are less than ideal, the statistical significance of the PV variable - which employs farming income data to explain land price movements - is curious. A credible explanation may be attributed to the effect of inflation. In Traill's Model both the farming income and land price series are valued at current prices. Because of this, the rate of inflation will link these variables to some degree, and consequently have a systematic influence in the regression. In order to assess the trending effect of inflation in the model, equations (V.2) and (V.3) were re-estimated using deflated series, and the results are displayed as equations (V.4) and (V.5) in Table V.1[15].

14 Furthermore, solving (V.9) for i_t using the coefficients estimated in (V.2) yields inconsistent results. Specifically, the coefficients on PV_t and $CAPGAIN_t$ should imply the same expected discount rate, yet we obtain rates of 9.88% and 23.16% using the coefficients estimated in (V.2).

The results of the deflation exercise are interesting although not entirely surprising given the foregoing discussion. The elimination of the 'trending' of inflation lowers the degree of association between actual and fitted land prices from 97% to 82% and remedies the multicollinearity problem highlighted in the current price models. More importantly however, the present value variable PV_t is no longer statistically significant at the 5% level[16].

Figure 4 : Average Land Prices in England and Wales and UK Net Farming Income per acre of Crops and Grass in Real Terms (Base year = 1945)



This evidence casts some doubt over the efficacy of net farming income data for the determination of land prices in the UK and suggests that the systematic relationship between these variables is due to the trending effect of inflation and not to any causal relationship, (as was implied by Traill) .

Although Traill's land price model performs well statistically over the 1945-77 sample period, certain features of the model are disquieting from a theoretical or methodological standpoint. These features are summarized as follows.

(i) On the strength of a high statistical correlation between land area traded and average land price Traill presents a model in which price is a function of area

15 The data were deflated by the GDP deflator , (base year 1945).

16 The estimated coefficient on PV_t in equations (V.4) and (V.5) are statistically significant at 20% and 50% levels respectively.

traded, yet [theoretically] it can be shown that these two variables are independent of each other. Because correlation does not infer causality the fundamental relationship on which the model is built may well be a spurious one.

(ii) In order to be consistent with the spirit of the present value framework the net farming income series must be adjusted to accommodate for the lag in the published land price series. Although Traill's model has not done so, making the necessary changes does not affect the statistical significance of the model, but it does alter its dynamic response quite significantly. In effect, expectations have a far less pronounced effect on land prices in the adjusted model.

(iii) The specification of the capital gains variable appears to be inconsistent with that derived from the theoretical framework, and hence implies a rather *ad hoc* formulation of the model. Furthermore, this aspect of the model is compounded by the switch in the expectations mechansim during the sample period.

(iv) Because net farming income is a poor indicator of the returns to land ownership, the inclusion of this variable as a determinant of land prices within a present value framework seems inappropriate. This conclusion is corroborated by an apparent negative correlation between land prices and net farming income using deflated series.

(v) The use of monetary series valued at current prices is another questionable feature of the model. Removal of the trending effect of inflation reduces the model's explanatory power considerably and invalidates the inclusion of the present value variable - a variable which assumed crucial importance in the original model. This result also questions the efficacy of net farming income as a measure of the returns to land ownership, as indicated in point (iv) above.

V.(iv): Re-estimation of the Traill Model Over an Enlarged Sample Period

In light of the criticisms presented in the preceding section Traill's land price model is re-estimated using additional data. Table V.2 comprises summary statistics of the four models of Table V.1 re-estimated using an enlarged (1945-85) sample. Referring to the models expressed in current prices, [equations (V.10) and (V.11)] there appear to be three important consequences of the updating procedure. These are summarized as follows.

(i) Although the correlation coefficient (r^2) has fallen slightly it is still relatively high indicating that fitted land prices accord reasonably well with actual values over the enlarged sample period. However, comparison of equations (V.2) and (V.3) with their updated counterparts indicates that re-estimation of the models over an enlarged sample period has resulted in a substantial change in the estimated values of the parameters[17]. In order to test whether the estimated parameters of each model have shifted through time, a Chow (1960) test for structural stability was conducted on the updated models and the results indicate that structural change has occurred; *i.e.* parameters estimated over the 1949-77 period no longer hold over the 1949-85 sample period.

(ii) An important consequence of the structural change relates to the dynamic property of the models. Specifically, the coefficient on $CAPGAIN_t$ in equations (V.10) and (V.11) exceeds unity and hence each model will exhibit unstable dynamics. Thus, given an initial increase in net farm income for example, land prices will no longer converge to a new equilibrium, but 'explode' in ever increasing oscillations around that equilibrium. The unstable dynamic responses of equations (V.10) and (V.11) are illustrated in Figures V.5 and V.6

(iii) In both Equations (V.10) and (V.11) the coefficients on the area of land traded and the dummy variable are statistically insignificant and the sign of the latter runs contrary to *a priori* expectations. Such perverse results are likely to be a consequence of the multicollinearity present in the data, of which a classic symptom is 'high r^2 and low t statistics'.

(iv) Referring to equations (V.12) and (V.13), which represent the enlarged sample counterparts of equations (V.4) and (V.5), it is clear that although r^2 has remained largely unchanged, coefficients estimated from the original sample period are no longer appropriate to the extended sample period, as indicated by the Chow test. This structural instability is most conspicuous in the present

17 Parameter estimates tend to be sensitive to the addition of new data in the presence of multi-collinearity and autocorrelation. Both these features are present in the updated models.

Figure 5: The Dynamic Response of the Updated Model Equation (V.10)

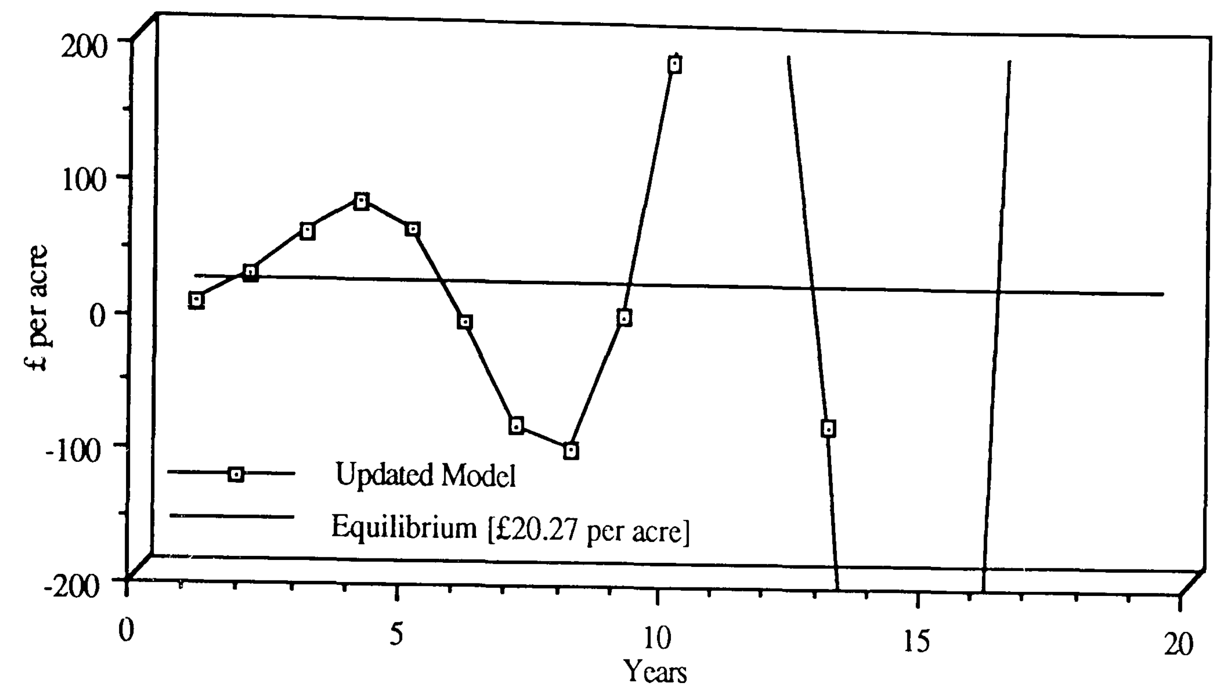
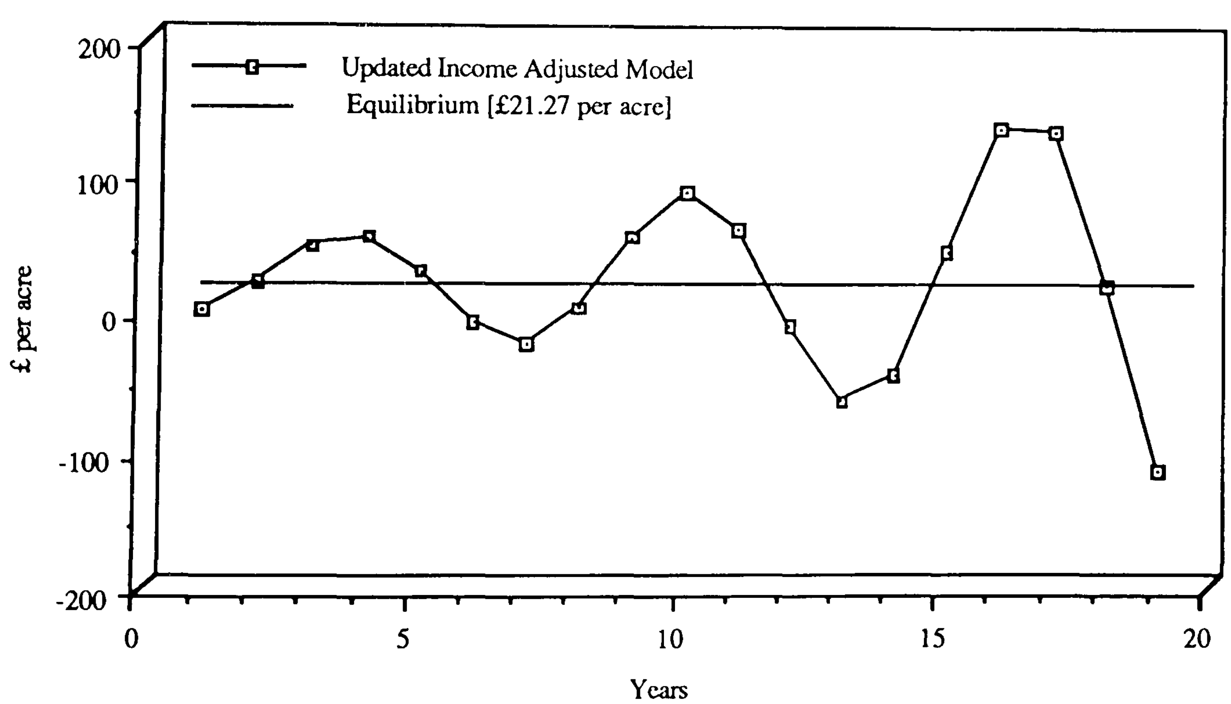


Figure V.6: The Dynamic Response of the Updated Income Adjusted ModelEquation (V.11)



value variable, which assumes a negative coefficient in both the updated models. Although this may be due to the multicollinearity that is still present in these models it is equally as likely that this coefficient is simply picking up the weak negative correlation between real farm incomes and real land prices suggested by Figure V.4.

Table V.2 : Summary Regression Results of the Land Price Models Estimated with 1945-85 Data Series

	Equation (V.10)	Equation (V.11)	Equation (V.12)	Equation (V.13)
	Nominal Terms		Real Terms	
	Updated	Adjusted Income	Updated	Income Adjusted
Constant	**-161.40**	**-144.58**	**173.06**	**181.32**
	(-0.90)	(-0.99)	(16.45)	(16.56)
PV_t	**20.27**	**21.27**	**-1.69**	**-2.54**
	(8.15)	(10.02)	(-0.93)	(-1.36)
$CAPGAIN_t$	**1.64**	**1.23**	**0.48**	**0.51**
	(3.50)	(3.19)	(2.56)	(2.94)
$AREASOLD_t$	**-0.08**	**-0.11**	**-0.15**	**-0.15**
	(-0.37)	(-0.62)	(-6.67)	(-7.09)
D_t	**-45.48**	**90.88**	**44.46**	**39.26**
	(-0.25)	(0.67)	(2.11)	(2.26)
Diagnostic Tests[18]				
r^2	0.85	0.89	0.81	0.81
Hetero'	Not Present	Present	Present	Not Present
Autocorr'	Present (Positive)	Present	Not Present	Present
Collinearity	Present	Present	Present	Present
Chow Test	Str. Change	Str. Change	Str. Change	Str Change

All statistical tests conducted at the 5% level of significance

18 Here, Hetero' denotes heteroscedasticity, Autocorr' denotes autocorrelation and Collinearity denotes multicollinearity. See Appendix I for details of these tests.

V.(iv) Conclusion

From this discussion it is apparent that econometric models of land prices on both sides of the Atlantic have encountered similar problems and are guilty of similar inadequacies. This is due to the relatively unstructured approach that these studies have adopted, with little attention being paid to the underlying economic rationale of the final estimating equation. Not surprisingly these models have broken down when re-estimated over longer time series. The Traill model is a case in point since it no longer captures the causal behavioural relationships once proposed and employs a specification of the market that is theoretically and methodoligically suspect. As demonstrated, the 'high' performance of the model is attributable to the systematic effect of inflation correlating the value-based variables in the regression and the strong, albeit spurious, correlation between transactions and land prices. The most recent models of land prices have attempted to resolve past deficiencies by adopting a logically consistent capital asset pricing framework similar to that discussed in previous Chapters. However, to the extent that all econometric models suffer from a lack of hindsight, *ex post* criticism is unavoidable, although new developments in econometric methodology may be of considerable assistance in this area. Having established the theoretical underpinnings of the present value framework, an empirical model that wishes to supplant the Traill model should also meet the requirements of this new econometric methodology and thus it is to these advances in econometrics that attention focuses in the Chapters that follow.

Appendix V.1

(a) Results from Two Diagnostic Tests for Multicollinearity on Traill's Original Land Price Model, Equation (V.2)

(i) [Zero Order] Correlation Matrix of Explanatory Variables

	PV_t	$CAPGAIN_t$	$AREASOLD_t$	D_t
PV_t	1			
$CAPGAIN_t$	0.156	1		
$AREASOLD_t$	-0.620	-0.421	1	
D_t	0.178	-0.016	-0.195	1

(ii) Farrar-Glauber Test

For the model,

$$Y_t = \sum_{j=1}^{k} X_{tj}\beta_j + u_t \qquad \text{(V.A1)}$$

regress each explanatory variable from (V.A1) on the remaining explanatory variables,

$$X_{tj} = \sum_{j=1}^{k-1} X_{tj}\ \beta_j\ + u_t$$

where $i \neq j$ for all $i = 1, \ldots k$.

Forming the hypotheses,

H_0: $\beta_j = 0$ for all j (no linear dependence)

H_1: $\beta_j \neq 0$ for all j (linear dependence)

the following F tests are performed, where the 5% critical value of F (3, 22) = 3.05

(a) $PV_t = f\ \{CAPGAIN_t, AREASOLD_t, D_t\ \}$ F: 5.16

(b) $CAPGAIN_t = f\ \{PV_t, AREASOLD_t, D_t\ \}$ F: 2.63

(c) $AREASOLD_t = f\ \{CAPGAIN_t, PV_t, D_t\ \}$ F: 10.43

As H_1 cannot be rejected in (a) and (c) at the 5% level of significance there is evidence that the explanatory variables have a systematic effect on the dependent variable in these regressions, implying they will be co-linear in equation (V.2).

(ii) Diagnostic Tests Used in Tables V.1 and V.2

The results reported are based on results obtained from the following diagnostic tests :

(1) Heteroscedasticity : For the auxillary regression,

$$e_t^2 = \text{constant} + \alpha \hat{P}_t^2$$

where $\hat{P}_t^2$ is the estimated land price squared.

$H_0 : \alpha = 0$ against $H_1 : \alpha \neq 0$

(2) Multicollinearity : a) Zero order correlation of explanatory variables.

b) Farrar Glauber (1967) Test.

(3) Autocorrelation : Because of the implicit presence of lagged dependent variables incorporated in the regressor $CAPGAIN_t$, Durbin-Watson's d statistic and Durbin's h statistic are not admissable. The test used here is based on Godfrey (1978) and is as follows. For the model,

$$Y_t = \sum_{j=1}^{k} X_{tj} \beta_j + \varepsilon_t$$

apply OLS and obtain the residuals $\hat{e}_t$ and form the regression

$$\tilde{Y}_t = \sum_{j=1}^{k} X_{tj} \tilde{\beta}_j + \alpha \hat{e}_{t-1} + \omega_t$$

where ω_t is a random error term and conduct a t test on $H_0 : \alpha = 0$ against $H_1 : \alpha \neq 0$

(iv) Structural Instability : The Chow (1960) test is conducted as follows,

For the [restricted] model,

$$Y_t = \sum_{j=1}^{k} X_{tj} \beta_j + \varepsilon_t$$

denote the [restricted] residual sum of squares as RSSR.

The unrestricted form is,

$$Y_t = \sum_{j=1}^{k} X_{tj} \beta_j + X_{tj} \gamma_j D_t + \varepsilon_t$$

where $t = 1, \ldots n$; $m < n$; $D_t = 0$ if $t \leq m$, $D_t = 1$ if $t > m$ and the [unrestricted] sum of squared residuals from this regression is denoted as USSR.

Conducting an F- test on $H_0 : \gamma_j = 0$ (no structural change)

$H_1 : \gamma_j \neq 0$ (structural change)

where the test statistic is

$$F = \frac{(RSSR - RSSU)/k}{(RSSU/(n - 2k))}$$

which is assumed to follow an F distribution with $(k,n\text{-}2k)$ degrees of freedom if H_0 is true.

Chapter VI
Stationary Processes in Time Series Analysis

VI. (i) Introduction

In recent years considerable attention has been paid to the time series properties of the empirical series used in statistical analysis. To an extent, this interest stems from a realisation that whilst the overwhelming majority of statistical techniques commonly used have been developed for a class of process with specific properties, most of the variables employed in empirical work have not exhibited such properties. Generally speaking, econometric techniques and the theoretical results that underpin them have been developed for a class of process characterised by parameters, (namely the mean, variance and covariance) that are invariant over time. This requirement is a necessary condition for the estimation of both pure time-series (ARIMA) and Gaussian (regression) type models since each method furnishes *fixed* estimates of the parameters of interest. In a situation where these parameters are not fixed, but vary over time, the estimation of fixed coefficients from a sample of observations, whether as a means of simulating the underlying relationship, testing economic hypotheses or forecasting future values, is seriously corrupted.

The use of time-dependent series violates important assumptions upon which estimation and inference are based and may lead the analyst to identify spurious relationships between uncorrelated variables. Whilst the discrepancy between theory and practice has been well known since the advent of applied econometrics, this important issue has only been confronted quite recently due to the proliferation of empirical work, (particularly involving time series data which is prone to time dependence) that has inevitably rendered its consequences more widespread.

In order for valid inferences to be made from time series data it is necessary to demonstrate that each series employed is described by parameters that are independent of time and it has become best practice in the recent literature to report such findings prior to any econometric analysis. The issue of time independence is called *stationarity* and is the focus of this Chapter, which is arranged as follows. Section (ii) describes stationarity and the two types of stationary processes that have been proposed in the literature. In Section (iii) a framework for testing for stationarity is presented and Section (iv) comprises a digression on variance stabilization in empirical time series. The empirical results are presented in Section (v) and a summary of the investigation is given in Section (vi). For convenience, tabulations of relevant critical values of the unit root tests are given in Appendix I.

VI.(ii) Stationarity and the Properties of a Stationary Process[1]

By means of introduction let us define a *stationary* time series to be one that has a constant mean and variance, and an autocovariance that depends on the distance apart in time but not on the position in time. Further, a series Y_t is said to *integrated of order d* if the series becomes stationary after differencing *d* times. Such a series is denoted $Y_t \sim I(d)$. Consequently, if Y_t is stationary after first differencing (*i.e.* $Y_t - Y_{t-1} = \Delta Y_t$ is stationary) then we may denote $Y_t \sim I(1)$ and $\Delta Y_t \sim I(0)$. Whilst few economic time series are stationary, most can be converted into series that are by application of certain transformations that render the mean, variance and covariance time invariant.

In order to clarify these statements, let Y_t be a set of observations, $Y_1, Y_2, \ldots, Y_n$ where $t = 1, 2, , n$ which represents a single realization of continuous random variables from a stochastic data generating process. The series Y_t may be thought of as being generated by a set of jointly distributed random variables such that any one realization of Y_t represents just one outcome of an infinite number of possibilities of the joint probability density function $p(Y_1, Y_2, \ldots, Y_n)$.[2] A future value of Y_t (say Y_{t+1}) can similarly be viewed as being generated by the conditional probability density function given the preceding observations of the series Y_t.

Now, the series Y_t is said to be *strictly* stationary if the joint distribution of the set of random variables is unaffected by the origin or starting date of the series, so that the joint probability distribution of the set of random variables $Y_{t_1}, Y_{t_2}, \ldots Y_{t_k}$, is the same as $Y_{t_1+T}, Y_{t_2+T}, \ldots, Y_{t_k+T}$, for any $t_1, t_2, \ldots, t_k$, T or k. In essence, strict stationarity requires the joint and conditional probability distributions to be stationary. This however is overly rigorous and for practical purposes may be replaced by *weak (covariance)* stationarity which simply requires that the parameters that describe any particular realization of Y_t are invariant to their position in time: *viz*, weak stationarity

1 The following explanation of stationarity is applicable to the analysis of annual time series such as those used in this study. Where quarterly or monthly data are employed seasonality should be taken into account in assessing the order of integration of a series and a discussion of integration tests using seasonal data may be found in Dolado *et al.* (1990).

2 The relationship between the stochastic data generating process and a particular realisation (Y_t) is analogous to that between population and sample in classical statistics.

implies that the series Y_t is characterised by a constant mean (μ) and variance (σ^2) throughout time, with autocovariance (γ_k) and hence autocorrelations (τ_k) that depend only on the lag (or distance apart in time) k.[3] More formally, a series is weakly stationary if the following conditions hold for all t

$$E[Y_t] = \mu \quad \text{(VI.1)}$$

$$\text{var}(Y_t) = E[(Y_t - \mu)^2] = \sigma^2 \quad \text{(VI.2)}$$

$$\text{cov}(Y, Y_{t-k}) = E[(Y_t - \mu)(Y_{t-k} - \mu)] = \gamma_k \quad \text{(VI.3)}$$

$$\tau_k = \frac{\gamma_k}{\gamma_0} = \frac{\text{cov}(Y_t, Y_{t-k})}{\sqrt{\text{var}(Y_t)\ \text{var}(Y_{t-k})}} \quad \text{(VI.4)}$$

Consequently, each realization of Y_t will have the same probability of occurrence and we may derive estimates of these quantities using the one realisation at our disposal, that being the sample data. These estimates are given by

$$\hat{\mu} = \bar{Y} = n^{-1}\sum_{t=1}^{n} Y_t \quad \text{(VI.5)}$$

$$\hat{\sigma}^2 = n^{-1}\sum_{t=1}^{n}(Y_t - \bar{Y})^2 \quad \text{(VI.6)}$$

$$\hat{\gamma}_k = cov_k = n^{-1}\sum_{t=1}^{n}(Y_t - \bar{Y})(Y_{t-k} - \bar{Y}) \quad \text{(VI.7)}$$

$$\hat{\tau}_k = \frac{\hat{\gamma}_k}{\hat{\gamma}_0} \quad \text{(VI.8)}$$

The most simple example of a stationary stochastic process is the trivial case comprising a series of uncorrelated random variables with constant mean and variance.[4] Because all observations in the series are uncorrelated, such a series, termed *white noise* (ε_t) generates (approximately) zero autocovariances for all lags $k > 0$. Consequently, the autocorrelation function (ACF) is characterised by the value of 1 at zero lag and zero thereafter and the series is summarized as,

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3 Note however that since a normal distribution is completely characterized by its mean m and s^2 then if a series is weakly stationary and the random variables distributed normally the process is also strictly stationary.

4 The mean of a white noise process may assume any real number; however, it is assumed to be zero here for simplicity and implies no loss of generality.

$E[\varepsilon_t] = 0$

$E[\varepsilon_t,\varepsilon_{t-k}] = \sigma^2$ when $k = 0$; 0 when $k \neq 0$ and hence,

$\tau_k = \gamma_k/\gamma_0 = 1$ when $k = 0$; 0 when $k \neq 0$.

The simplest example of a non-stationary stochastic process is the first order autoregression in which the autoregressive coefficient, ϕ is equal to unity. Such a series is called a *random walk* process and takes the form,

$$Y_t = \phi\, Y_{t-1} + \varepsilon_t \qquad \text{(VI.9)}$$

$$t = 1,2,\ldots, n\ ;\ \varepsilon_t \sim \text{iid}(0,\sigma^2)$$

We will examine (VI.9) in some detail in order to obtain a handle on non-stationary processes *per se*. Testing for stationarity in (VI.9) simply involves testing hypotheses concerning the value of the autoregressive parameter ϕ. Providing the process, (whilst observed at t) actually begun at some point in the distant past, a sufficient condition for stationarity in the first order autoregressive {hereafter AR(1)} case is simply, $|\phi| < 1$.[5] This may be shown by performing successive substitutions of lagged values of Y_t into (VI.9) yielding

$$Y_t = \phi^n Y_{t-n} + \sum_{i=0}^{n-1} \phi^i \varepsilon_{t-i} \qquad \text{(VI.10)}$$

If the process began in the distant past (*i.e.* n tends to infinity) then the first term in (VI.10) is negligible, hence

$$Y_t = \sum_{i=0}^{\infty} \phi^i \varepsilon_{t-i}$$

where the mean is given by its expected value,

$$E[Y_t] = E\left[\sum_{i=0}^{\infty} \phi^i \varepsilon_{t-i}\right] = 0$$

and variance by,

$$E[Y_t^2] = E\left[\sum_{i=0}^{\infty} \phi^i \varepsilon_{t-i}\right]^2 = \sum_{i=0}^{\infty} \phi^{2i} E\left[\varepsilon_{t-i}^2\right] = \sigma^2 \sum_{i=0}^{\infty} \phi^{2i} \qquad \text{(VI.11)}$$

When the AR(1) process is characterised by $|\phi| < 1$ the expected value of Y_t is zero for all t with a finite variance independent of t since summing the squared coefficients

5 Note here that any finite MA process is always stationary. See Harvey (1981) pp.21-53 for the conditions of stationarity in AR(p), and ARMA(p,q) processes.

in (VI.11) as a geometric progression yields ,

$$\sigma^2 \sum_{i=0}^{\infty} \phi^{2i} = \frac{\sigma^2}{(1-\sigma^2)}$$

and thus the variance is time invariant. The autocovariance at lag k is also independent of t if $|\phi| < 1$ since setting $i = k$ gives,

$$\gamma_k = \mathrm{E}(Y_t, Y_{t-k}) = \mathrm{E}\left[\left(\phi^k Y_{t-k} + \sum_{i=0}^{k-1} \phi^i \varepsilon_{t-i}\right) Y_{t-k}\right]$$

which collapses to

$$\gamma_k = \phi^k \mathrm{E}\left[Y_{t-k}^2\right] = \phi^k \sigma^2$$

because $\varepsilon_t, \ldots \varepsilon_{t-k+1}$ are all uncorrelated with Y_{t-k}. It is thus clear that the autocovariances depend only upon the distance apart in time (k) and not time itself.

In contrast, when $|\phi| = 1$, the mean of the series becomes

$$\mathrm{E}[Y_t] = \mathrm{E}\left[\sum_{i=0}^{\infty} \phi^i \varepsilon_{t-i}\right] + \mathrm{E}\left[\phi^i Y_{t-i}\right] = Y_{t-\infty}$$

which although constant, depends on the starting value of the series in t-∞. More critically, the series now has infinite variance since (VI.11) is obviously an infinite quantity. When $|\phi| > 1$, the mean and variance of the series grow exponentially through time and hence in the limit are also infinite quantities.

VI.(iii). Trend and Difference Stationary Processes

Having reviewed the properties of these simple stationary time series it should be apparent that few economic series actually exhibit such properties . Indeed, the trends and cycles observed in economic time series exemplify non-stationary behaviour, although in almost all cases stationarity may be induced by application of an appropriate transformation. What form the transformation takes critically depends on how the non-stationarity is generated. Nelson and Plosser (1982) identify two classes of non-stationary processes: the trend stationary (TS) process and the difference stationary (DS) process. While both exhibit behaviour that is virtually indistinguishable by casual inspection their properties are quite distinct and the implications of incorrectly identifying the process generating a time series can, in many cases, be quite serious.

A series rendered stationary by differencing such as,

$$Y_t = \alpha + Y_{t-1} + \varepsilon_t \tag{VI.12}$$

where ε_t is iid$(0,\sigma_\varepsilon^2)$ is an example of a *difference stationary process*, (DSP) whilst one that requires *detrending* to achieve stationarity such as,

$$Y_t = \alpha + \beta t + \varepsilon_t \tag{VI.13}$$

is a *trend stationary process*, (TSP). Note that in the DSP case it is the first difference of the variable that is stationary ; whereas it is the deviations from a deterministic function of time (here a linear trend) that is stationary in a TSP. The similarity of the two models can be made apparent by accumulating changes in Y_t using (VI.12) from any historical value (say Y_0). This yields,

$$Y_t = Y_0 + \alpha t + \sum_{i=1}^{t} \varepsilon_i \tag{VI.14}$$

which does not appear to be vastly different from (VI.13). However, two important differences emerge from a comparison of (VI.13) and (VI.14). First, the intercept in (VI.14) is not a fixed number but a function of the historical past. Second, it is the deviations from trend in (VI.13) that are stationary whereas in (VI.14) these deviations from trend are accumulations of stationary changes - and hence non-stationary. In essence, trend stationary processes are fundamentally deterministic whereas difference stationary processes are purely stochastic although telling the difference between the two types of non-stationarity by 'eyeballing' is virtually impossible, particularly in small samples.

When attempting to obtain a stationary series from a non-stationary series, it is important to know the type of non-stationarity that is present since each requires a distinct transformation. For example, differencing a TSP will produce an over-parameterised and misspecified model, since first differencing the TSP shown in (VI.13) will induce serial correlation and thus further manipulation is required to achieve stationarity. . However, the implications of detrending a DSP are more serious and in practice, far more common, since detrending is the usual remedy employed in series that give the appearance of trend, as most economic series do. Indeed, Nelson and Plosser (1982) found that twelve out of the fourteen series they considered for the US economy were difference stationary processes, yet time trends were frequently employed in published work that used those series. Nelson and Kang (1981, 1984) analyse the effects of including a trend in a series that is actually difference stationary and the following points are particularly worthy of note. First, conventional testing leads to highly spurious inference : assuming Y_t is generated by a random walk process (*i.e.* is a DSP) then a standard t test of the significance of the trend variable in

(VI.13) will incorrectly reject the null (β = 0) 87% of the time. Consequently, standard tests will suggest the use of time trends even when they play no role in explaining the behaviour of a time series. Second, the explanatory power of regressions with time trends are artificially high. For example, the R^2 of a random walk process that is regressed solely on a time trend will lie around 44%, and will approach unity as the sample size increases if drift is present in the random walk. Coupled with the first result, this implies that time trends will invariably be used in time series regressions. Moreover, since time trends are usually employed as a proxy for such influences as technology, inferences concerning say, the rate and efficacy of technological change will be highly misleading. Furthermore, the autocorrelation function of a detrended random walk will suggest the presence of a (spurious) long cycle and in turn this may lead to completely spurious analysis of say, business cycle effects in the data. Finally, the residuals of a detrended random walk will have a variance that is only some 14% of the true stochastic variance of the series and thus seriously affect inference concerning other explanatory variables.

Consequently, incorrectly identifying the type of nonstationarity exhibited by a series has serious implications for modelling. Fortunately the testing framework outlined below incorporates tests which are able to discern the two. The essence of these tests may be summarised by considering the following. If, in the regression,

$$Y_t = \alpha + \phi Y_{t-1} + \gamma t + \varepsilon_t$$

ϕ <1 and $\gamma \neq 0$ then Y_t is trend stationary and if ϕ = 1 and γ = 0 then Y_t is difference stationary. Although there is another possible combination, *i.e.*, ϕ = 1 and $\gamma \neq 0$ this is unlikely to occur in practice, as will be discussed below.

VI.(iv). Testing for Stationarity[6]

As noted above, the AR(1) process

$$Y_t = \phi Y_{t-1} + \varepsilon_t \qquad \text{(VI.9)}$$

t=1,2,. . ., n ; ε_t iid(0,σ^2)

is stationary only when the autoregressive coefficient $|\phi| < 1$. The process will thus be non stationary for all other values of ϕ. However, the explosive behaviour implied by

6 See Dickey and Fuller (1979) and Dickey, Bell and Miller (1986) for a review of unit root tests. For a didactic account of the unit root testing procedure see Appendix A of Perman (1989).

$|\phi| > 1$ is implausible for economic time series in general and hence when testing for stationarity hypothesis tests are stated as H_0: $|\phi| = 1$ against H_1: $|\phi| < 1$. Note that if $\phi = 1$ then (VI.9) follows a random walk and is said to have a *unit root*. Consequently, testing for stationarity is simply a case of testing for the presence of a unit root. If (VI.9) has a unit root it is non stationary but its first difference,

$$\Delta Y_t = Y_t - Y_{t-1} = \varepsilon_t$$

is stationary by assumption. Expressing (VI.9) in first difference form all terms are stationary under the null and may be estimated legitimately by OLS.[7] Thus in order to test the null in (VI.9) the equation is reparamterized to yield

$$\Delta Y_t = \rho Y_{t-1} + \varepsilon_t \qquad \text{(VI.15)}$$

where $\rho = (\phi - 1)$. Consequently, testing the hypothesis that $\rho = 0$ in (VI.15) is equivalent to testing for a unit root in (VI.9). Should estimation of (VI.15) indicate that $\rho = 0$ then Y_t has a unit root, the first difference of Y_t is stationary and hence $Y_t \sim I(1)$ and $\Delta Y_t \sim I(0)$. This demonstrates the link between stationarity, unit root tests and the level of integration of a series.

(a) Informal Tests of Stationarity

A commonly used tool for identifying stationarity in a time series is the correlogram which is a visual representation of the autocorrelation function plotting $\hat{\tau}_k$ against the length of lag, k. Given that white noise comprises independently distributed random variables with zero autocovariances for $k > 0$, the correlogram will die down immediately, with autocorrelations randomly distributed around zero. In contrast, the temporal dependence that characterises a non-stationary series entails that the autocorrelation function has high values that die down only slowly as the length of lag increases, and thus the correlogram decays slowly in an almost linear fashion. Between these two extremes lie the correlograms of the stationary AR(p) and ARMA(p,q) processes. Although the form the correlogram assumes will depend on the generating process, any series that exhibits a rapidly decaying correlogram will be stationary. Whilst this is not a formal test of stationarity the autocorrelation function and correlogram are useful diagnostic tools for the detection of stationarity and are used in the empirical analysis to corroborate results from the testing framework outlined below.

In passing it should be noted that other tests of stationarity have been developed in the literature[*inter-alia* by Barlett (1946), Box and Pierce (1970) and Ljung and Box

7 This is because the standard results of regression analysis only apply to stationary processes.

(1978)], however a discussion of these tests is unwarranted due to the formal testing framework developed more recently. It will suffice here simply to mention that all these procedures attempt to test whether successive autocorrelations of the residuals in a regression such as (VI.9) are distributed as white noise.

(b) Formal Tests of Stationarity

Formal statistical tests for the detection of stationary series (commonly known in the literature as tests for unit roots) have been developed primarily by Dickey and Fuller (1979, 1981) and more recently by Phillips and Perron (1988) and Kwiatkowski, Phillips and Schmidt (1990). The appropriate test for stationarity, critically depends on the choice of

(i) maintained model
(ii) null hypothesis and
(iii) form of alternative hypothesis.

In what follows the maintained model is assumed to be an adequate representation of the data generating process and hypothesis tests are based on relevant alternatives that may exist within the confines of each maintained model as defined. We will begin with the most elementary form of model, which implicitly imposes the most restrictions, and successively relax each implicit restriction until we arrive at the most general (unrestricted) maintained model. For convenience the testing procedure is demonstrated for a series Y_t that has an AR(1) representation, although, as will be shown later we may test any AR(p) model in an analogous fashion.

Note that in testing for stationarity we assume under the null that the series Y_t has a unit root and is thus I(1), against the alternative of stationarity, in which case Y_t is I(0). The hypotheses are formulated such that the null is stationary in first differences whereas the alternative is stationary in levels. In what follows ε_t is a sequence of independent random variables normally distributed with zero mean and constant variance, *i.e.* nid(0,σ^2).

Maintained Model I:

$$Y_t = \phi Y_{t-1} + \varepsilon_t$$

$H_0 : \phi = 1, \qquad \Rightarrow \Delta Y_t = \varepsilon_t$

$H_1 : -1 < \phi < 1 \qquad \Rightarrow Y_t = \phi Y_{t-1} + \varepsilon_t$ where $\phi \neq 0$.

Under the null, Y_t is a random walk with no drift and hence a non-stationary I(1) process, but ΔY_t is stationary by definition, ε_t being a white noise process. Under the alternative Y_t is a stationary first order autoregression.

Model I may be assumed too restrictive in that it assumes Y_t has a zero mean. If we incorporate a non zero mean (denoted by u) which is zero under the null we have

Maintained model II:

$Y_t = c + \phi Y_{t-1} + \varepsilon_t \qquad$ where $c = u(1 - \phi)$

$H_0 : \phi = 1 \qquad \Rightarrow \Delta Y_t = \varepsilon_t$

$H_1 : -1 < \phi < 1 \qquad \Rightarrow Y_t = u(1-\phi) + \phi Y_{t-1} + \varepsilon_t$

Under the null Y_t is a random walk with no drift and ΔY_t is stationary. The alternative states that Y_t is a stationary AR(1) process with no zero mean. In cases where the null cannot be rejected in the two models above the results suggest that Y_t is a random walk with no drift and ΔY_t is a stationary process with zero mean. In order to test whether the drift really is zero we may use the t ratio in a regression of ΔY_t on a constant. If significant, this implies that Y_t has a trend component which drifts the random walk upward if $\delta > 0$, (downward if $\delta < 0$), *i.e.*

$$Y_t = \delta + Y_{t-1} + \varepsilon_t$$

We may now generalize the model for Y_t further and allow for the possibility of a deterministic linear time trend, this yields,

Maintained Model III:

$Y_t = c_1 + c_2 t + \phi Y_{t-1} + \varepsilon_t \qquad$ where $c_1 = u(1 - \phi)$,

$c_2 = \beta(1 - \phi L)$

$H_0 : \phi = 1 \qquad \Rightarrow \Delta Y_t = \beta + \varepsilon_t$

$H_1 : -1 < \phi < 1 \qquad \Rightarrow (Y_t - u - \beta t) = \phi(Y_{t-1} - u - \beta t_{-1}) + \varepsilon_t$

The formulations of the hypotheses here requires some explanation. L is the lag operator so that under the null, c_1 disappears and the time trend reduces to a constant β implying that Y_t is a random walk with drift and is thus nonstationary, but its first difference is a stationary process with non zero mean. The alternative states that deviations of Y_t from a linear function of time *i.e.* $(Y_t - \text{u} - \beta t)$ follow a stationary

AR(1) model. This is more easily seen if we expand the model under the alternative and let,
$z_t = (Y_t - u - \beta t)$, in which case the alternative may be restated as $z_t = \phi z_{t-1} + \varepsilon_t$. The alternative used here is the trend stationary process discussed earlier.

For convenience the preceding development has been confined to the simple AR(1) case, however, as Nelson and Plosser (1982) demonstrate, if we allow the process generating Y_t to be of higher order, (in addition to a time trend and non zero mean) *i.e.*,

$$Y_t = \beta_1 + \beta_2 t + \phi_1 Y_{t-1} + \ldots + \phi_p Y_{t-p} + \varepsilon_t \quad \text{(VI.16)}$$

the process can be made stationary by differencing only if

$$\sum_i^p \phi_i \quad \text{and} \quad \beta_2 = 0$$

These conditions represent the AR(p) equivalent to the unit root test in the AR(1) case of the maintained model III above. Notice that by rearranging the lagged Y's in (VI.16) into lagged first differences yields,

$$Y_t = \left[\sum_{i=1}^p \phi_i\right] Y_{t-1} + \left[-\sum_{i=2}^p \phi_i\right]\left[Y_{t-1} - Y_{t-2}\right] + \ldots + (-\phi_p)(Y_{t-p+1} - Y_{t-p}) + \beta_1 + \beta_2 t + \varepsilon_t$$

which, having subtracted Y_{t-1} from both sides, leaves,

Maintained model IV:

$$\Delta Y_t = \beta_1 + \beta_2 t + \beta_3 Y_{t-1} + \sum_{i=1}^p \delta_i \Delta Y_{t-i} + \varepsilon_t \quad \text{(VI.17)}$$

which is the equation adopted by Dickey and Fuller for the unit root testing procedure of a series in which the order of autoregression is unknown.[8] Equation (VI.17) is known as the Augmented Dickey-Fuller (ADF) regression where β_1 represents a nonzero mean, t is a linear time trend and p is chosen so that the resulting residuals from (VI.17) are white noise. Because, all terms in (VI.17) are now stationary under the null, estimation of the parameters is efficient. Testing the Augmented model is identical to that set out for maintained model III.

Inclusion of a time trend in (VI.17) is warranted on the grounds that inferences from

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8 The structure of the residuals is taken into account using non-parametric adjustments developed by Phillips and Perron (1988), and yield tests of higher power than the ADF unit root tests where a moving average term is present in the series or where the disturbances are heterogeneously distributed.

testing for a unit root in the AR(1) model are only valid if the series does not exhibit a (linear) time trend. Clearly, if a trend is apparent in (VI.17) then this differenced series will have a time dependent mean and hence cannot be stationary - invalidating the inferences made solely on the basis of the estimate of the autoregressive parameter β_3.

However, generally speaking, the case where Y_t has both a linear trend and a unit root is implausible for time series encountered in economics. The reasoning Nelson and Plosser (1982) put forward to account for this rests on the need to transform most economic time series into natural logs because their mean and variance tend to vary in proportion to absolute level. Consequently, if Y_t represents the log of y_t, then under the null of a unit root, a significant time trend would imply that the rate of change of y_t *i.e.* ΔY_t in (VI.17) is deterministic: ever increasing if the time trend coefficient is positive, ever decreasing if negative. Such behaviour, they conclude is inadmissible for economic time series.

We may now turn to the ADF testing procedure itself. Initially it is assumed that (VI.17) is an adequate representation of the data and hence forms the most general maintained model within which successive restrictions are tested until we obtain the most parsimonious representation of the time series. After checking for the appropriate number of first differenced terms to be incorporated into the Augmented Dickey-Fuller regression,

$$\Delta Y_t = \beta_1 + \beta_2 t + \beta_3 Y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t$$

the test procedure can be thought of a comprising three steps.

Test 1

To test whether a unit root is present in Y_t we initially test the hypothesis

$H_0 : \beta_3 = 0$

$H_1 : \beta_3 \neq 0$

using a standard t test. Under the null Y_t is non-stationary against the alternative of stationarity. If the null cannot be rejected this implies that ΔY_t is stationary[9], *i.e.*

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[9] Note that if the null cannot be rejected and there are grounds (such as exponential growth of Y_t) for believing second differencing is required to ensure stationarity,we may test for the presence of a second unit root by forming the regression,

ΔY_t~I(0) and Y_t~I(1)

Test 2

As noted earlier, inferences based on β_3 are only valid in the absence of a significant time trend in ΔY_t. If the null could not be rejected in test 1 we may test the significance of the time trend either by comparing the *t* ratio of β_3 in the ADF with its distribution under the null, or by performing an *F* test of the restrictions that β_2 and β_3 are jointly zero by estimating the auxiliary regression,

$$\Delta Y_t = \beta_1 + \sum_{i=1}^{m} \delta^i \Delta Y_{t-i} + \varepsilon_t$$

If the null of test 2 is rejected it implies that ΔY_t is non stationary having a deterministic trend, however as alluded to above, this is not likely in the presence of a unit root. If the null cannot be rejected then this implies $Y_t \sim$ I(1) and $\Delta Y_t \sim$ I(0).

Test 3

Additionally we may wish to test whether the constant term in the ADF regression is significantly different from zero. Having performed the previous two tests, this may be ascertained in two ways. We may either compare the *t*-ratio of the intercept in the ADF regression with the appropriate critical value , or estimate an auxiliary model in which β_1,β_2 and β_3 are jointly restricted to zero, *i.e.*

$$\Delta Y_t = \sum_{i=1}^{m} \delta^i \Delta Y_{t-i} + \varepsilon_t$$

and test the validity of the restrictions imposed under the null using a standard F test. The results of test 3 do not affect the conclusions of the previous two tests concerning stationarity but rather identify the most appropriate representation of the differenced series.

(c) Critical Values of the Unit Root Tests

Despite being able to test for a unit root by ordinary least squares a complication arises in hypotheses testing. As Fuller (1976, chapter 8) demonstrates, the least squares estimate of β_3 in the ADF regression is biased towards a value somewhat less than

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$$\Delta^2 Y_t = \alpha_1 + \alpha_2 \Delta Y_{t-1} + \sum_{i=1}^{j} \delta_i \Delta^2 Y_{t-i} + \varepsilon_t$$

and comparing the *t*-ratio of α_2 with the appropriate critical value, which here is the τ_μ statistic of Fuller (1976), p.373. Should the (absolute) value of the statistic exceed the chosen critical value of τ_μ the presence of a second unit root is rejected and second differencing to achieve stationarity is not required.

zero and thus does not approach zero even asymptotically. Consequently, comparison of the t ratio generated from OLS to standard critical values given by the t distribution under the null that $\beta_3 = 0$, results in misleading inferences.[10] Tables of critical values which take into account the nonstandard distribution of the unit root t statistic (and F statistic where the null of a unit root forms part of a joint hypothesis test) are available, although not for all sample sizes, numbers of parameters and significance levels. Sources of these tables are listed below and have been reproduced in Appendix VI.A.1 for convenience. As is usual, the null hypothesis is rejected for all unit root tests described above where the absolute value of test statistic exceeds the absolute value of the designated critical value.

In applying Test 1, the t-ratio on β_3 should be compared with the critical values of the $\hat{\tau}_\tau$ statistic tabulated in Fuller (1976; p.373), and reproduced here as Table A1 in the Appendix. A more detailed tabulation of this statistic may be found in Guilkey and Schimdt (1989).

In applying the t test version of Test 2 the t ratio of β_2 should be compared with the critical value of the $\hat{\tau}_{\beta\tau}$ statistic in Dickey and Fuller (1981) Table III p.1062 and as Table A2 in the Appendix. Alternatively, if using the F version of this test, (which is computed in the normal way using the restrictions imposed on the maintained model under the null) the F statistic should be compared with the Φ_3 statistic of Dickey and Fuller (1981), Table VI, p.1063, (or Table A3 here).

Using the t test version of Test 3, the t ratio of the intercept should be compared with the distribution of the $\hat{\tau}_{\alpha\tau}$ statistic in Dickey and Fuller (1981) Table II p.1062, (Table A4 in the Appendix). If the F version of this test is required, then the computed F statistic should be compared with the Φ_2 statistic of Table V in Dickey and Fuller (1981) p.1063, (reproduced here as Table A5).

The complexity of testing for stationarity derives in part from its relative youth in the literature, and the very nature of unit root testing which is sensitive to the choice of maintained model, unlike a standard hypothesis test. In light of extensive Monte Carlo simulation experiments conducted by Dickey and Fuller (1981) both F and t type test statistics are used here because where the empirical values of the intercept, trend and

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[10] As a point of interest, use of the adjusted tables raises the common 'rule of thumb' critical value from 2 to about 3.5 for this test with sample size around 50.

root are different, but close to the values implied under the null, the F tests have higher power than the corresponding t type tests, although this does not necessarily hold where the null is true.

VI.(v). Stabilizing the Variance of a Time Series

In the preceding discussion, use of a time trend or difference operator on a non-stationary series resulted in stationarity. Whilst effective at removing trends and thus a time dependent mean these techniques may have only a minor affect on stabilizing the variance. Moreover, empirical time series in economics typically have variances that grow in proportion to the absolute level of the series and hence motivates the use of a log transformation in order to stabilize the variance. However, using the logarithm is only one of a number of possibilities that may be used to stabilize the variance. Informal evidence on the appropriate power transformation can be derived by plotting what are called *range-mean* or *range-median* plots - a convenient tool for the detection of non constant variance.

This involves splitting the time series into small subsets (of some 4-12 observations depending on total sample size) for which the median and range of each subset is calculated. When plotted, the resulting scatter is suggestive of the appropriate power transformation that should be applied to the series in order to produce (approximately) constant variance.[11] Figure VI.1 represents some hypothetical range median plots annotated with the appropriate transformation necessary to achieve constant variance, (*i.e.*the horizontal line).

For example a range median plot of linear form is suggestive of a logarithmic transformation, whereas a horizontal plot suggests that the variance is already constant and no transformation need be applied.

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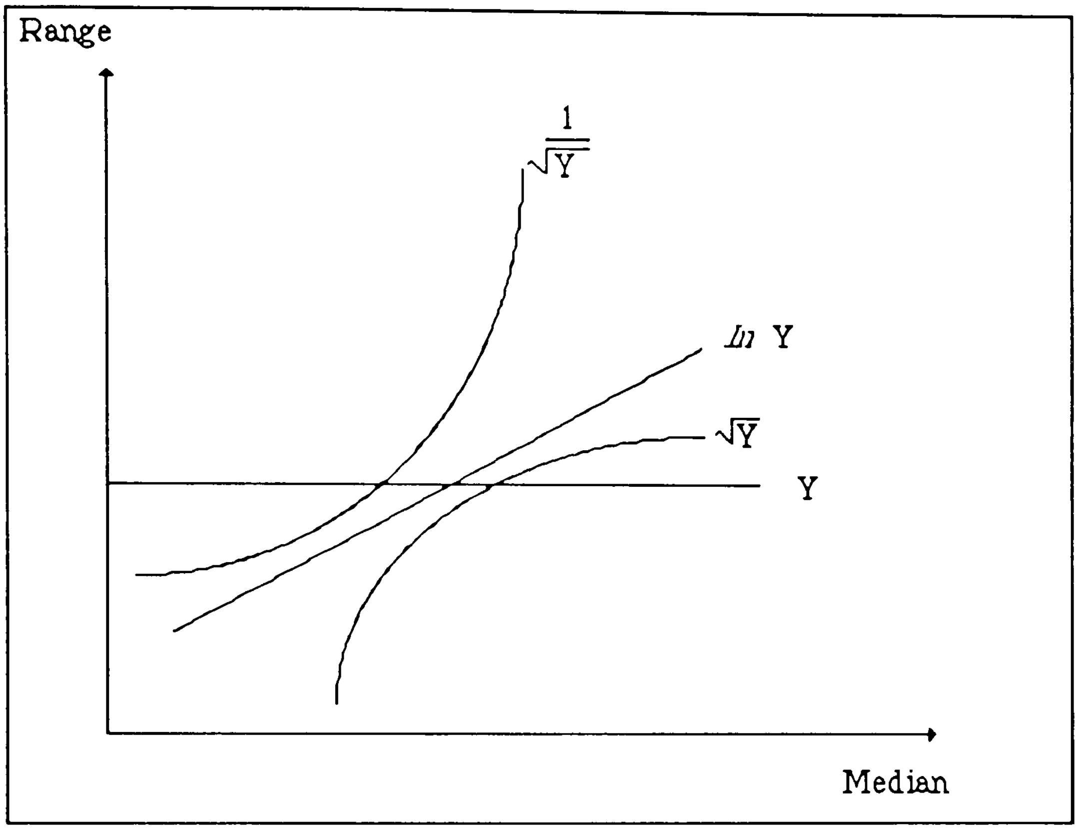
11 It is usual to use range-median plots as these are more robust where the series being used is subject to considerable variability. See Jenkins (1979) for further details.

Figure VI.1 Hypothetical Range-Median Plots



Frequently, empirical time series requires both a power transformation and differencing to attain stationarity as is the case in the empirics that follow. Where the logarithmic transformation and difference operator of the first order are combined a particularly useful result emerges since,

$$\Delta lnY_t = lnY_t - lnY_{t-1} = ln\left(\frac{Y_t}{Y_{t-1}}\right) \cong \frac{Y_t}{Y_{t-1}} - 1 = \frac{Y_t - Y_{t-1}}{Y_{t-1}}$$

Therefore, providing that the ratio (Y_t/Y_{t-1}) is moderately small, the first difference of the log of Y_t is equivalent to the rate of growth of the original series Y_t.

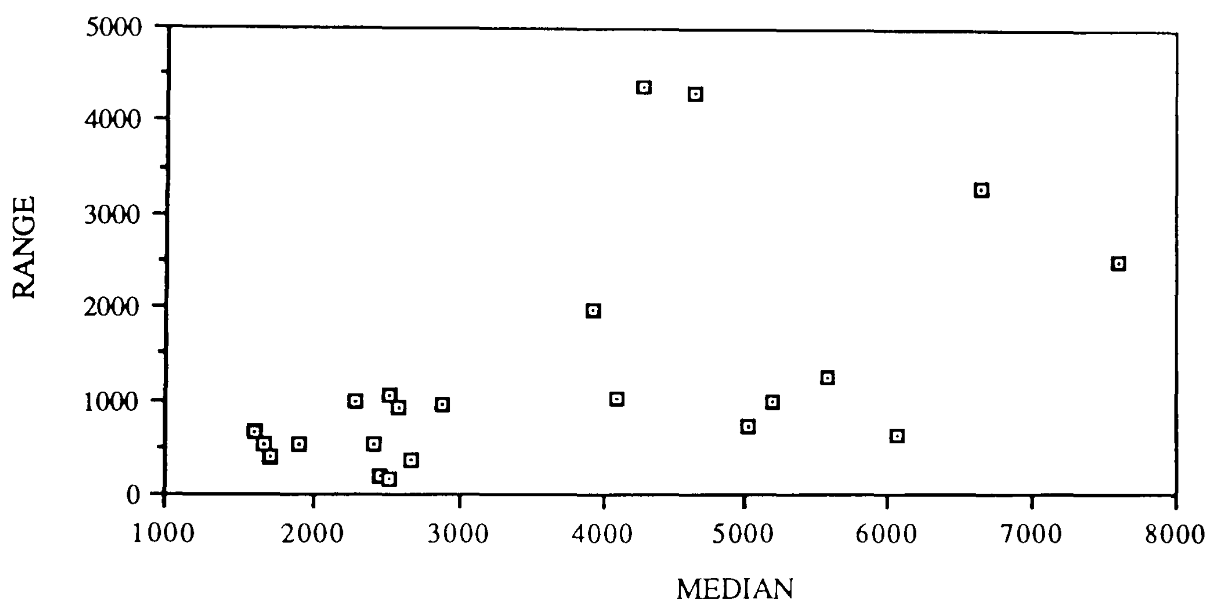
We may now proceed to the empirical analysis where these techniques are applied to the series on farm rents and land prices.

VI.(vi). Testing for Stationarity in the Empirical Series

(a) Stabilizing the Sample Variance

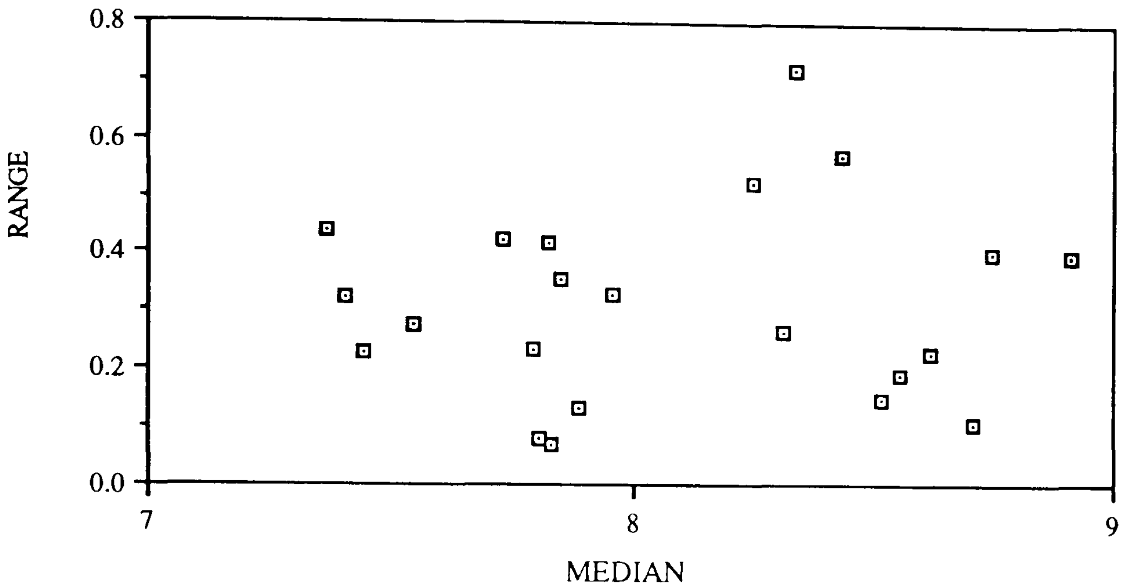
As discussed in the last section, economic time series frequently require a power transformation to stabilise their variances, to render them stationary in order that they may be legitimately used in econometric investigations. Due to the similarity of the results obtained from the various series, only the range-median plots of the Oxford land price series are presented here, although identical conclusions are applicable to all the other series. Using subsets (of 6 observations in length) of the series PX_t, ranges and medians are calculated and presented as a scatter in Figure VI.2 in which an erratic but discernible upward pattern may be detected indicating that the variance of this series rises proportionately with the level of the series.

Figure VI.2 Range-Median Plot of (PX_t)



The pattern of the scatter of points prescribes the use of a logarithmic transformation to stabilise the variance as discussed above. Taking logs of this series and calculating new ranges and medians yields the results illustrated in Figure VI.3 where the points appear to be much more evenly dispersed implying that $\ln PX_t$ has reasonably constant variance and may be used in further analysis.

Figure VI.3 Range-Median Plot of ($\ln PX_t$)



(b) Casual Inspection of the Data

As with most statistical procedures, testing for unit roots can quite easily become a mechanical and opaque exercise in which the analyst's role is relegated to one of button pushing and comparing critical values. Furthermore, it may be believed that the presence of formal tests makes the process of familiarisation with the data redundant. From a methodological standpoint it is essential that one gains some 'feel' for the data under scrutiny, although all too frequently, attention focuses immediately on the 'black-box' approach to statistical measurement in empirical work. Here, each of the time series that will be used in the following chapters are illustrated in levels and (logged) first differences. .

(a) The Agricultural Rent Series

Figures VI.4 and VI.6 illustrate well that both rent series are non-stationary in levels, portraying dominant trends despite being expressed in constant (1990) prices. Differencing the log of each series produces series in Figures VI.5 and VI.7 that are at least candidates for stationarity, in that the means and variances of both series appear to be constant. Furthermore, the means of each series could reasonably be expected to lie around zero. This casual evidence suggests that stationarity may be induced simply by differencing the logged series, implying that lnR_t and $lnRN_t$ are integrated processes of order one with stationary first differences, *i.e.* $lnP_t \sim I(1)$, $lnR_t \sim I(1)$; ΔlnR_t

$\sim$ I(0) , $\Delta lnP_t \sim$ I(0).[12]

Figure VI.4: Average Real Farm Rents, R_t

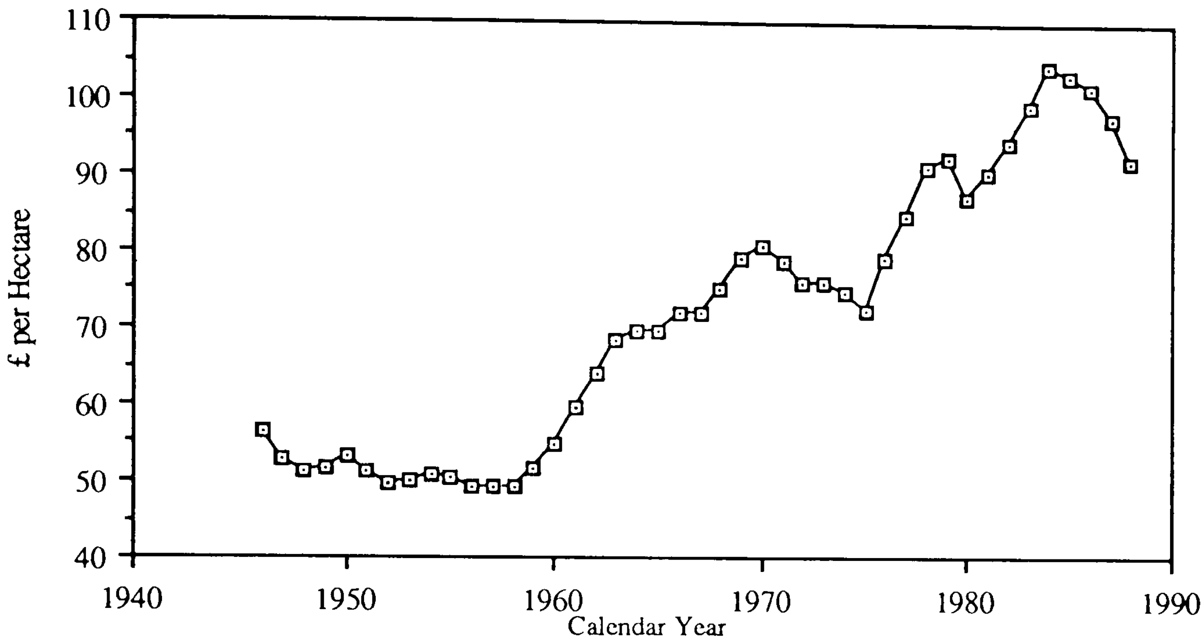
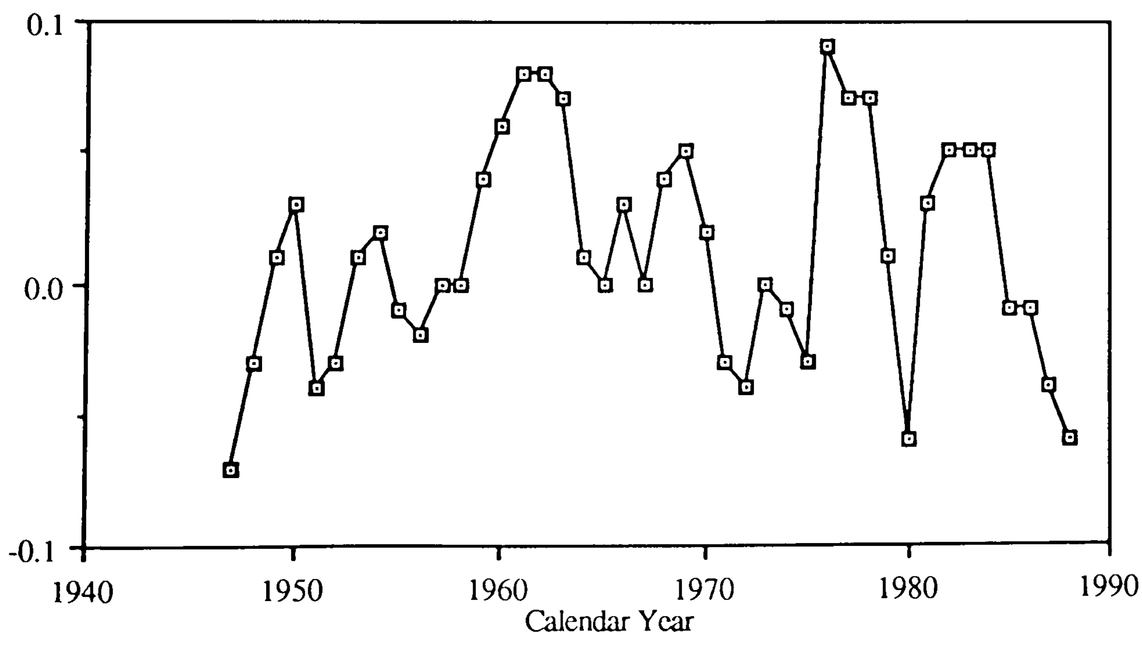


Figure VI.5: The ΔlnR_t Time Series



[12] Due to the similarity of the series R_t and RN_t the time series plots of the latter, have not been presented here.

Figure VI.6 : The Historical Rent Series, RH_t

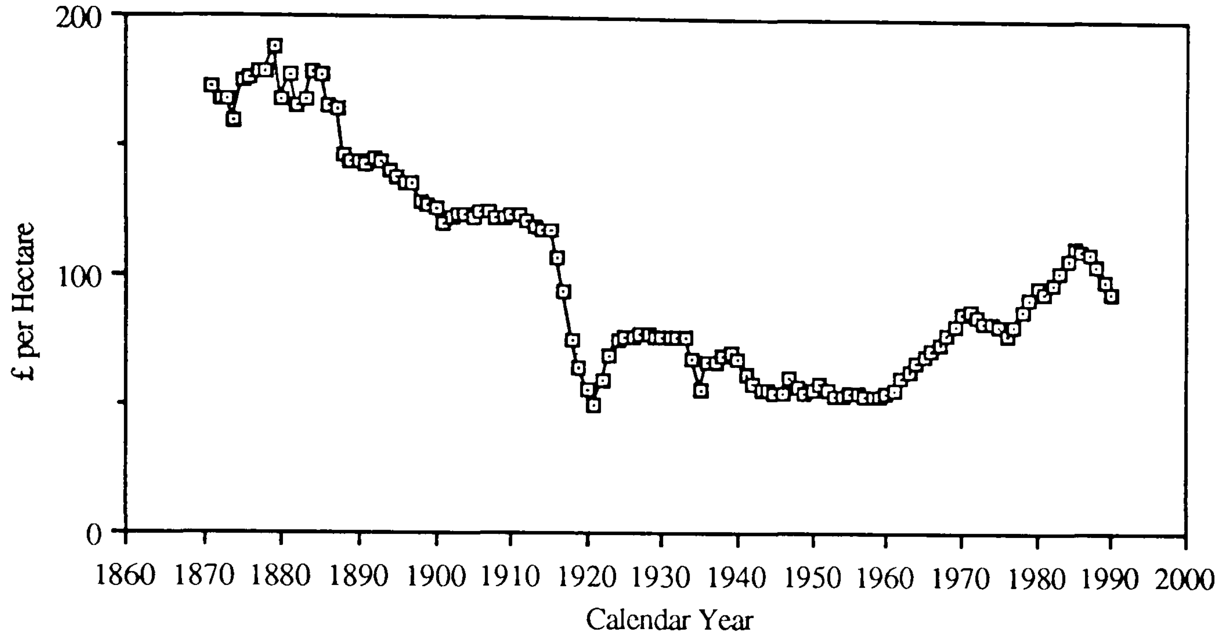
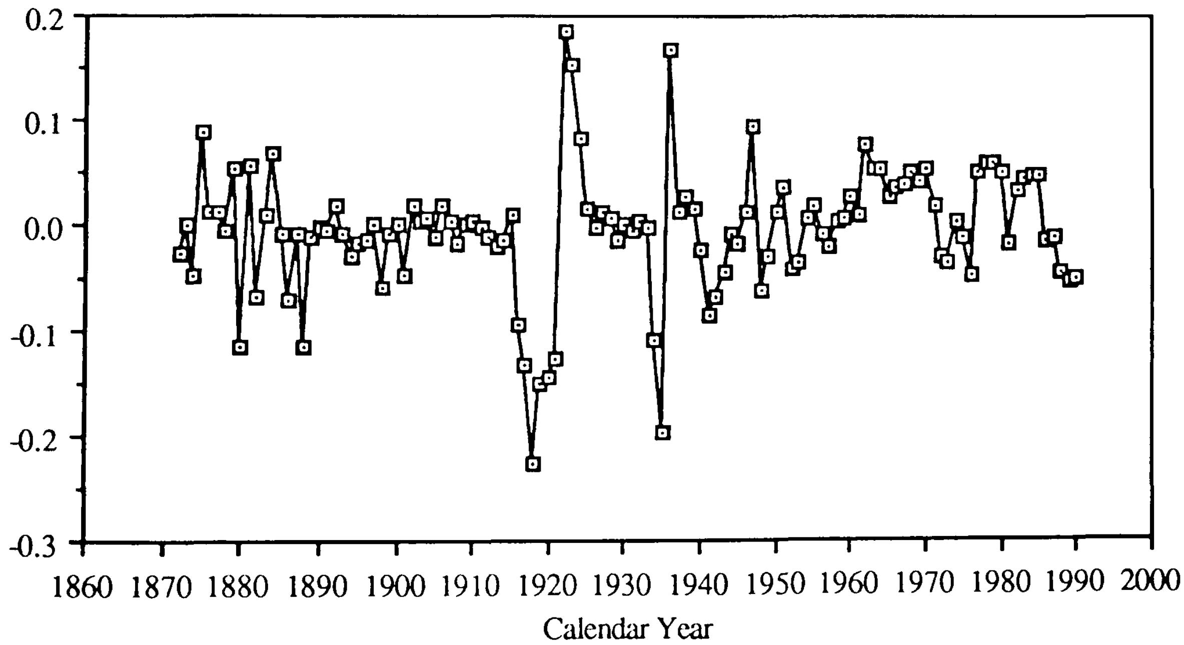


Figure VI.7 : The $\Delta \ln RH_t$ Time Series



(b) Farmland Prices

A similar story emerges with the land price series as with rents, in that transformation of the series expressed in levels is clearly necessary in order for these series to resemble stationary processes. When expressed in logged first differences, the shorter average land price series illustrated in Figure VI.9 appears to exhibit constant mean (that could reasonably be zero) and a constant variance.

Figure VI.8: The Average Land Price Series P_t

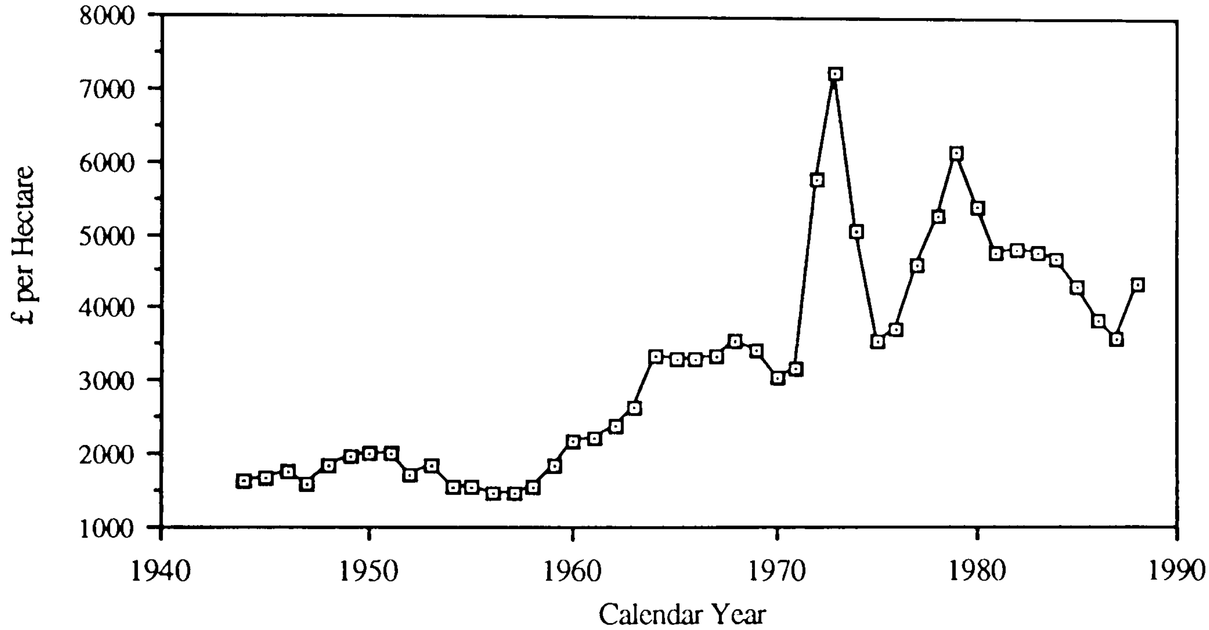


Figure VI.9: $\Delta \ln P_t$ Time Series

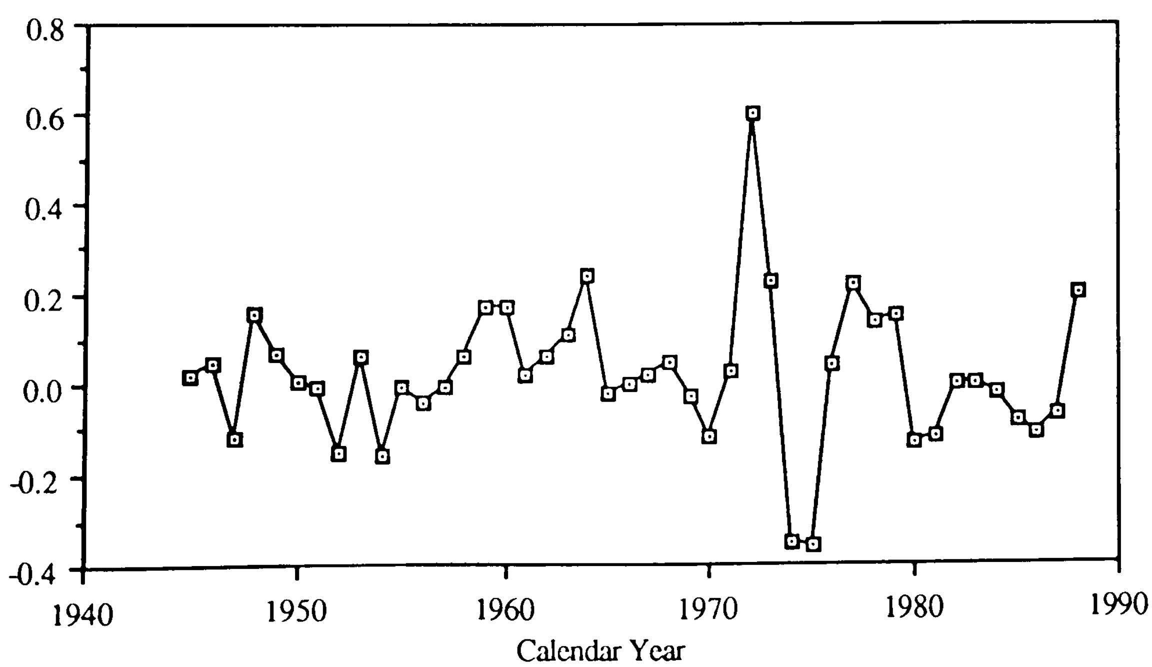


Figure VI.10 : The Oxford Land Price Series PX_t

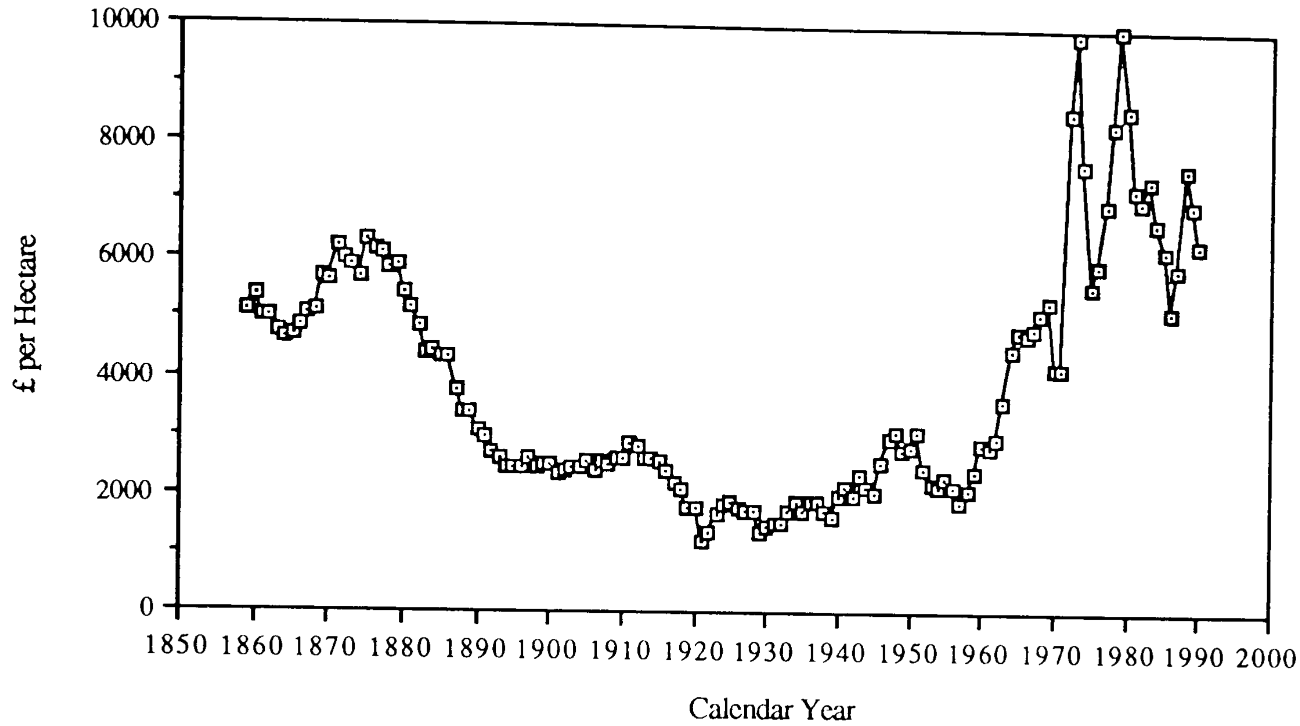
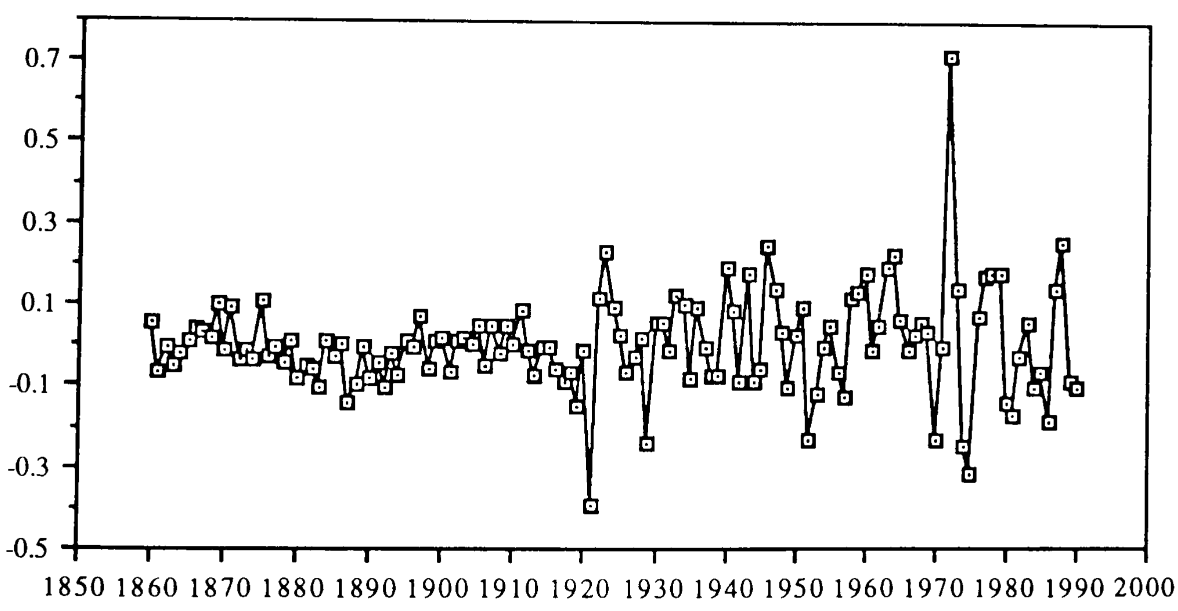


Figure VI.11 : The $\Delta \ln PX_t$ Time Series



Whilst $\Delta \ln PX_t$ also appears to have zero mean, Figure VI.11 suggests that the variance of the series is characterised by a degree of time dependence despite the log transformation. In particular the dispersion of $\Delta \ln PX_t$ appears to be larger after the crash in land prices in the 1920s than before the crash. With this reservation in mind (which we will return to in the next section), the casual evidence presented here suggests that $lnP_t \sim$ I(1), $lnPX_t \sim$ I(1); $\Delta lnP_t \sim$ I(0) and $\Delta lnPX_t \sim$ I(0).

(d) The GDP Deflator

The deflator series, F_t illustrated in Figure VI.12 is clearly non-stationary. Applying log and first difference transformations yields the series in Figure VI.13. Whilst these transformations have clearly removed the upward trend present in F_t the series still appears to exhibit non-stationarity.

Differencing the series for a second time yields the time series in Figure VI.14 which is clearly stationary. The $\Delta^2 \ln F_t$ series does not appear to be over differenced since its variance appears to be less than that of $\Delta^2 \ln F_t$ from casual inspection although this will be tested formally later. Consequently, we may tentatively suggest that $F_t \sim$ I(2), $\Delta \ln F_t \sim$ I(1) and $\Delta^2 \ln F_t \sim$ I(2).

Figure VI.12 : The GDP Deflator Time Series (1871 base year) F_t

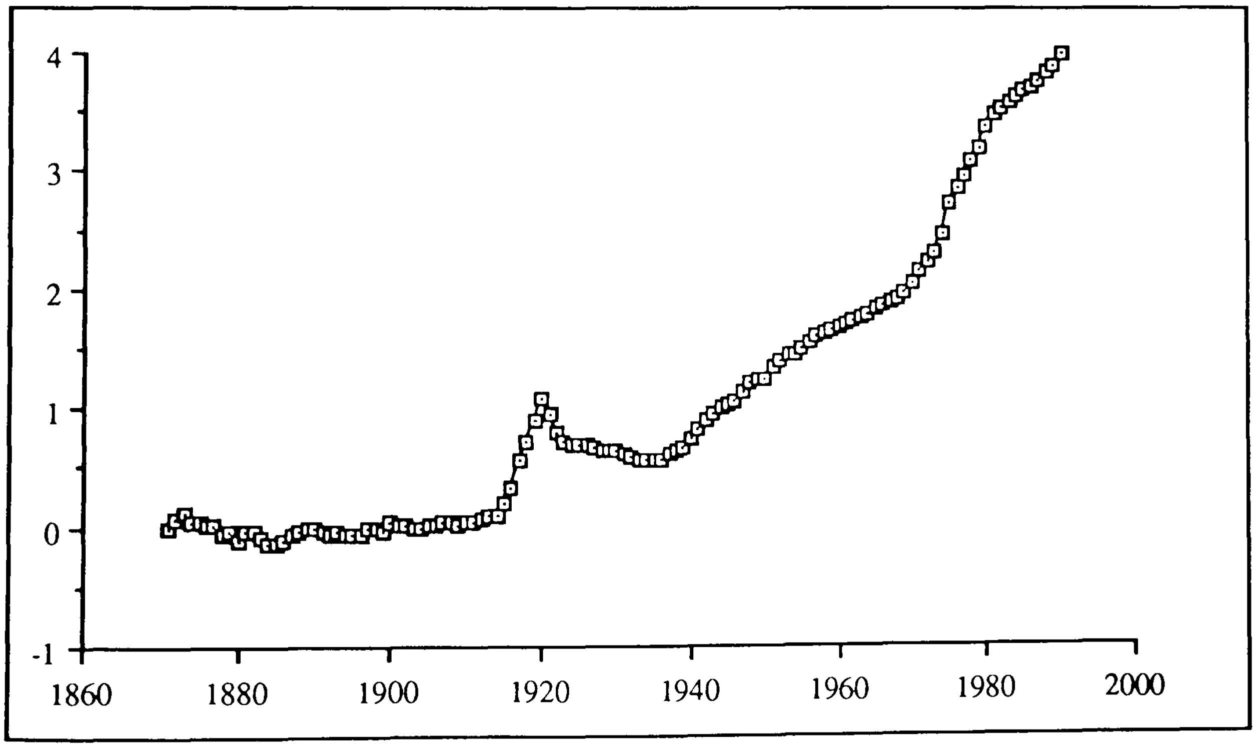


Figure VI.13 : The $\Delta \ln F_t$ Time Series

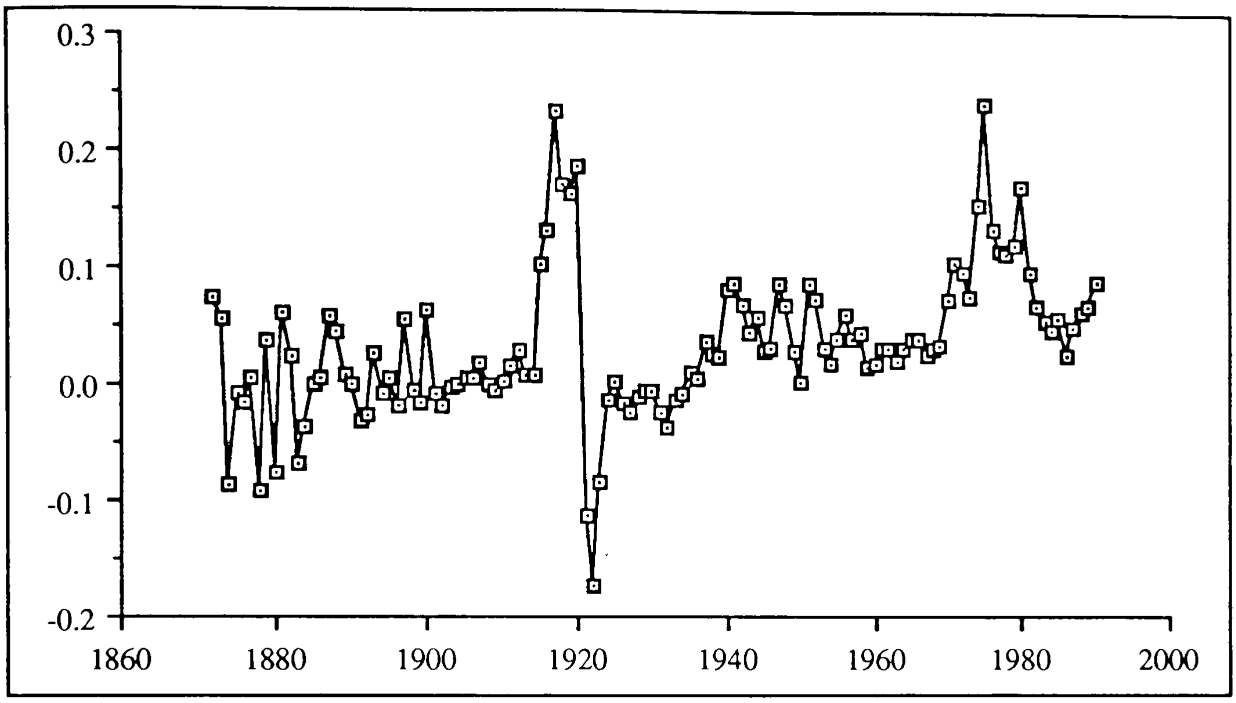
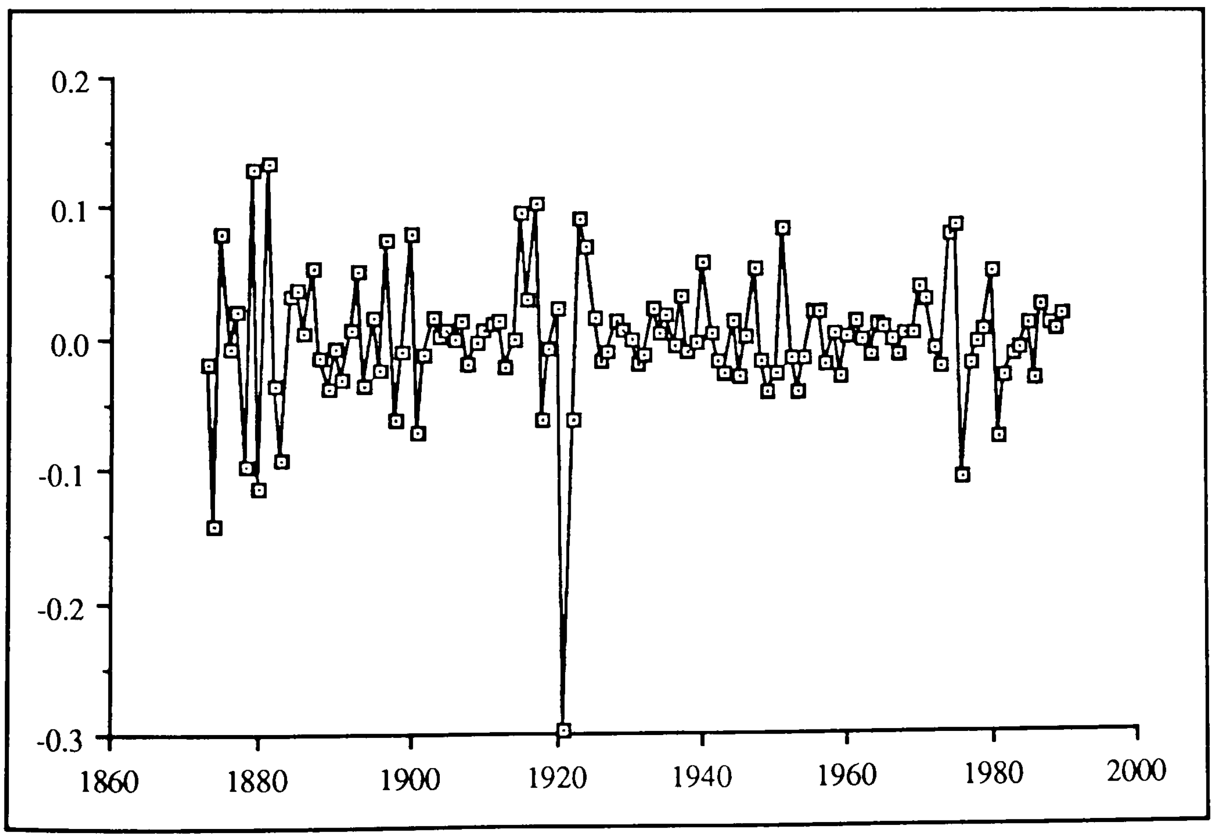


Figure VI.14 : The $\Delta^2 \ln F_t$ Time Series



Consequently the first differences of the logarithm of each of the rent, and land price series appear to be stationary whilst the deflator appears to require double differencing.

Due to the fact that the combination of log and difference operators measures the rate of change in the original series, this informal inquiry suggests that the rate of change in rents and land prices are stationary, the rate of inflation is I(1) and that the rate of change in inflation is stationary. Whilst such visual inspection of the data is useful, let us now find more formal justification for these tentative conclusions.

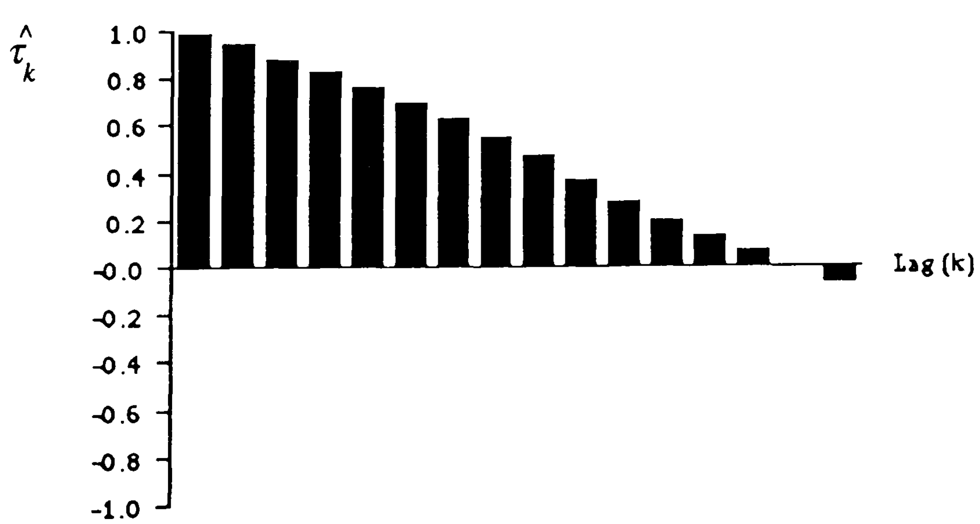
(c) Testing For Unit Roots

The empirical results of testing the rent series (lnR_t and $lnRN_t$), the agricultural land price series (lnP_t and $lnP20_t$) and the deflator series ($\ln F_t$) are presented below. The shorter series for land prices are not tested due to the relatively small sample size available. In all the tables that follow t ratios are in parentheses.[13]

(a) lnR_t

As an initial exercise, the correlograms of lnR_t and its first difference ΔlnR_t are presented in Figures VI.15 and VI.16 respectively. It is evident that lnR_t is non-stationary ; the correlogram exhibiting a slow linear decline. However, its first difference, ΔlnR_t appears to be a candidate for stationarity: autocorrelations appear to fluctuate around a mean of zero in a sine wave - behaviour characteristic of a stationary AR(2) model. Pretesting lnR_t indicates that one lagged dependent variable is sufficient to obtain white noise residuals in the Augmented Dickey-Fuller regression, which lends support to the notion that rents are AR(2), as indicated by Figure 16.

Figure VI.15 : Correlogram of lnR_t



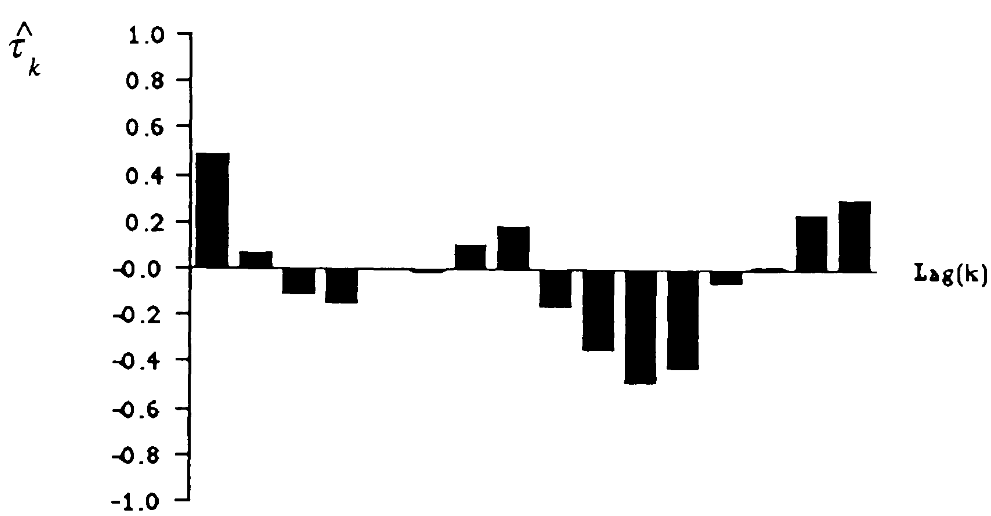
13 All the series under investigation have also been tested for double unit roots. The tests strongly reject the null hypothesis that any of the series are I(2) which allows us to be more confident in the inferences made in the text where this possibility was not directly tested.

On the assumption that lnR_t is adequately represented by the model,

$$lnR_t = \beta_0 + \beta_1 t + \beta_2 lnR_{t-1} + \beta_3(lnR_{t-1} - lnR_{t-2}) + \varepsilon_t \qquad \text{(VI.18)}$$

where ε_t are independent and identically distributed $(0, \sigma^2)$ random variables, we may perform the unit root tests outlined in the previous section. Reparameterizing (VI.18) in terms of ΔlnR_t, yields the ADF regression, (VI.19) and the restricted versions of it {(VI.20), (VI.21) and (VI.22)}, which are presented in Table VI.1.

Figure VI.16 : Correlogram of ΔlnR_t



Recall that if lnR_t has a unit root then the t ratio on the coefficient of lnR_{t-1} in (VI.19) should be insignificantly different from zero. Comparing the test statistic of -3.13 to the 5% critical value of $\hat{\tau}_\tau$ of -3.51 indicates that the null hypothesis of a unit root cannot be rejected at the 95% confidence level. Consequently, this implies that lnR_t has a unit root and that its first difference is stationary, *i.e.* $lnR_t \sim I(1)$; $\Delta lnR_t \sim I(0)$. However, this result is conditional on the linear time trend in (VI.19) being insignificant. For reasons stated earlier, a significant trend is most unlikely in the presence of a unit root, and the F statistic testing the restriction that the coefficients on time and lnR_{t-1} are jointly zero, is,

$$\Phi_3 = \frac{(0.0485574 - 0.0391089)/2}{0.0391089/(39-4)} = 4.22$$

which compares to a 5% critical value for Φ_3 of 6.73 indicating that the restrictions imposed under the null are valid at the 95% confidence level. This inference is not supported however, by the $\hat{\tau}_{\beta\tau}$ statistic - the t ratio on the trend coefficient. The 5% critical value of $\hat{\tau}_{\beta\tau}$ is 2.81 indicating a non-zero time trend although due to the higher power of the F test and the improbable implications of a significant trend, the $\hat{\tau}_{\beta\tau}$

result is treated as spurious. Consequently, lnR_t is a random walk with drift and ΔlnR_t is stationary with non-zero mean. Hence, $Y_t \sim$ I(1) and $\Delta Y_t \sim$ I(0). We may now test for the significance of the drift in lnR_t by performing an F test of the restrictions that $\beta_0 = \beta_1$ and $\beta_2 = 1$ in (VI.18), or equivalently, that the first three parameters in (1) are jointly zero. The test statistic,

$$\Phi_2 = \frac{(0.0498748 - 0.0391089)/3}{0.0011174/(39-4)} = 3.2$$

implies the null cannot be rejected at the 5% significance level, the critical value of Φ_2 being 5.13. This result however is contradicted by a simple t test on the intercept of the ADF regression (VI.19) of 3.17 which compares to a 5% critical value of $\hat{\tau}_{\alpha\tau}$ of 3.14. Whilst the contradictory evidence of the t-type tests is not wholly satisfactory here, the the F-type tests (which have superior power) points to the conclusion that the second order autoregressive process lnR_t has a unit root and is therefore I(1) implying that $\Delta lnR_t \sim$ I(0) with zero mean.

Table VI.1: Testing for Unit Roots Tests in lnR_t

Equation No.	Regressors				RSS
	constant	Time trend	lnR_{t-1}	ΔlnR_{t-1}	
(VI.19)	0.875	0.005	-0.231	0.623	0.0391089
	(3.17)	(2.85)	(-3.13)	(4.78)	
(VI.20)	0.126		-0.028	0.536	0.0467803
	(1.35)		(-1.28)	(3.90)	
(VI.21)	0.006			0.515	0.0485574
	(1.00)			(3.45)	
(VI.22)				0.574	0.0498748
				(4.17)	

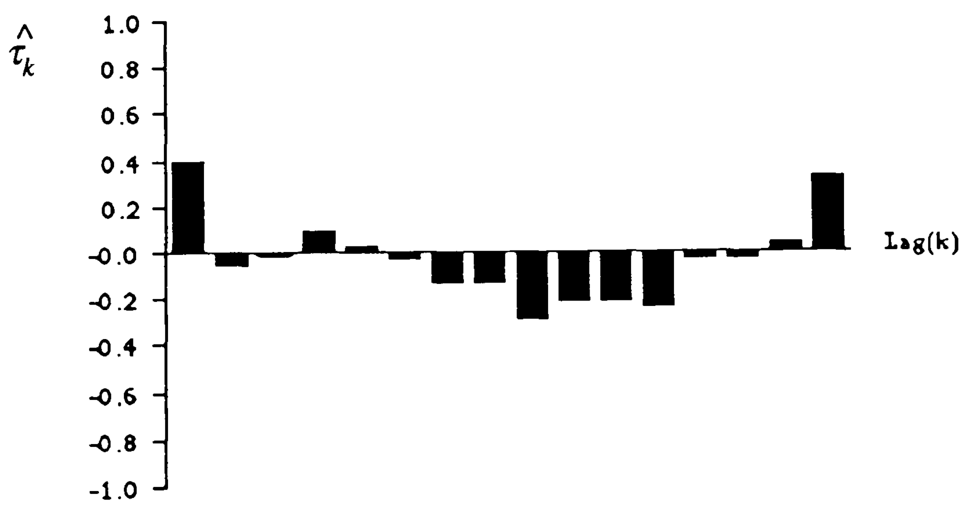
Sample comprises 39 observations (1950 - 1988) of the dependent variable ΔlnR_t.

(b) $lnRN_t$

The autocorrelation function of $lnRN_t$ is very similar to that of lnR_t shown in Figure VI.8, displaying a slow linear decline indicative of nonstationarity. Figure VI.17 is the correlogram of $\Delta lnRN_t$ which appears to suggest the series is stationary due to the rapid fall in the correlogram. The spike in the correlogram at the 16th lag may reasonably be considered to be spurious: for pure chance will produce a 'significant' autocorrelation coefficient every twenty lags on average, if the 5% significance level is used.

Turning to the unit root results in Table VI.2, one lagged differenced term is introduced into the ADF regression (VI.23) to induce observationally white noise errors, suggesting that $lnRNE_t$ is also a second order autoregression. The ADF test statistic ($\hat{\tau}_\tau$) in (VI.23) has a 5% critical value of -3.50

Figure VI.17 : Correlogram of $\Delta lnRN_t$



which does not allow rejection of the unit root null implying that $lnRN_t \sim$ I(1) and its first difference $\Delta lnRN_t \sim$ I(0). To test whether the time trend is simultaneously zero under the null the Φ_3 is computed as,

$$\Phi_3 = \frac{(0.0791818 - 0.0687221)/2}{0.0687221/(39-4)} = 2.66$$

which cannot reject the null at the 95% confidence level, the critical value of the Φ_3 distribution being 6.73. This inference is also supported by the $\hat{\tau}_{\beta\tau}$ statistic which tests whether the *t* ratio on the time trend in the ADF regression (VI.23) is insignificantly different from zero. The test statistic of 1.97 cannot reject the zero restriction under the null, the 5% critical value of $\hat{\tau}_{\beta\tau}$ being 2.81.

These tests suggest that $lnRN_t$ is a random walk (possibly with drift) and $\Delta lnRN_t$ is stationary. To check whether the drift implied above is actually non-zero the Φ_2 statistic is computed using the residual sum of squares from (VI.23) and (VI.26) - the latter model being estimated with the restrictions imposed under the null. This yields,

$$\Phi_2 = \frac{(0.0813643 - 0.0687221)/3}{0.0687221/(39-4)} = 2.15$$

which cannot reject the null at the 95% confidence level the critical value of Φ_2 being 5.13. This result is corroborated by the t ratio on the constant in (VI.23) which does not exceed the 5% critical value of the $\hat{\tau}_{\alpha\tau}$ statistic of 3.14. Therefore, the zero drift null cannot be rejected. The upshot of this testing is that $lnRN_t$ is a non-stationary I(1) series and that $\Delta lnRN_t$ is a stationary I(0) variable with zero mean. These results are qualitatively identical to those obtained from the first rent series tested.

Table VI.2: Unit Root Tests Results on $lnRN_t$

Equation No.	Regressors				RSS
	constant	Time trend	$lnRN_{t-1}$	$\Delta lnRN_{t-1}$	
(VI.23)	0.722	0.003	-0.183	0.476	0.0687221
	(2.34)	(1.97)	(-2.30)	(3.34)	
(VI.24)	0.163		-0.036	0.437	0.0759256
	(1.34)		(-1.27)	(2.98)	
(VI.25)	0.008			0.408	0.0791818
	(1.03)			(2.79)	
(VI.26)				0.447	0.0813643
				(3.16)	

Sample comprises 39 observations (1950 - 1988) of the dependent variable $\Delta lnRN_t$.

(c) $\ln RH_t$

The Correlograms of $\ln RH_t$ and $\Delta\ln RH_t$ are similar in shape and form to those for the other rent series and indicate that $\ln RH_t$ is nonstationary and that $\Delta\ln RH_t$ is stationary due to the rapid decay of the correlogram for the first differenced series. Results of the formal unit root tests are reported in Table VI.3 and all critical values of the tests relate to a sample size of 100. Pre-testing indicated that one lagged differenced term was sufficient to produce residuals that are empirical white noise.

Table VI.3 : Unit Root Test Results on $lnRH_t$

Equation No.	Regressors				RSS
	constant	Time trend	$lnRH_{t-1}$	$\Delta lnRH_{t-1}$	
(VI.27)	0.104	-0.000009	-0.023	0.351	0.37189
	(1.11)	(-0.04)	(-1.27)	(3.91)	
(VI.28)	0.100		-0.023	0.350	0.37189
	(1.64)		(-1.70)	(4.03)	
(VI.29)	-0.003			0.348	0.38137
	(-0.62)			(3.97)	
(VI.30)				0.352	0.38267
				(4.04)	

Sample comprises 117 observations (1873 - 1990) of the dependent variable $\Delta lnRH_t$.

Comparing the t ratio of the coefficient on $lnRH_{t-1}$ in (VI.27) with its 5% critical value, suggests that $lnRH_t$ has a unit root but that that $\Delta \ln RH_t$ is stationary. The t ratio on the time trend coefficient is clearly insignificant, as would be expected given the previous result indicating that $lnRH_t$ has a unit root. For completeness, the Φ_3 statistic testing the zero restrictions on the time trend and $lnRH_{t-1}$ is computed as,

$$\Phi_3 = \frac{(0.38137 - 0.37189)/2}{0.37189/(117-4)} = 1.44$$

which cannot reject the null at the 5% critical value of 6.49, lending support to the conclusions from the individual t tests. Consequently, these results imply that $lnRH_t$ is a random walk (possibly with drift) and that $\Delta \ln RH_t$ is a stationary AR(1) process. To test whether the drift in this process is significant we compute the Φ_2 statistic [using the residual sum of squares from (VI.27) and (VI.30)] as,

$$\Phi_2 = \frac{(0.38267 - 0.37189)/3}{0.37189/(117-4)} = 1.64$$

which is too small to reject the zero restrictions imposed under the null at the 5% critical value of this test (4.88). Using the $\hat{\tau}_{\alpha\tau}$ statistic to test this hypothesis yields the same conclusion since the t ratio on the constant in (VI.27) is 1.11 compared to the 5% critical value of $\hat{\tau}_{\alpha\tau}$ being 3.11.

These results are similar to those obtained from the previous rents series and furthermore bear out the conclusions of the informal investigation, namely in that all the rent series are driftless random walks in levels and thus zero mean stationary processes in first differences.

(d) lnP_t

The log of the average land price series in levels lnP_t is characterised by a persistent correlogram indicative of nonstationarity, but appears *a priori* to be stationary in first differences as Figure VI.18 illustrates with a correlogram that decays rapidly in the form of a sine wave - similar to the rent series.

Figure VI.18: Correlogram of ΔlnP_t

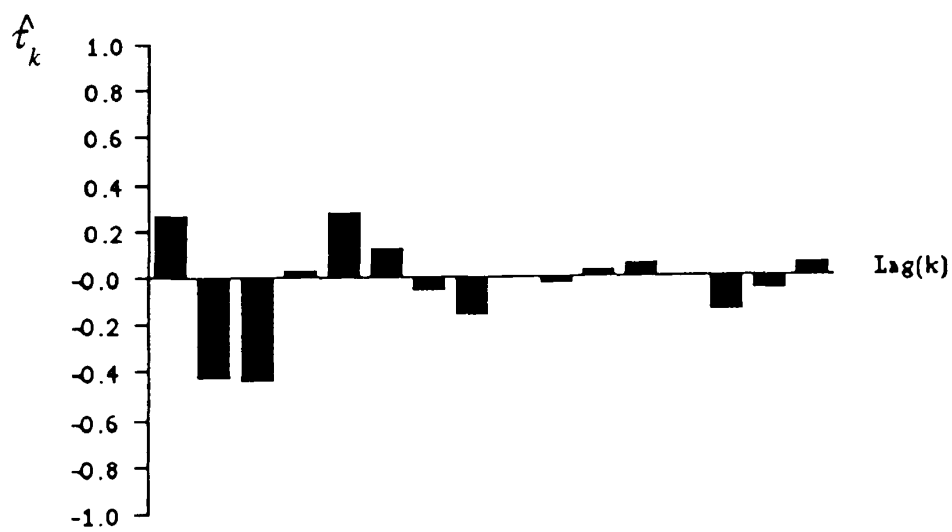


Table VI.4 summarizes the results obtained from estimating the ADF regression and the restricted versions of it for tests 2 and 3. A prior search indicated the need for two lagged terms in order to obtain white noise residuals, suggestive of a third order autoregressive process generating lnP_t. Again t ratios are in parentheses. On the assumption that lnP_t is adequately represented by such a model, we adopt the previous testing framework with,

$$\Delta lnP_t = \beta_0 + \beta_1 t + \beta_2 lnP_{t-1} + \beta_3(lnP_{t-1} - lnP_{t-2}) + \beta_4(lnP_{t-2} - lnP_{t-3}) + \varepsilon_t \qquad \text{(VI.31)}$$

as the maintained model, where ε_t are independent and identically distributed $(0, \sigma^2)$ random variables.

Table VI.4: Unit Root Test Results for lnP_t

Equation. No.	Regression Parameters					RSS
	constant	Time trend	lnP_{t-1}	ΔlnP_{t-1}	ΔlnP_{t-2}	
(VI.32)	1.486	0.007	-0.204	0.538	-0.399	0.611981
	(1.77)	(1.42)	(-1.73)	(3.64)	(-2.37)	
(VI.33)	0.37		-0.045	0.45	-0.508	0.661087
	(0.96)		(-0.91)	(3.36)	(-3.57)	
(VI.34)	0.025			0.465	-0.556	0.667914
	(1.13)			(3.26)	(-3.92)	
(VI.35)				0.475	-0.537	0.691678
				(3.32)	(-3.80)	

Sample comprises 39 observations (1950 - 1988) of the dependent variable ΔlnP_t.

Visual inspection of the ADF regression (VI.32) suggests that lnP_t has a unit root so that $\Delta lnP_t \sim I(0)$; $lnP_t \sim I(1)$. Specifically, the $\hat{\tau}_\tau$ statistic (of -1.73) is well inside the 5% critical value of -3.51 indicating that we cannot reject the null hypothesis of a unit root. As this result is conditional upon the the time trend being insignificantly different from zero the Φ_3 statistic is computed from the residual sum of squares of (VI.32) and (VI.34), the latter being the auxiliary model estimated under the null that $\beta_1 = \beta_2 = 0$.

$$\Phi_3 = \frac{(0.667914 - 0.611981)/2}{0.611981/(39-5)} = 1.55$$

which fails to reject the null at the 5% critical value of 6.73. The $\hat{\tau}_{\beta\tau}$ statistic, estimated at (1.42) also fails to reject the null that $\beta_1 = 0$ when compared to its critical value of 2.81.

Computing the Φ_2 statistic under the joint set of restrictions imposed under the null that $\beta_0 = \beta_1 = \beta_2 = 0$ we may test the significance of drift in lnP_t implied by the previous results.

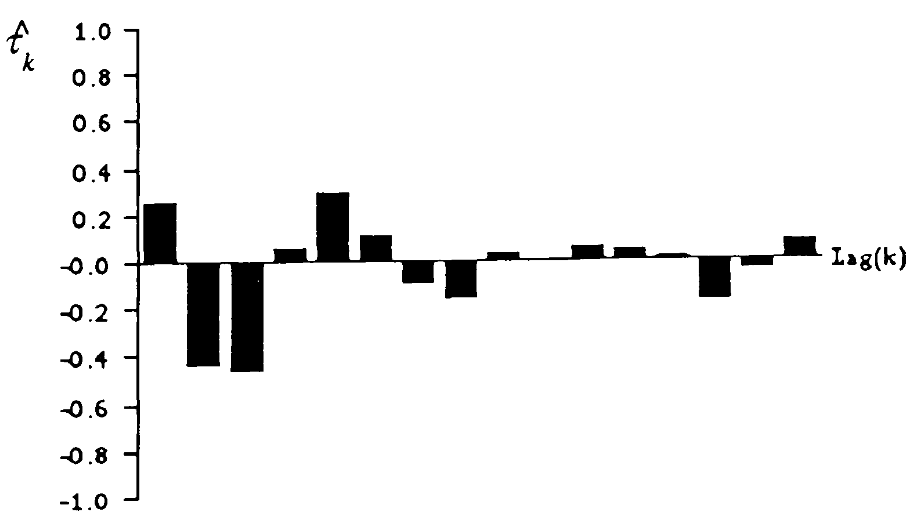
$$\Phi_2 = \frac{(0.691678 - 0.0687221)/3}{0.0687221/(39-5)} = 1.48$$

which cannot reject the restrictions imposed under the null at the 5% significance level (critical value 5.13). This result is also corroborated by the $\hat{\tau}_{\alpha\tau}$ statistic of 1.77 which is well below the 5% critical value of 3.14. Consequently, ΔlnP_t appears to be a stationary process with zero mean and lnP_t a non-stationary third order autoregression with no drift.

(d) $lnP20_t$[14]

The series $lnP20_t$ has a persistent autocorrelation function but $\Delta lnP20_t$ appears stationary as Figure VI.19 illustrates. .Verifying this observation with the ADF framework yields results shown in Table VI.5.

Figure VI.19: Correlogram of ΔlnP_t



As for the previous land price series two lagged terms are required to obtain white noise residuals and thus equation (VI.31) represents the maintained model for $lnP20_t$ also. The $\hat{\tau}_\tau$ statistic of -1.84 in the ADF regression (VI.36) does not allow rejection of the

14 Recall from the data appendix that $P20_t$, denotes a series of real average agricultural land prices in England and Wales excluding those sales of 20 ha.

unit root null suggesting that $lnP20_t$ is a random walk and $\Delta lnP20_t$ a stationary variable. The $\hat{\tau}_{\beta\tau}$ statistic is also too low at 1.50 to reject the null of an insignificant time trend, the 5% critical value being 2.81.

Table VI.5: Unit Root Tests Results for *lnP20*$_t$

Equation. No.	Regression Parameters					RSS
	constant	Time trend	$lnP20_{t-1}$	$\Delta lnP20_{t-1}$	$\Delta lnP20_{t-2}$	
(VI.36)	1.694	0.007	-0.233	0.525	-0.382	0.676695
	(1.88)	(1.50)	(-1.84)	(3.52)	(-2.25)	
(VI.37)	0.512		-0.062	0.452	-0.521	0.721512
	(1.15)		(-1.11)	(3.15)	(-3.57)	
(VI.38)	0.023			0.437	-0.557	0.746716
	(1.00)			(3.05)	(-3.91)	
(VI.39)				0.445	-0.452	0.767740
				(3.11)	(3.83)	

Sample comprises 39 observations (1950 - 1988) of the dependent variable $\Delta lnP20_t$.

Testing the set of zero restrictions imposed under the null of Test 2, (*i.e.* $\beta_1 = \beta_2 = 0$) reaches the same conclusion: The Φ_3 statistic calculated from the residual sum of squares from (VI.36) and (VI.38) is,

$$\Phi_3 = \frac{(0.746716 - 0.676695)/2}{0.676695/(39-5)} = 1.76$$

and cannot reject the null at the 5% critical value of 6.73.

To test for the significance of the drift in $lnP20_t$ implied by the constant in (VI.36), we compare the $\hat{\tau}_{\alpha\tau}$ statistic of 1.15 from (VI.36) with its distribution under the null that its true value is zero. As the 5% critical value of $\hat{\tau}_{\alpha\tau}$ is 3.14 the coefficient is insignificant, a result corroborated by the Φ_2 test of the null that $\beta_0 = \beta_1 = \beta_2 = 0$.

$$\Phi_2 = \frac{(0.767740 - 0.676695)/3}{0.676695/(39-5)} = 1.52$$

cannot reject the null at the 5% critical value of 5.13 implying that $lnP20_t$ is a simple random walk, hence an I(1) variable and $\Delta lnP20_t$ is a stationary I(0) process.

(e) lnPX_t

The correlograms for the Oxford series in levels and first differences are very similar to those presented for the other land price series and suggest that the first difference of the series is a stationary AR(2) process due to the sine wave decay of the correlogram of this series and the unit root test results are presented in Table VI.6 below. Pretesting suggests that, in accordance with the other land price series the Oxford series also requires two lagged differenced terms in the ADF regression to obtain white noise residuals.

Table 6: Unit Root Tests Results for $lnPX_t$

Equation. No.	Regression Parameters					RSS
	constant	Time trend	$lnPX_{t-1}$	$\Delta lnPX_{t-1}$	$\Delta lnPX_{t-2}$	
(VI.40)	0.141	0.0005	-0.021	0.207	-0.329	1.7312
	(0.82)	(1.63)	(-1.01)	(2.41)	(-3.79)	
(VI.41)	0.157		-0.019	0.221	-0.313	1.7690
	(0.91)		(-0.90)	(2.57)	(-3.62)	
(VI.42)	0.003			0.212	-3.268	1.7807
	(0.26)			(3.05)	(-3.83)	
(VI.43)				0.212	-0.326	1.7816
				(2.50)	(-3.85)	

Sample comprises 127 observations (1863 - 1990) of the dependent variable $\Delta lnPX_t$. All critical values of the tests outlined below are for a sample size of 100.

Referring to the ADF regression (VI.40), the t ratio on the coefficient of $lnPX_{t-1}$ is clearly insignificant, the critical value of the $\hat{\tau}_\tau$ statistic being -3.73. The coefficient on the time trend in (VI.40) is also insignificant (critical value of The $\hat{\tau}_{\beta\tau}$ being 3.11) and consequently these results imply that $lnPX_t$ has a unit root and that $\Delta lnPX_t$ is a stationary I(0) variable. Testing the joint restriction that both these coefficients are zero simultaneously corroborates this inference, Φ_3 taking the value of,

$$\Phi_3 = \frac{(1.7807 - 1.7312)/2}{1.7312/(127-5)} = 1.74$$

which cannot reject the null hypothesis at the 5% level (the critical value of Φ_3 being 6.49). To test for the significance of any drift in the random walk process we compare the t-ratio of the constant in the ADF regression to the critical value of the $\hat{\tau}_{\alpha\tau}$ statistic. At the 5% significance level the critical value is 3.11 thus the test statistic cannot reject the null of no drift of this test. For completeness we may test whether all three coefficients tested individually above are jointly zero by computing the Φ_2 statistic which is calculated as,

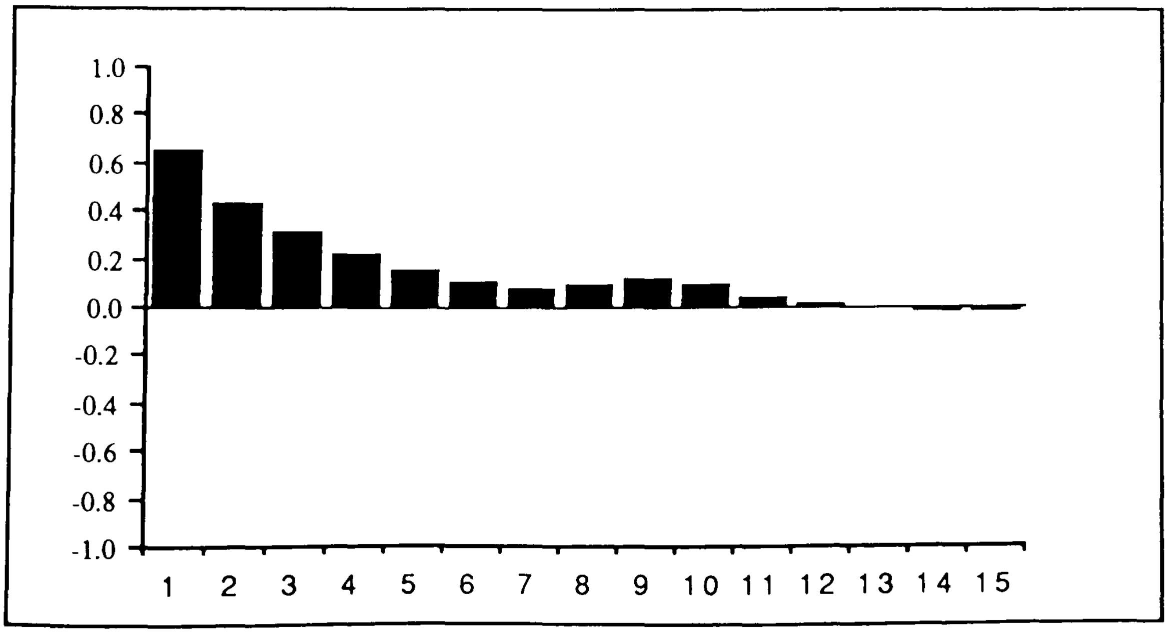
$$\Phi_2 = \frac{(1.7816 - 1.7312)/3}{1.7312/(127-5)} = 1.18$$

which cannot reject the null at the 95% confidence level (critical value 4.88). As with the other land price series these results imply that $lnPX_t$ is a driftless random walk, hence an I(1) variable and $\Delta lnPX_t$ is a stationary I(0) process with zero mean.

(f) The GDP Deflator series lnF_t

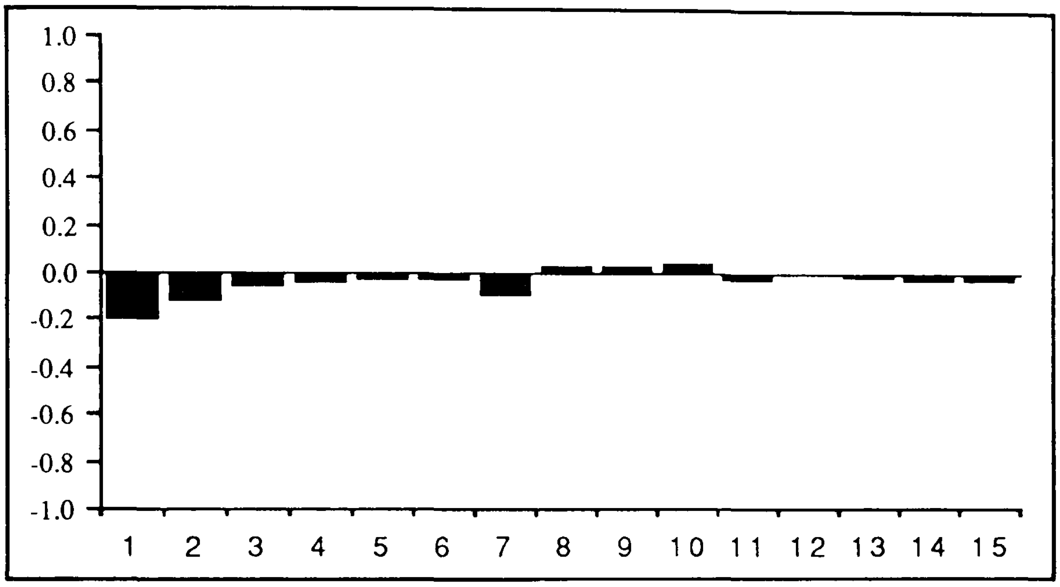
The informal analysis of this series in the last section suggested that the series is stationary when expressed in the second difference of the log of the original series, *i.e.* $\ln F_t \sim I(2)$ and $\Delta \ln F_t \sim I(1)$ and $\Delta^2 \ln F_t \sim I(0)$.

Figure VI.20 : Correlogram of $\Delta \ln F_t$



The Correlogram of $\Delta \ln F_t$ is illustrated in Figure VI.20 and the slow decline that is characteristic of non-stationarity is easily discernible, whereas the correlogram of the double differenced series rapidly approaches zero.

Figure VI.21 : Correlogram of $\Delta^2 \ln F_t$



On the basis of this informal evidence we set about testing for double unit roots. This may be achieved by regressing $\Delta^2 \ln F_t$ on a constant, $\Delta \ln F_{t-1}$ (and as many lagged terms as required to induce white noise residuals) and comparing the t ratio of the coefficient on $\Delta \ln F_{t-1}$ to the τ_μ distribution in Fuller (1976, p.373). Alternatively we may regress $\Delta^2 \ln F_t$ on F_{t-1}, $\Delta \ln F_{t-1}$ and as many lagged terms as required to induce white noise residuals and compute an F statistic for the joint significance of F_{t-1} and $\Delta \ln F_{t-1}$. Under the null of a double unit root this statistic has a distribution given by Hasza and Fuller (1979) as $\Phi_1(2)$. Here we will simply compare the t ratio with the critical values of τ_μ although neither test performs particularly well in the presence of departures from normality which characterises the distribution of this particular series. Equation (VI.44) in Table VI.7 reports a t ratio of -4.92 which rejects the null (5% and 10% critical values of this test being -2.89 and -2.58 respectively) suggesting that $\ln F_t$ does not have a double unit root, so that $\Delta \ln F_t$ is stationary.

Table VI.7: Testing for Double Unit Roots in lnF_t

Equation No.	Regressors	
	constant	$\Delta\ln F_{t-1}$
Sample 1873 - 1990		
(VI.44)	0.012	-0.347
	(2.31)	(-4.92)
Sample 1945-1990		
(VI.45)	0.021	-0.299
	(2.40)	(-2.76)

The dependent variable is $\Delta^2\ln F_t$.

However the unit root tests perform poorly in the presence of departures from the n.i.i.d. assumptions and in (VI.44) the $\chi^2(2)$ test for normality of the residuals yields a test statistic of 194.28, the 5% critical value of the test being 5.99. This casts some doubt on inferences made purely on the unit root test and suggests that we should look elsewhere for criteria on which to base a decision. Noting that the variance of a series diminishes with differencing until stationarity is achieved but increases if the series is over-differenced this quick informal test may also shed some light on the appropriate degree of differencing. Here the variances are,

$\text{var}(\ln F_t) = 1.3964$

$\text{var}(\Delta\ln F_t) = 0.0041$

$\text{var}(\Delta^2\ln F_t) = 0.0028$

$\text{var}(\Delta^3\ln F_t) = 0.0067$

which suggests that double differencing is required as $\Delta^2\ln F_t$ has the lowest variance. An alternative strategy is to limit the sample size since the departures from normality in this series occur in the first half of the series. Given that the deflator will be most extensively used in models based on post World War II samples this seems appropriate. Unit root testing on a post war sample lends some support to the informal evidence presented here, in that the 't' ratio in (VI.45) is not statistically different from zero at the 5% level implying the presence of a double unit root and thus we conclude that the inflation growth rate, ($\Delta^2\ln F_t$) is I(0); inflation, ($\Delta\ln F_t$) is I(1) and the GDP deflator index, (F_t) is I(2).

VI.(vii) Conclusion

Testing for stationarity forms an important preliminary stage of time series analysis, for if inferences concerning the parameters that describe the series are to be valid it is necessary that the parameters do not exhibit time dependence. The order of integration of a series is a descriptive statistic and tells us very little about the economic behaviour that underlies the series. However, since we wish to answer economic hypotheses using statistical analysis the quality and accuracy of our final inference is critically dependent on this somewhat arduous preparation. Furthermore, when we open up the analysis to consider the relationships between two or more series, stationarity and the order of integration play pivotal roles in an economic context, as will be discussed in the following Chapter on cointegration.

The analysis of the empirical time series on farm rents, land prices and inflation has indicated the need to apply a logarithmic transformation to each series prior to differencing to stabilize their variances. All the series are therefore difference stationary processes. No trend stationary processes have been identified. Using a battery of informal and formal methods, the variables have been transformed into stationary series characterised by constant mean and variance with autocovariances that depend only on the displacement in time. Here, the rent and land price series are shown to be I(1) driftless random walks in levels and hence stationary I(0) series in first differences. The GDP deflator appears to be I(2) entailing inflation is a non-stationary I(1) process, and the change of inflation I(0). Despite the low power of some of the ADF tests used, the formal results are generally consonant with the other less formal methods employed, with the exception of the GDP deflator series where a substantial departure from normality in unit root regressions biased inference in the ADF tests.

Appendix 1: Summary Tabulations of Unit Root Tests

Table A1: Empirical Distribution of $\hat{\tau}_\tau$

Sample Size	Confidence Level			
	0.90	0.95	0.975	0.99
25	-3.24	-3.60	-3.95	-4.38
50	-3.18	-3.50	-3.80	-4.15
100	-3.15	-3.45	-3.73	-4.04
250	-3.13	-3.43	-3.69	-3.99
500	-3.13	-3.42	-3.68	-3.98
∞	-3.12	-3.41	-3.66	-3.96

Source : Fuller (1976, p.373)

Table A2: Empirical Distribution of $\hat{\tau}_{\beta\tau}$

Sample Size	Confidence Level			
	0.90	0.95	0.975	0.99
25	2.77	3.20	3.59	4.05
50	2.75	3.14	3.47	3.87
100	2.73	3.11	3.42	3.78
250	2.73	3.09	3.39	3.74
500	2.72	3.08	3.38	3.71
∞	2.72	3.08	3.38	3.71

Source : Dickey and Fuller (1981, p.1062)

Table A3: Empirical Distribution of Φ_3

Sample Size	Confidence Level			
	0.90	0.95	0.975	0.99
25	5.91	7.24	8.65	10.61
50	5.61	6.73	7.81	9.31
100	5.47	6.49	7.44	8.73
250	5.39	6.34	7.25	8.43
500	5.36	6.30	7.20	8.34
∞	5.34	6.25	7.16	8.27

Source : Dickey and Fuller (1981, p.1063)

Table A4: Empirical Distribution of $\hat{\tau}_{\alpha\tau}$

Sample Size	Confidence Level			
	0.90	0.95	0.975	0.99
25	2.77	3.20	3.59	4.05
50	2.75	3.14	3.47	3.87
100	2.73	3.11	3.42	3.78
250	2.73	3.09	3.39	3.74
500	2.72	3.08	3.38	3.72
∞	2.72	3.08	3.38	3.71

Source : Dickey and Fuller (1981, p.1062)

Table A5: Empirical Distribution of Φ_2

Sample Size	Confidence Level			
	0.90	0.95	0.975	0.99
25	4.67	5.68	6.75	8.21
50	4.31	5.13	5.94	7.02
100	4.16	4.88	5.59	6.50
250	4.07	4.75	5.40	6.22
500	4.05	4.71	4.35	6.15
∞	4.03	4.68	5.31	6.09

Source : Dickey and Fuller (1981, p.1063)

Chapter VII
Testing for Long Run Relationships in the Present Value Model

VII.(i) Introduction

The analysis of univariate processes examined in the previous Chapter serves both to identify the temporal properties of the series at hand and as a prerequisite to the arguably more interesting study of the relationship between variables. Specifically, the belief that certain variables should not systematically diverge from each other, at least in the long run, is a common one in economics. In a host of circumstances economic forces militate against prolonged deviations from some ordained path, ensuring that divergence is only transitory. For example, the prices obtaining to a specific commodity in geographically separated markets, spot and futures prices, and short and long term interest rates, all possess this common notion. For the most part, this belief manifests itself in the equilibrium relationships posited by economic theory. The relationship between asset prices and returns is a case in point; intuition and present value theory suggest that there is a special relationship 'tying' these two variables together, such that they do not 'drift too far apart' in the long run. The existence of short run discrepancies reflects the possibility that adjustment to equilibrium is neither instantaneous nor perfect or that extraneous shocks may temporarily upset the hypothesised relationship. In short, such temporary divergences may be interpreted as representing some form of short-run disequilibrium.

Loosely speaking, a set of variables that exhibits this special relationship is said to be cointegrated. Consequently, testing for cointegration has recently become very popular in applied circles as a means of identifying the existence of equilibrium relationships posited by economic theory.

This Chapter has seven Sections and two Appendices. It opens with a brief review of the approaches that have previously been employed to model non-stationary time series prior to the development of cointegration. Leaning on the time series properties of stationary and integrated processes developed in the previous Chapter the concept of cointegration is set out and its relationship with error correction models explained. In Section (iii) two procedures are then presented which estimate and test for the presence of a cointegrating relationship in a data set. In Section (iv) there is a brief digression about econometric methodology in which the limits of cointegration are discussed. In Section (v) the present value model is re-introduced and in Section (vi) the techniques are applied to the empirical data and inferences are drawn. Finally, the results of the empirical analysis are summarised in Section (vii). In addition there are two appendices. The first summarises some relevant critical values for the cointegration tests and the second explains the technical detail of the main technique used for estimation and inference.

VII.(ii) Cointegration

(a) Modelling Non-stationary Variables

Following the work of Granger and Newbold (1977) considerable attention has been paid to the time series properties of variables entering into econometric models. Of particular concern is the use of integrated variables (characterised by strong trend components) which one commonly finds in economics. Unlike those for stationary series, the statistical properties of integrated series are not 'well behaved' as alluded to in the previous Chapter. Of note, the regression coefficients do not converge in probability as the sample size is increased; the regression coefficients and R^2 have non-degenerate distributions; and standard critical values are no longer appropriate in significance testing, (although the correct values can be obtained). Consequently, because orthodox estimation techniques, such as ordinary least squares assumes a distributional theory that is applicable only when the underlying processes generating the data are stationary the use of integrated series in these procedures invalidates the statistical tests on which hypotheses are commonly tested and frequently lead to the acceptance of spurious regressions.[1]

The initial solution to the analysis of integrated variables, adopted by some time series workers, was to formulate regressions in which variables were expressed as first differences. Whilst this procedure tends to induce stationarity, (subject to the caveats outlined in the previous chapter concerning trend staionary processes) it also entails loss of the potentially valuable long run information contained in the variables expressed in levels. Moreover, we are left with an equation comprising the short run dynamic relationships, about which economic theory has little to contribute, and have removed the long run relationships about which economic theory is informative.

The concept of cointegration has been introduced as a means of incorporating long run (or levels) information into equations that comprise only stationary components to which standard hypothesis testing may be legitimately applied. One class of models in

1 See Granger and Newbold (1974) and Phillips (1986) on this point.

which this is the case is the 'error correcting model', (ECM) introduced by Sargan (1964) and developed subsequently by Davidson *et al.* (1978) and in a number of papers by David Hendry. Cointegration has become increasingly popular with applied econometricians as a means of avoiding spurious regressions and as a means of purging standard (yet illegitimate) practice.

(b) Time Series Properties and Cointegration

From the analysis of the previous chapter it should be apparent that the time series properties of variables integrated to different orders are quite distinct. For example, consider an I(1) series, such as a random walk, given by,

$$y_t = y_{t-1} + \varepsilon_t$$

where ε_t is a normally distributed set of random variables with mean zero and constant variance *i.e.* NID(0, σ^2). The evolution of y_t is characteristically smooth returning to a previous value (or say the mean) only very infrequently. The process also has a variance that increases with the number of observations in the series and a persistent autocorrelation function indicating that the memory of an I(1) process is indefinitely long.

In contrast, an I(0) series, such as the first difference of a random walk, *i.e.* $\Delta y_t = \varepsilon_t$ is characterised by a constant mean, (here it is zero) around which the series fluctuates with constant variance, irrespective of sample size, and thus observations cross the mean value frequently with sustained deviations being rare. Consequently, the mean in an I(0) series assumes a special significance, in that it represents a 'central tendency' around which observations are dispersed. This contrasts distinctly with the mean of an I(1) process which does not have such an interpretation. Furthermore, autocorrelations in an I(0) series decay rapidly as the lag increases indicative of a process with finite memory. In the illustrative case considered here, Δy_t is a white noise process thus autocorrelations are zero for lags $k > 0$ indicating that the process has no memory at all. The point of this recapitulation is that these contrasting temporal properties play a pivotal role in testing for cointegration.

In general, any linear combination of two series integrated to different orders will result in a series that is integrated to the highest order in the linear combination. For example, suppose that,

$$z_t = \alpha x_t + \beta y_t$$

where $x_t \sim$ I(a) and $y_t \sim$ I(b) then in general $Z_t \sim$ I{max(a,b)}. A formal proof of this result is given in Granger (1981), but the dominance of higher order series may be demonstrated intuitively using the temporal properties of I(1) and I(0) series summarized above. Given that an I(1) variable, such as a random walk has a variance ($t\sigma_1^2$) yet an I(0) process has a constant variance (σ_0^2) then a linear combination of these series suggests that the I(0) process will be swamped by the influence of the I(1) process whose variance becomes infinitely large as the number of observations (t) increases. Following on in the same vein, a linear combination of two or more I(1) series will also be I(1) yet there may be instances where the linear combination is of lower order and this exception to the rule occurs where the variables are cointegrated.[2]

(c) Defining Cointegration

Consider a ($n * 1$) vector of variables $\mathbf{y}_t$ comprising n series each of which may be transformed into stationary processes (if not already). The vector of variables is said to be cointegrated if there exists at least one n-element vector α_i such that a linear combination $\alpha_i'\mathbf{y}_t = \varepsilon_t \sim$I(0). In this framework α_i is called a cointegrating vector and if there exists r such linearly independent vectors, α_i, ($i = 1, \ldots r$) we may state that $\mathbf{y}_t$ is cointegrated with cointegrating rank r allowing us to form a ($n * r$) cointegrating matrix $\alpha = (\alpha_i, \ldots, \alpha_r)$ so that the r elements of the vector $\alpha_i'\mathbf{y}_t$ are also stationary.

This is a more general definition of cointegration than given in Engle and Granger (1987), which required that all elements of $\mathbf{y}_t$ be integrated of the same order. Motivating the use of this more general definition is the fact that in practice the analyst will wish to include variables in y_t that are integrated to different orders in the ECM, {typically I(1) and I(0) processes} although only variables of the same order may be cointegrated and hence enter the long run (cointegrating) regression. To see this, consider the case where the I(1) variables do not form a cointegrating set so that the residuals from the 'cointergating' regression are themselves I(1). Clearly, the addition of any number of I(0) variables will not induce cointegration since a linear combination

2 This points out why regressions in which components are not I(0) give misleading inferences because a linear combination of I(1) variables which are not cointegrated will yield non-stationary residuals which as a consequence will not have finite first and second moments (mean and variance) and thus the basic assumption of OLS is violated.

of the I(1) residuals and additional I(0) variables will always be I(1). In contrast, where cointegration is found among the I(1) variables, the addition of I(0) variables is unnecessary.

It should be apparent that where $\mathbf{y}_t$ is composed entirely of I(0) variables cointegration is a trivial artefact since any linear combination of the I(0) variables will yield a stationary error term. Thus in cases where $\mathbf{y}_t$ contains both I(1) and I(0) variables a cointegrating vector will also be trivially discovered; that being the unit vector which selects the stationary variables. However, in order to find a n element vector (consistent with the definition above) in such circumstances implies the presence of a special relationship between the I(1) components of $\mathbf{y}_t$ which yields an I(0) linear combination. Similarly, where $\mathbf{y}_t$ consists solely of I(1) components a linear combination that is I(0) implies cointegration and Engle and Granger (1987) have shown that where $\mathbf{y}_t$ consists solely of I(1) components there can be no more than (n - 1) cointegrating vectors, *i.e.*, $r \leq (n - 1)$.

Moreover, where $\mathbf{y}_t$ comprises just two I(1) variables such that the normalized linear combination, $y_{1t} + \alpha y_{2t} = \varepsilon_t$ is I(0) the cointegrating vector $(1\ \alpha)$ must be unique, since any other combination would yield ε_t that was I(1) although this is not necessarily the case for $n > 2$ as is discussed below.[3]

To clarify the concept of cointegration let us consider the simplest case: where $\mathbf{y}_t$ comprises just two variables, y_{1t} and y_{2t} each of which is I(1) and generated by a random walk process. Generally, any linear combination of these series, ε_t will also be I(1), yet there may exist some vector α which renders $\varepsilon_t \sim$ I(0) . If this is the case then the variables in $\mathbf{y}_t$ are said to be *cointegrated* and α is known as the *cointegrating vector*. Noting that, in this instance $\alpha'\mathrm{y}_t = \varepsilon_t$ is simply

$$\begin{bmatrix}\alpha_1 & \alpha_2\end{bmatrix}\begin{bmatrix}y_{1t}\\ y_{2t}\end{bmatrix} = \begin{bmatrix}\varepsilon_t\end{bmatrix}$$

if we normalize on one variable[4], say, y_{1t} then,

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3 To see why the cointegrating vector is unique in the bivariate case, consider the following. If we change the cointegrating vector to $(1\ \alpha - \delta)$ we now have $y_{1t} = (\alpha - \delta)y_{2t}$ which differs by the quantity δy_{2t}. Since y_{2t} is I(1), so will δy_{2t} and thus $y_{1t} - (\alpha - \delta)y_{2t}$ must also be nonstationary. Consequently, $(1\ \alpha - \delta)$ cannot represent a valid cointegrating vector.

4 Normalising simply involves the division of every element of the cointegrating vector by the negative of the coefficient on the dependent variable, so that the dependent variable has a coefficient equal to minus one.

$$y_{1t} = \alpha y_{2t} + \varepsilon_t \qquad \text{where } \alpha = (\alpha_2/\alpha_1)$$

The existence of a cointegrating vector implies that there exists a very special relationship between the two series, in that, the behaviour of one series is 'mirrored' (albeit with random error ε_t) by the other : α merely representing a scaling factor. If we regard $y_{1t} = \alpha y_{2t}$ as an equilibrium (or steady state) relationship posited by economic theory then ε_t denotes a quantity which measures the extent to which the relationship is out of equilibrium; ε_t may thus be interpreted as a 'disequilibrium error'. Hence, the existence of a linear combination of two I(1) series that is I(0) suggests that in the long run the series generally move together. Providing ε_t is I~(0) then non-zero values of ε_t simply reflect the fact that the adjustment to the steady state equilibrium is not instantaneous but is observed with error - an error however, that has a expected value of zero, given that the mean ε_t is zero.

If y_{1t} is I(0) and y_{2t} I(1) then the only value that α could plausibly assume is zero : in essence, the two series have such distinct temporal properties that no scaling constant exists to produce the 'mirroring' that is implied by a cointegrating relationship. This reveals why testing for the order of integration forms such an important part of cointegration analysis. Therefore cointegration represents an effective specification test against spurious regressions because only variables with the same temporal properties can be cointegrated, *i.e.* have a long run relationship.

(d) An Error Correction Representation of a Cointegrated System

The consideration of cointegration presented so far has only focussed on the long run or equilibrium properties posited by economic theory. Indeed economic theory itself has very little to say of the dynamic process by which variables move toward equilibrium. Engle and Granger (1987) have proved that if two or more series are I(1) and cointegrated then there exists an error correction representation of the model and *vice versa*. For example, consider two variables x and y which have a simple distributive lag structure of order one such that,

$$y_t = a_0 + a_1 x_t + a_2 x_{t-1} + a_3 y_{t-1} + \varepsilon_t \qquad \text{(VII.1)}$$

where ε_t are white noise residuals. Subtracting y_{t-1} from both sides of (VII.1) yields,

$$\Delta y_t = a_0 + a_1 x_t + a_2 x_{t-1} + (a_3 - 1) y_{t-1} + \varepsilon_t \qquad \text{(VII.2)}$$

Adding and subtracting $(a_1 - 1)x_{t-1}$ from the RHS of (VII.2) leaves,

$$\Delta y_t = a_0 + a_1 x_t + a_1 x_{t-1} - a_1 x_{t-1} + a_2 x_{t-1} + (a_3 - 1)y_{t-1} + \varepsilon_t$$

$$= a_0 + a_1 \Delta x_t + (a_1 + a_2)x_{t-1} + (a_3 - 1)y_{t-1} + \varepsilon_t \qquad \text{(VII.2')}$$

Grouping the terms of (VII.2') into linear functions of variables in first differences and levels yields,

$$\Delta y_t = a_1 \Delta x_t - \lambda(y_{t-1} - \psi_1 x_{t-1} - \psi_0) + \varepsilon_t \qquad \text{(VII.3)}$$

where $\lambda = (1 - a_3)$, $\psi_1 = (a_1 + a_2)/(1 - a_3)$ and $\psi_0 = a_0/(1 - a_3)$. Equations (VII.3) and (VII.1) are observationally equivalent since each equation produces the same error term ε_t. Also, the error correction model lends itself quite nicely to economic interpretation. The differenced terms in the ECM describe the short-run dynamic relationship given here by a_1, whereas the long run information is picked up by the lagged-levels term in parentheses: ψ_1 representing the long run relationship between the variables and λ is a scalar adjustment coefficient which quantifies the extent to which the two series diverge from their long-run equilibrium. The negative sign of λ signifies that disequilibrium in the previous period will be 'corrected' for in the following period as the process adjusts back to equilibrium, hence the label *error correction* model. The novelty of the error correction form derives from its incorporation of information pertaining to both the long-run relationship and the short run dynamics between the variables.

To recognise the link between the ECM and cointegration note that if y and x are I(1) then the dependent variable, Δy_t is I(0) which inturn must also be explained by I(0) processes. Whilst Δx_t is I(0) by assumption, the error correction term $(y_{t-1} - \psi_1 x_{t-1} - \psi_0)$ contains I(1) variables, namely y and x. Consequently, there only exists an error correction representation of these two variables if the linear combination of y and x is I(0) and this will only occur where the two variables are cointegrated Further, the error correction term in (VII.3) may be thought of as the residuals from a static cointegrating regression of y on x which will only be I(0) if the movement in one variable is reflected in the movement of the other, albeit with error given by $(y_{t-1} - \psi_1 x_{t-1} - \psi_0)$.

Thus if y and x are I(1) and cointegrated the error correction term will be I(0). Should they not be cointegrated, then the error correction term would be I(1) and hence could have no valid role in the ECM, which attempts to explain Δy_t, which is I(0) by definition. Consequently, in the presence of cointegration the ECM represents a plausible description of the dynamic process between a set of integrated variables. As all components are stationary under cointegration, the ECM can be estimated by OLS and inferences may be legitimately based on standard critical values.

In many empirical applications of (VII.3) the restriction $\psi_1 = 1$ is appropriate, since if the variables are expressed in logarithmic form this restriction ensures that the ratio of x to y is unity in the long run. Consequently, the ECM takes the form,

$$\Delta y_t = \alpha + \beta \Delta x_t - \gamma(y_{t-1} - x_{t-1}) + \varepsilon_t$$

which has a long run solution (when $y_t = y_{t-1} = y$ and $x_t = x_{t-1} = x$) of,

$$y = \alpha/\gamma + x \qquad \text{(VII.4)}$$

Antilogging (VII.4) yields the non-linear function Y = KX, hence K is the scaling factor which translates the level of X to Y in the long run. Although we will examine the error correction formulation with reference to cointegration in the land market in Section (iv), simply note here the similarity between Y = KX and the annuity derivation of the present value hypothesis discussed in Chapter IV. In terms of the present value hypothesis, K represents the capitalisation rate 1/r between returns and land prices where r is the long run rate of discount.

VII.(iii) Testing For a Cointegrating Relationship

The appealing properties of the ECM and its relationship with cointegration have provided an (empirically tractable) bridge between static equilibrium in economics and the role of dynamic behaviour. In recent years a great number of test procedures and statistics have been spawned in the literature on cointegration, {*inter alia* Engle and Granger (1987), Wickens and Breusch (1988), Johansen (1988), Stock and Watson (1990) Park (1990) and Phillips and Ouliaris (1988)} most of which are reviewed in a recent paper by Campbell and Perron (1991). Attention here focuses on two of the most enduring and widely used test procedures of Engle and Granger (1987) and Johansen (1988). The two approaches are essentially different in that each is grounded in a distinct econometric methodolgy. Specifically, the Johansen procedure assumes that all the variables of interest are endogenous whereas the Engle and Granger approach assumes that there is one endogneous variable and the remaining variables are exogenous. Consequently, the Engle and Granger approach uses a single equation, the Johansen a system of equations approach. In special circumstances however both approaches yield identical results, that being where all but one of the variables is exogenous.

(a) Cointegration Testing Using a Static Regression

The Engle and Granger (1987) test procedure is a two-step method in which a static cointegrating regression comprising I(1) components is estimated and its residuals tested for stationarity. Finding stationary residuals implies that the I(1) variables are cointegrated. Conditional upon finding cointegration, residuals from the static regression are then incorporated into an ECM to estimate the short run dynamics of the hypothesised relationship. Applying OLS to the cointegrating regression yields,

$$\hat{\alpha}' y_t = \hat{\varepsilon}_t \tag{VI.5}$$

Assuming that the residuals $\hat{\varepsilon}_t$ follow an AR(1) process so that,

$$\hat{\varepsilon}_t = \rho \hat{\varepsilon}_{t-1} \tag{VI.6}$$

then cointegration in y_t implies that $\rho < 1$, *i.e.* the residuals $\hat{\varepsilon}_t$ are stationary.

In principle, any test for a unit root versus stationarity can be used as a test for no cointegration versus cointegration when applied to the residuals of the cointegration regression. Engle and Granger (1987) analyse the properties of seven tests for cointegration and on the basis of their investigation, recommend two; the CRDW and ADF tests. The Cointegrating Regression Durbin-Watson (CRDW) statistic proposed by Bhargava (1983) is advocated due to its simplicity although should only be used as a means of obtaining 'a quick approximate result', Engle and Granger (1987, p.269). The CRDW test uses the standard Durbin-Watson statistic,

$$\text{DW} = \frac{\sum_{t=2}^{T} (\hat{\varepsilon}_t - \hat{\varepsilon}_{t-1})^2}{\sum_{t=1}^{T} \hat{\varepsilon}_t^2}$$

from the cointegrating regression and tests for cointegration in y_t by testing the implicit hypothesis that,

H_0: $\rho = 1$

H_1: $\rho < 1$.

in (VI.6). Under the null of a unit root in (VI.6), $\hat{\varepsilon}_t$ are a random walk and hence cannot be stationary implying that there is no cointegration in y_t. Under the alternative $\hat{\varepsilon}_t$ are a stationary I(0) process and this implies cointegration. In cases where $\hat{\varepsilon}_t$ are nonstationary the DW statistic will approach zero and the null hypothesis of no cointegration will not be rejected. Hence a large DW statistic is suggestive of I(0) residuals and this implies cointegration. Critical values of the CRDW test are non-standard, depending on the number of integrated variables in the cointegrating regression and the order of the autoregressive process of $\hat{\varepsilon}_t$. At present a limited number of critical values are available but have been reproduced here in Table A1 of

Appendix I.

The second and preferred test is the Augmented Dickey Fuller (ADF) test proposed by Dickey and Fuller (1981). Using the residuals $\hat{\varepsilon}_t$ from a cointegrating regression an ADF regression is formed such that,

$$\Delta\hat{\varepsilon}_t = \phi\hat{\varepsilon}_{t-1} + \sum_{i=1}^{m} \delta_i \Delta\hat{\varepsilon}_{t-i} + v_t \qquad \text{(VI.7)}$$

where m is chosen so as to produce errors v_t that are empirical white noise. The ADF test statistic is the 't-ratio' on the estimated value of ϕ.

Under the null hypothesis, $H_0 : \phi = 0$, $\Delta\hat{\varepsilon}_t$ are stationary, implying that $\hat{\varepsilon}_t$ are not. Consequently, if the variables in the static regression are cointegrated then $\hat{\varepsilon}_t$ are I(0) and rejection of the null of the ADF test implies cointegration. Again, the distribution of this statistic is nonstandard; importantly, critical values are not the same as those applied to the raw series in unit root tests as they depend on the number of integrated regressors in the cointegrating regression. Engle and Granger (1987) present some summary tabulations of this statistic for the bivariate case although more extensive tables appear in Engle and Yoo (1987). These are reproduced in Appendix I as Table A2 and Table A3 for convenience. In circumstances where $m = 0$ in the empirical specification of (VI.7), appropriate critical values are those in Table A2, otherwise use those in Table A3.[5]

Research by a number of authors has shown that when using the two-step procedure cointegration has several important implications for the estimation and testing process, which may be summarized as follows.

(i) When the variables are cointegrated, ordinary least squares (OLS) should give an 'excellent' estimate of the true long run parameter α in large samples. This arises from the property of 'superconsistency' which characterises the cointegrating regression under the null of cointegration. Stock (1987) proves that under cointegration not only is the estimate of α consistent (in that it converges to the true value as sample size increases) but it is also highly efficient (in that the variance of the estimate is smaller than in the standard case where the variables are

5 Strictly, a set of critical values should apply for each m specified, hence the critical values reported here where $m = 4$ are not fully efficient where the empirical specification of the ADF does not require four lagged first difference terms. Nevertheless, such efficiency will disappear as the sample size increases.

not cointegrated). Consequently, the parameters in the cointegrating vector converge to the true parameter values more rapidly than the least squares estimator in the standard case.[6]

(ii) The superconsistency property does not require the absence of correlation between the explanatory variables and the error term because the correlation is of a lower order in T than the variance of the regressors. In short, biases arising from correlation are asymptotically negligible, thus the long run parameters estimated in the static cointegrating regression will be unbiased (in large samples) despite misspecification (in this case exclusion) of the dynamics of the relationship. See Stock (1987).

(iii) Engle and Granger (1987) demonstrate that estimates of the short run parameters from the ECM are as efficient (asymptotically) as those that would be produced if the true long run parameters had been used in the ECM (as opposed to those estimated from the cointegrating regression). Intuitively, this result derives from imposing the set of parameter values from the cointegrating regression, which have minimum least squares errors and allow faster convergence for the remaining parameters in the ECM.

(iv) If all variables are I(1) and cointegrated then there always exists an error correction model describing the short run relationship between the variables. Further, the reverse is also true, in that data generated by an error correction formulation must be cointegrated. This results derives from the *Granger representation theorem* (Engle and Granger (1987) and may be recognized by stating that if the variables are I(1) their first differences will be stationary I(0) and so every term in the ECM is I(0) providing the residuals are stationary. This will occur only if the variables in levels are cointegrated. If the residuals are not I(0) then the variables are not cointegrated and hence they do not belong in an error correction model.

(v) For the two variable case the cointegrating parameter is unique since the estimate of the cointegrating parameter from the reverse regression of Y_{2t} on Y_{1t} should be equivalent to the reciprocal of α estimated in the forward regression in large samples. However, this is not necessarily the case where the number of integrated

6 It is important to note that superconsistency is an asymptotic (or large sample) result. Banerjee *et al*. (1986) suggest that the bias in small samples may be considerable and for the bivariate case outlined above is related to $(1 - R^2)$. Stock (1987) demonstrates that the finite sample bias to be of the order T^{-1}: monte carlo simulation experiments tend to confirm these analytical results. Consequently, the benefits of superconsistency may be outweighed by the bias where the sample size is 'small'.

variables in the cointegrating regression exceeds two, a problem we will investigate later.[7]

(vi) If y and x are cointegrated then there must be Granger Causality in at least one direction as one variable can aid the forecasting of the other. Granger (1986).

Some Caveats Regarding the Two-Step Procedure

There are however a number of problems that remain unresolved in the empirical application of the two-step procedure. Specifically, the bias of the cointegrating regression parameter estimates in small samples has been shown by Banerjee *et al.* (1986) to be around $(1 - R^2)$. Second, recall that where there are more than two integrated variables in the cointegrating regression the uniqueness of the cointegrating vector is not guaranteed: indeed, for n integrated variables the number of distinct cointegrating vectors is given by $r \leq n - 1$. Consequently, in circumstances where there are more than two variables in $\mathbf{y}_t$ several equilibrium relationships may exist depending on which variable is chosen as the regressand with no objective means of identifying the true relationship. Although Hall (1986) suggests that the estimates from performing all different inversions of the cointegrating regression may define bounds in which the true equilibrium values of the parameters lie, ideally we require more than informed supposition in this matter. Third, the test procedures do not have well defined limiting distributions and are thus sensitive to choice of maintained model in which the null and alternative hypotheses are nested. Fortunately, these problems have been addressed by Johansen (1988a) who proposes a maximum likelihood estimation procedure, to which our attention now turns.

(b) The Johansen Procedure

Given that there may exist upto $n - 1$ cointegrating vectors in a regression of n integrated variables the analyst may be confronted with large parameter space in which the true relationship may lie using the Engle and Granger (1987) method. Clearly, where estimation of all the possible inversions of the original specification of the cointegrating regression imply similar results the analyst may feel safe to assume that each inversion is simply a reciprocal estimation of the same long-run relationship and choose the regression with the highest R^2 as yielding the most precise estimate of the true relationship. Where this is not the case a method that allows the number of distinct cointegrating vectors to be tested is clearly beneficial. The method proposed by

7 This is not so for OLS in general but arises under cointegration because of the superconsistency property. See Hall and Henry (1988) for an intuitive explanation of why this is so.

Johansen (1988a) and developed in Johansen and Juselius (1990) does precisely that using Full Information Maximum Likelihood (FIML) methods. For instance, in a trivariate system we may test the null of one cointegrating vector against an alternative that there are two or three cointegrating vectors linking the variables - the latter case being where all the variables are I(0) in the first place (and is effectively a multivariate or general test for unit roots).[8]

The Error Correction Model in a Vector Autoregressive Framework

It will be worthwhile to dwell at some length on the specification and testing framework adopted by Johansen since such issues are ignored in the formal derivations given in the references and a less rigourous treatment of the procedure has not yet been published. To begin, the analysis is couched in a general polynomial distributed lag framework, more commonly known as a vector autoregression (VAR) model. In this framework each variable in the system is regressed on its own lagged values, lagged values of each of the other variables plus any deterministic components (such as linear trends, dummy variables and a constant) until the error term in each equation is empirical white noise, implying that the chosen specification of the VAR is an adequate (but perhaps over-parameterised) description of the data generation process for each of the variables in the system. The VAR(k) model of variables comprising X_t may be written as,

$$X_t = \Pi_1 X_{t-1} + \ldots + \Pi_k X_{t-k} + \mu + \Phi Z_t + \varepsilon_t \qquad t = 1, \ldots, T \qquad \text{(VI.8)}$$

where X_t is a $(n * 1)$ vector of I(1) variables, Z_t a vector of I(0) variables[9], μ a constant vector and ε_t an $(n * 1)$ vector of random disturbances of zero mean and variance matrix Ω, *i.e.* $\varepsilon_t \sim$ n.i.d.$(\mathbf{0}, \Omega)$. The VAR representation is attractive for a number of reasons, not least because estimation proceeds in the first instance with the minimum of *a priori* restrictions imposed on the model's structure: the nature of causality between the variables in the system and the specification of dynamics are both left to the data to determine, within the confines of the variables actually specified in the first place. Restricted versions of the original VAR can then be tested against each other

8 Note that the Johansen procedure does not require all variables to be of the same order as Engle and Grangers' two-step procedure does, thus the rank of the cointegrating matrix r may equal the number of variables, in the case where all variables are I(0), although clearly this is a special case of trivial practical importance. As a result any I(0) regressors are treated separately.

9 As a point of interest z_t actually represents a vector of any variables that are included in the system to ensure that the errors in the system ε_t are as close to being Gaussian as possible and thus may also contain dummy variables that are exogenous to the VAR under consideration.

so that a final (and perhaps highly restricted model) can be demonstrated (rather than presumed) to be consonant with the data. The methodological advantages of the general to specific approach embodied in the VAR are however obtained at the cost of initial over-parameterisation. Since the number of parameters increases dramatically as the number of variables and lag length increases, the initial over-parameterisation implies a loss of efficiency in estimation using small samples, and although the effect diminishes asymptotically the inefficiency of the estimation is an acknowledged drawback.[10]

We will develop the notion of a cointegrating matrix below but for the time being it is worth noting that if account is taken of the lagged influences between the variables in the VAR (given by the coefficient matrices $\Pi_1 + \ldots + \Pi_k$) then what remains will represent the coefficients of the long-run relations between the variables. From the model in (VI.8) the cointegrating matrix is therefore,

$$\mathbf{I} - \Pi_1 - \Pi_2 \ldots - \Pi_k = \Pi$$

which is a $(n * n)$ matrix with a rank r equal to the number of distinct long run (or cointegrating) relations between the variables in X_t.

Due to the non-stationarity that characterizes economic time series in general, and the implications this has on estimation and inference the vector autoregression representation in levels, (VI.8), is reparameterized as an error correction model,

$$\Delta X_t = \Gamma_i \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \mu + \Phi Z_t + \varepsilon_t \qquad \text{(VI.9)}$$

where

$$\Gamma_i = (-\mathbf{I} + \Pi_1 + \Pi_2 \ldots + \Pi_i) \qquad i = 1 \ldots k-1$$

and

$$\Pi = (-\mathbf{I} + \Pi_1 + \Pi_2 \ldots + \Pi_k)$$

Notice that (VI.8) and (VI.9) are equivalent since the vector of errors in both models are identical. This is an important point and deserves some explanation since it is not immediately obvious why models with a vector of variables in levels and a vector of variables in first differences on the LHS should possess the same error terms, although as we will see the procedure is similar to that set out for the single equation case. Consider the VAR(2) model that will be used in the empirical analysis,

$$X_t = \Pi_1 X_{t-1} + \Pi_2 X_{t-2} + \mu + \Phi Z_t + \varepsilon_t \qquad t = 1, \ldots, T \qquad \text{(VI.10)}$$

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10 If d represents the number of deterministic components in the VAR (constants, dummies, time trends and so forth) then the number of coefficents to be estimated is $n(nk+d)$.

which, according to (VI.9) has an ECM,

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \Pi X_{t-2} + \mu + \Phi Z_t + \varepsilon_t \qquad t = 1,\ldots,T \qquad \text{(VI.11)}$$

The reparameterisation begins by subtracting X_{t-1} from (VI.10) so that the LHS is in first difference form yields,

$$\Delta X_t = (-\mathbf{I} + \Pi_1)X_{t-1} + \Pi_2 X_{t-2} + \mu + \Phi Z_t + \varepsilon_t \qquad t = 1,\ldots,T \qquad \text{(VI.12)}$$

If we add and subtract $(\Pi_1 - \mathbf{I})X_{t-2}$ to the RHS of (VI.12) we have,

$$\begin{aligned}\Delta X_t &= (-\mathbf{I} + \Pi_1)X_{t-1} + \Pi_2 X_{t-2} + (\Pi_1 - \mathbf{I})X_{t-2} - (\Pi_1 - \mathbf{I})X_{t-2} + \mu + \Phi Z_t + \varepsilon_t \\ &= (-\mathbf{I} + \Pi_1)X_{t-1} - X_{t-2} + (\Pi_1 - \mathbf{I})X_{t-2} + \Pi_2 X_{t-2} + \mu + \Phi Z_t + \varepsilon_t \\ &= (-\mathbf{I} + \Pi_1)\Delta X_{t-1} + (-\mathbf{I} + \Pi_1 + \Pi_2)X_{t-2} + \mu + \Phi Z_t + \varepsilon_t \qquad \text{(VI.13)}\end{aligned}$$

which is identical to (VI.11) since in this example $(-\mathbf{I} + \Pi_1)$ is Γ_1 and $(-\mathbf{I} + \Pi_1 + \Pi_2)$ is Π. It should now be clear that it is legitimate to use ε_t in both parameterisations since by rewriting (VI.13) purely in terms of levels,

$$X_t - X_{t-1} = -X_{t-1} + \Pi_1 X_{t-1} + X_{t-2} - \Pi_1 X_{t-2} + (-\mathbf{I} + \Pi_1 + \Pi_2)X_{t-2} + \mu + \Phi Z_t + \varepsilon_t$$

it is obvious that $-X_{t-1}$ cancels, leaving an equation composed entirely of levels. Therefore, the manipulation has not altered the relationship between the variables in any way but merely expresses it in a form that is statistically appropriate and more economically meaningful than the (observationally equivalent) levels specification given by (VI.8).

If X_t comprises I(1) processes then the ECM given by (VI.13) comprises stationary components, if and only if, the I(1) variables yield a linear combination that is I(0). This occurs where the variables are cointegrated, and since all components are stationary, ordinary least squares can be legitimately applied. Where the variables comprising X_t do not cointegrate, the linear combination of the variables expressed in levels will be I(1) because in general, any linear combination of variables integrated to different orders will have an order corresponding to the highest order in the linear combination.[11] This entails that the error term in the ECM will thus be I(1), violating the classical assumptions on which estimation and inference are based.

Furthermore, if economic theory suggests that two or more variables form an equilibrium relationship then economic forces will ensure that deviation from equilibrium - disequilibrium - will be transitory. Disequilibrium enters the ECM of

[11] The exception to the general rule is where the variables cointegrate.

equation (VI.9) via ΠX_{t-k} (see below) and will therefore be stationary if disequilibrium is transitory. This implies that if a long run relationship exists between the variables included in X_t then ΠX_{t-k} will be stationary and if not then the variables in X_t do not constitute a long run relationship. In this light the usefulness of cointegration as a means of discriminating spurious and valid equilibrium relationships is clearly apparent.

The interpretation of a VAR error correction mechanism follows similar lines to the discussion in Section (ii) of this Chapter, except that by expressing the relationship between a set of variables as a VAR there is no presumption concerning the direction of the relationship(s) *i.e.* the causality. With a single equation an important prior has been imposed on the estimation, in that the equation is specified as Y = *f*(X), without the direction of the causality (in the Granger sense) actually having been tested. Using the more general VAR approach there is no such presumption since all inversions of the model are estimated within the VAR. The VAR does however collapse to a single equation in special circumstances, namely where a subset of the variables are exogenous to the remaining variable in the VAR. Consequently, if we begin by assuming that all the variables in the system are endogenous and find that (n -1) variables are exogenous to the remaining variable then the Johansen method of estimating the long run relationship collapses to the Engle-Granger method where the right hand side variables are exogenous by assumption.

A further advantage of the error correction specification is that it isolates the long run equilibrium relationship from the short run (or dynamic) response to disequilibrium in a convenient way. Returning to (VI.11), we can interpret $\Gamma_1 \Delta X_{t-1}$ as describing the short run dynamic relationships between the variables whereas the long run relations pertinent to the concept of equilibrium are described in the linear combination ΠX_{t-2}. In order to interpret the coefficients of Π in an economically meaningful way Johansen (1988a) defines two $(n * r)$ vectors, where r is the rank of Π, such that,

$$\Pi = \alpha\beta' \qquad \text{(VI.14)}$$

where the linear combination,

$$\beta' X_{t-2} = W \qquad t = 3, \ldots T$$

is a $(r * r)$ matrix of stationary variables. The presence of cointegration implies that $r > 0$ and that the number of rows in β' represents the number of distinct cointegrating relations, r. Assuming that $r = 1$ so that the cointegrating vector is unique the single row of coefficients in β' define the parameters of the cointegrating or long run relationship between the variables of the system. The error correction model can consequently be rewritten in the form,

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \alpha W + \mu + \Phi Z_t + \varepsilon_t \qquad t = 1, \ldots, T \qquad \text{(VI.15)}$$

The role of the (n * 1) vector α now becomes clear in that it represents the fixed coefficients to which the disequilibrium errors are weighted in each inversion of the ECM. Because each element of α weights the disequilibrium errors in each equation α is the vector of error correction coefficients which Johansen calls the *loading vector*. The coefficents of α represent the average rate of adjustment back to equilibrium in the error correction model given an initial disequilibrium error. In other words, each coefficient in the loading vector gives the sign and magnitude of the error correcting term in each of the dynamic equations represented by (VI.11).

Using maximum likelihood methods, Johansen demonstrates that β may be consistently estimated by $\hat{\beta}$ from the available sample data and develops two likelihood ratio statistics that test for the presence of cointegration, called the *trace* and *maximal eigenvalue* statistics. These test statistics are derived in Appendix II, however, both seek to test hypotheses concerning the rank of the estimated cointegrating matrix Π since it is this that determines the number of distinct cointegrating vectors $\beta = (\beta_1, \beta_2, \ldots, \beta_r)$. Denoting $r = \text{Rank}(\Pi)$, there are two possible cases,

(i) $r = 0$ and Π is the null matrix since there are no cointegrating vectors in β. This means that all linear combinations of X_t are I(1) and thus do not belong in an ECM. None of the variables cointegrate and the VAR must be respecified by, for example, the inclusion of extra variables.

(ii) $0 < r < n$ so that Π is of reduced rank, implying that there exist r linear combinations of some or all of the variables in X_t that are I(0). Providing that all the variables in X_t are I(1) this implies cointegration and allows us to formulate the hypothesis that $\Pi = \alpha\beta'$ described above.[12]

The trace statistic tests the null that there are at most r cointegrating vectors and the

12 Should $r = n$ so that Π is of full rank, this implies that there are n cointegrating vectors in β. This means that all variables in X_t are stationary since all linear combinations of I(0) variables are also I(0). However, because all stationary variables are confined to the $\mathbf{Z}_t$ vector in the formulation given in (1) the full rank case should not occur by construction.

maximal eigenvalue statistic tests the null hypothesis of r cointegrating vectors against the alternative of $r + 1$ cointegrating vectors. Whilst both statistics have invariant and well defined limiting distributions, entailing that a single set of critical values can be tabulated for any number of variables specified in the VAR, the presence of a constant term plays a crucial role in the interpretation of the model and the underlying probabilistic analysis - requiring two sets of critical values depending on whether the constant in (VI.9) is included explicitly or not.

Johansen (1991) Theorem 4.1 proves the general result that if $\Pi = \alpha\beta'$ a constant term μ in (VI.9) implies that the non-stationary variables in X_t have linear trends. However, where linear trends are absent from X_t simply excluding μ from (VI.9) not only restricts the trend term to be absent but also entails that (VI.8) has no constant. This is because the constant term in (VI.9) can be decomposed into two parts, one of which contributes to the intercept in the cointegrating relation and the other which determines a linear trend. The coefficents of the linear trend are functions of μ although only through $\alpha_T'\mu$ where α_T is an $n * (n - r)$ matrix of vectors chosen orthogonal to α', *i.e.* $\alpha_T\alpha' = \mathbf{0}$. Thus in order to restrict the trend to be absent from (VI.8) but not the constant term Johansen augments the $\beta' X_{t-k}$ term to $\beta^{*\prime} X_{t-k}^*$ where $\beta^* = (\beta', \beta'_0)$ and $X_{t-k}^* = (X_{t-k}, 1)$. To see how this gives a constant term to both (VI.8) and (VI.9) without implying a trend, consider by means of illustration the restricted VAR(2) model in error correction form where $\Pi = \alpha\beta^{*\prime}$,

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \alpha\beta^{*\prime} X_{t-2} + \Phi Z_t + \varepsilon_t \qquad t = 1,\ldots,T \qquad \text{(VI.16)}$$

Assuming for simplicity that $n = 2$ and $r = 1$, then,

$$\beta^{*\prime} X_{t-k}^* = (\beta_1 X_{1,t-2} - \beta_2 X_{1,t-2} - \beta_0)$$

so that when combined with the loading vector α the constant vector in (VI.16) becomes $\alpha_1\beta_0$. This implies that the constant in a levels VAR equivalent to (VI.16) is restricted to be $\mu = \alpha_1\beta_0$. Consequently, and as Johansen and Juselius (1990) state, testing for the absence of linear trends in X_t given that $\Pi = \alpha\beta'$ simply boils down to testing whether $\mu = \alpha_1\beta_0$ is a hypothesis supported by the data. Critical values of the trace and maximal eigenvalue statistics are reported in Johansen and Juselius (1990) and have been reproduced here for convenience Tables A4 and A5 corresponding to whether a time trend in X_t is observed or not respectively.

Estimation of the VAR and Testing for Cointegration

Johansen estimation is performed automatically in a number of econometric packages such as *REG - X*, *PC-Give* and *MicroFIT,* although due to the relative youth of the technique in the literature, the routines required to apply the full set of hypotheses that are discussed shortly are still being developed.[13] The statistical details of the procedure are explained more formally in Appendix II and the reader may well wish to refer to it in what follows. An impression of the procedure may be given using the following three-variable example.

For illustrative purposes we will begin by assuming that a VAR(2) version of equation (VI.8) adequately characterises the data generation process of each of the three I(1) series of interest (say X_t, Y_t and Z_t) in that the residuals of each equation are empirical white noise. Further, it is assumed that because these series are characterised by linear trends, a constant is explicitly incorporated in the specification of each first differenced process.

The aim is to obtain maximum likelihood estimates of α,β and Ω. To do this the likelihood function - a formula proportional to the probability of drawing the particular set of error terms - is concentrated with respect to the free parameters, (*i.e.* given initial values of those parameters to which cointegration does not impose restrictions on) namely, the coefficients of Γ_1, μ (and the coefficients on any dummy or I(0) variables, if included). This is achieved by regressing ΔX_t and X_{t-2} on 1, ΔX_{t-1} and any dummy variables or I(0) variables. Omitting dummies and I(0) variables for simplicity, we have two sets of regressions,[14]

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13 Consequently, the coverage of the empirical analysis is somewhat limited, although detailed explanation of the hypothesis testing is included as comprehensive software is soon to be released and will be applied at a later date.

14 Where the integrated variables do not appear to be trending over time the constant in (VII.17) and (VII.18) no longer appear and the two sets of regressions take the following form:

$$\begin{aligned}
\Delta X_t &= a_1\Delta X_{t-1} + a_2\Delta Y_{t-1} + a_3\Delta Z_{t-1} \\
\Delta Y_t &= b_1\Delta X_{t-1} + b_2\Delta Y_{t-1} + b_3\Delta Z_{t-1} \qquad \text{(VII.17')} \\
\Delta Z_t &= c_1\Delta Y_{t-1} + c_2\Delta X_{t-1} + c_3\Delta Z_{t-1}
\end{aligned}$$

and,

$$\begin{aligned}
X_{t-2} &= d_1\Delta X_{t-1} + d_2\Delta Y_{t-1} + d_3\Delta Z_{t-1} \\
Y_{t-2} &= e_1\Delta X_{t-1} + e_2\Delta Y_{t-1} + e_3\Delta Z_{t-1} \qquad \text{(VII.18')} \\
Z_{t-2} &= f_1\Delta Y_{t-1} + f_2\Delta X_{t-1} + f_3\Delta Z_{t-1} \\
1 &= g_1\Delta Y_{t-1} + g_2\Delta X_{t-1} + g_3\Delta Z_{t-1}
\end{aligned}$$

$$\begin{aligned}\Delta X_t &= a_0 + a_1\Delta X_{t-1} + a_2\Delta Y_{t-1} + a_3\Delta Z_{t-1}\\ \Delta Y_t &= b_0 + b_1\Delta X_{t-1} + b_2\Delta Y_{t-1} + b_3\Delta Z_{t-1}\\ \Delta Z_t &= c_0 + c_1\Delta Y_{t-1} + c_2\Delta X_{t-1} + c_3\Delta Z_{t-1}\end{aligned} \qquad \text{(VII.17)}$$

and,

$$\begin{aligned}X_{t-2} &= d_0 + d_1\Delta X_{t-1} + d_2\Delta Y_{t-1} + d_3\Delta Z_{t-1}\\ Y_{t-2} &= e_0 + e_1\Delta X_{t-1} + e_2\Delta Y_{t-1} + e_3\Delta Z_{t-1}\\ Z_{t-2} &= f_0 + f_1\Delta Y_{t-1} + f_2\Delta X_{t-1} + f_3\Delta Z_{t-1}\end{aligned} \qquad \text{(VII.18)}$$

which yield residual vectors that are substituted into the likelihood function. The procedure then involves maximising the likelihood function for the remaining unknowns, namely α,β and Ω. The solution to this constrained maximisation yields n eigenvalues and their associated eigenvectors: each eigenvector comprises the coefficients of one of the n candidate cointegrating relationships and represents a column of the matrix β. In order to establish the number of *distinct* cointegrating vectors implied by the data, (*i.e.*the rank of β) each eigenvalue that corresponds to an eigenvector is tested to determine whether it is significantly different from zero. Therefore, for every non-zero eigenvalue there is a corresponding eigenvector which yields a candidate cointegrating vector. Denoting $\hat{\lambda}_i$ as the i^{th} largest eigenvalue (where $i = r + 1$ to n) we may test the null hypothesis that there are at most r distinct cointegrating vectors by calculating the *trace* statistic, given by

$$-2\ln(Q) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i)$$

The null will be rejected for values larger than the appropriate critical value. Alternatively, we may use the maximal eigenvalue statistic (λ_{max}), calculated as,

$$-2\ln(Q) = -T\ln(1 - \hat{\lambda}_{r+1})$$

and test the null that there exist r distinct cointegrating vectors against the alternative that there are $(r+1)$ cointegrating vectors. The critical values of these tests are not distributed as χ^2 even asymptotically, but as multivariate versions of the Dickey-Fuller distribution, although critical values have been tabulated by monte carlo simulation and are presented in Johansen and Juselius (1990) and have been reproduced here for convenience; Tables A4 and A5 corresponding to whether a time trend in X_t is observed or not respectively.

Thus the n eigenvalues are used to test for the rank of β to find the precise number of

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and the residuals are used as above in the computation of the tests for cointegration.

cointegrating vectors implied by the data. Once this is known then the maximum likelihood estimates of Γ_1 μ and $\mathbf{Z}_t$ are then obtained by substituting the estimates of α and β back into the VAR.

In situations where *a priori* one expects a cointegrating relationship to exist, obtaining results indicating two or more distinct cointegrating vectors is puzzling and frequently has no useful economic interpretation, for whilst multiple equilibria are allowed for in the estimation, it is not clear what this means in an economic context. All being well however, only one distinct cointegrating vector should be identified using the test statistics. Note however, that in circumstances where the variables of X_t have not been adequately tested for stationarity the Johansen procedure will select a cointegrating vector for each I(0) variable identified in X_t. A quick glance at the β matrix however will detect this occurrence since the cointegrating vector would look something like (0 0 0 1) after normalisation.

Hypothesis Testing

(i) Linear Trends

The Johansen procedure faciliates the testing of a variety of hypotheses using standard likelihood ratio tests. All hypotheses are restrictions on the n^2 parameters of the Π matrix. Unless it is clear that all the variables in X_t do not possess a linear trend, the first hypothesis that we need to test is whether such a restriction is supported by the data. Assuming that r cointegrating vectors have been found in the unrestricted model, (with linear trends) we may test whether the absence of linear trend is congruent with the data by comparing the ratio of the likelihoods from the with and without trend models under the assumption that there are r cointegrating vectors. Hence the likelihood ratio test is computed as,

$$-2\ln(Q) = -T \sum_{i=r+1}^{n} \ln\left\{\frac{(1-\hat{\lambda}_i^*)}{(1-\hat{\lambda}_i)}\right\} \qquad \text{(VII.19)}$$

where $\hat{\lambda}_i^*$ and $\hat{\lambda}_i$ are the i^{th} eigenvalues in the restricted and unrestricted (*i.e.* constant included) VARs. The test statistic is distributed asymptotically as χ^2 with $n - r$ degrees of freedom under the null that absence of the trend is consistent with the data.

(ii) Restrictions on the cointegrating matrix β[15]

Frequently, it may be desirable to establish whether certain parameter values estimated in the Johansen procedure are consistent with predictions of the theoretical model. Economic theory has little to say about the short run dynamics of a relationship so the testing of theoretical predictions will focus on the parameters of the cointegrating matrix β. To simplfy this discussion suppose that a single cointegrating vector has been identified, *i.e.* $r(\beta) = 1$. Johansen formulates theoretical restrictions under the hypothesis, $\beta = \mathbf{H}\phi$ where $\mathbf{H}$ is a $(n * s)$ matrix of restrictions and ϕ is an $(s * r)$ vector of parameters to be estimated from the data, where s reflects the nature of the restrictions. The VAR is then estimated subject to these restrictions and a likelihood ratio test developed to test whether the restrictions are supported by the data. The test is calculated as,

$$-2\ln(Q) = T\sum_{i=1}^{r} \ln\left\{\frac{(1-\hat{\lambda}_{Hi})}{(1-\hat{\lambda}_i)}\right\} \qquad \text{(VII.20)}$$

where $\hat{\lambda}_{H.i}$ are the eigenvalues of the VAR estimated under the null hypothesis. The test statistic follows a $\chi^2\, r(n - s)$ distribution under the null that $\beta = \mathbf{H}\phi$.

By means of an example consider the simple bivariate present value relationship to be estimated in the following section. Suppose that a single cointegrating vector has been identified and that we wish to establish whether the unit elasticity hypothesis of rents to land prices can be maintained as a cointegrating relationship from the data. Denoting $\ln P_t$ and $\ln R_t$ as the log of land price and rent series respectively, then unit elasticity simply implies that the coefficients of each variable in the cointegrating vector β is equal with opposite sign. The null of unit elasticity is thus,

$$H_0 : \beta_1 = -\beta_2$$

against the alternative,

$$H_0 : \beta_1 \neq -\beta_2$$

In matrix notation this hypothesis can be formulated as $\beta = \mathbf{H}\phi$, *i.e.*

$$\beta = \begin{bmatrix} 1 & 0 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix}$$

where ϕ is a $(2 * 1)$ column vector of coefficients to be estimated from the data. The eigenvalues from the VAR estimated under the β restrictions can then be substituted

[15] In the empirical analysis that follows the hypotheses that are tested are limited to those imposed on the cointegration matrix β due to the limitiations of the software used to run the Johansen procedure, although as mentioned above the other tests are described for completeness.

into the likelihood ratio test given by (VII.20) to ascertain whether the restriction is supported by the data. To see how this implies unit elasticity the cointegrating vector $\beta'X$ becomes,

$$\begin{bmatrix}\phi_1 & -\phi_1\end{bmatrix}\begin{bmatrix}lnP_t \\ lnR_t\end{bmatrix} = \phi_1\, lnP_t - \phi_1\, lnR_t$$

Normalising on land prices by dividing through by ϕ_1 yields the cointegrating relation,

$$\ln P_t = \ln R_t$$

Using this type of formulation any number of homogenous linear restrictions can be imposed on the cointegrating relation. For instance suppose X_t contained four variables we could test the equivalence of two pairs of coefficients simultaneously by manipulation of the **H** matrix.[16] Note that where the intregrated variables of X_t do not contain linear trends the matrix of restrictions is augmented to allow for a constant term and in the bivariate case considered here, **H** is an $(n + 1 * s)$ matrix of restrictions and ϕ remains an $(s * r)$ vector although β now has dimensions of $(n + 1 * r)$, *i.e.*

$$\beta = \begin{bmatrix} 1 & 0 \\ -1 & 0 \\ 0 & 1 \end{bmatrix} \varphi$$

A useful application of this testing procedure is to ascertain whether the space spanned by β in the Engle and Granger cointegrating regressions would be accepted by those produced by FIML in the Johansen procedure. Suppose that the Engle and Granger method had estimated a relationship between the log of land prices ($\ln P_t$), log of rents ($\ln R_t$) and inflation ($\Delta \ln F_t$) such that after normalisation on land price we have an estimate of the cointegrating relationship,

$$\ln P_t = 1.06 \ln R_t - 1.50 \Delta \ln F_t + \text{constant}$$

In order to test whether it is possible to accept the hypothesis that the coefficient on rents is 1.06 times that on land prices and that the coefficient on inflation is minus 1.50 times the coefficent on land prices with the constant left unrestricted using the Johansen procedure, we again formulate the hypothesis in matrix notation as, $\beta = \mathbf{H}\phi$ where

$$\beta = \begin{bmatrix} 1 & 0 \\ 1.06 & 0 \\ 1.50 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} = \begin{bmatrix} \phi_1 \\ 1.06\phi_1 \\ 1.50\phi_1 \\ \phi_2 \end{bmatrix}$$

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[16] For an example of more than one homogenous linear restriction see Johansen and Juselius (1990) p.195.

Therefore the cointegrating vector $\beta'X$ becomes,

$$\begin{bmatrix}\phi_1 & -1.06\phi_1 & 1.50\phi_1 & \phi_2\end{bmatrix}\begin{bmatrix} lnP_t \\ lnR_t \\ \Delta lnF_t \\ -1 \end{bmatrix} = \phi_1\, lnP_t - 1.06\phi_1\, lnR_t + 1.50\phi_1\, \Delta lnF_t - \phi_2$$

which after normalisation and rearranging for $\ln P_t$ yields a cointegrating relation,

$$lnP_t = 1.06 lnR_t + 1.50\Delta lnF_t + (\phi_2 / \phi_1)$$

Using the likelihood ratio test in (VII.20), we may test the restrictions using the data by comparing the largest eigenvalue from the restricted VAR estimated under $\beta = \mathbf{H}\phi$ with that from the unrestricted model.

(ii) Restrictions on the Loading Vector α

Johansen has also developed a likelihood ratio test for hypotheses on the vector that weights the long-run relationships in (VII.14), *i.e.* the coefficients attached to the error correcting terms. To perform such tests it is necessary to have first identified at least one cointegrating vector when estimating the VAR unrestrictedly. Restrictions on the $(n * r)$ matrix of loadings α are formulated in a similar way to those on β. Under the hypothesis that $\alpha = \mathbf{A}\psi$ where $\mathbf{A}$ is a $(n * m)$ matrix of restrictions and ψ an $(m * r)$ matrix of parameters to be estimated under the restictions imposed in $\mathbf{A}$ the VAR is estimated and its eigenvalues compared with those from the unrestricted VAR. There are essentially only two types of restriction on α that we would wish to test, relating to the sign of each loading coefficient in α and the number of statistically significant loading coefficients in α. If a single cointegrating vector has been isolated, it follows that α must also be a vector to conform in the combination $\Pi = \alpha\beta'$. A useful hypothesis to test in this circumstance is whether only one of the elements in the loading vector is statistically different from zero since where this is the case the n dimensional VAR collapses to a single equation.this implies that the long run vector may be estimated as a single equation rather than in the VAR. Johansen and Juselius (1990), Corollary 6.2, prove that when a single cointegrating vector is isloated so that the rank of β' is one, acceptance of the hypothesis that,

$$H_0 : \alpha_2 = \alpha_3 =, \ldots, = \alpha_n = 0$$

implies that (n - 1) variables are exogenous to the system and thus need not be explicitly modelled. As a consequence, the maximum likelihood estimate of β is given by the coefficients of X_{t-k} in the OLS regression of $\mathbf{A}'\Delta X_t$ on X_{t-k}, $\mathbf{B}'\Delta X_t$ and $\Delta X_{t-1}, \ldots, \Delta X_{t-k+1}$, Z_t and the constant; where A is the $(n * m)$ matrix of restrictions on α

and **B** is an $(n * (n - m))$ matrix such that $\mathbf{B}'\mathbf{A} = \mathbf{0}$.

To test this hypothesis, which in effect is a mulitvariate Granger casuality test, the VAR is estimated under the null that all but one of the coefficients in α are zero. Using the bivariate model to illustrate, the restrictions $\alpha = A\psi$ take the form,

$$\alpha = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \psi_1 \end{bmatrix}$$

and the likelihood ratio statistic calculated to test whether the resulting estimate of the parameters in the restricted model occupy the cointegrating space spanned under the unrestricted model is computed according to (VII.20) and follows a χ^2 distribution on $(n - (n - r))$ degrees of freedom. If the null cannot be rejected then a single equation may be used legitimately to estimate α and β. Hence, in this special case the estimates of α and β from the Engle and Granger two step procedure are identical to that from restricted Johansen estimation.

Using the three variable illustration of land price, rent and inflation, then, accepting the null hypothesis entails that two of the equations in the VAR are redundant since they can be treated as being determined exogenously to the VAR. Should this be the case, then the VAR(2) of equation (VII.10) reduces to a single equation, the autoregressive model,

$$A(L)\ln P_t = B(L)\ln R_t + C(L)\Delta\ln F_t + d + eD72_t + \varepsilon_t \qquad \text{(VII.21)}$$

where the lag polynominals are of second order, d is a constant, $D72_t$ the dummy variable and ε_t are nid$(0,\sigma^2)$.

In full, equation (VII.21) may be written as,

$$\begin{aligned}(1-a_1L-a_2L^2)\ln P_t &= (1+b_1L+b_2L^2)\ln R_t + (1+c_1L+c_2L^2)\Delta\ln F_t + eD72_t + \varepsilon_t \\ &= L\ln R_t + b_1L\ln R_t + b_2L^2\ln R_t + \Delta\ln F_t + c_1L\Delta\ln F_t \\ &\quad + c_2L^2\Delta\ln F_t + d + eD72_t + \varepsilon_t \qquad \text{(VII.22)}\end{aligned}$$

To obtain the static long run solution we evaluate (VII.22) at L = 1. Noting that in equilibrium we may drop time subscripts this leaves,

$$\begin{aligned}(1-a_1-a_2)\ln PX &= \ln RH + b_1\ln RH + b_2\ln RH + \Delta\ln F + c_1\Delta\ln F + c_2\Delta\ln F + d + \varepsilon_t \\ &= (1+b_1+b_2)\ln RH + (1+c_1+c_2)\Delta\ln F + d\end{aligned}$$

This may then be incorporated into the error correction model for land prices. The usefulness of this hypothesis test is therefore two-fold in that not only does it simplify matters considerably, but since there are fewer coefficients to be estimated the efficiency of the estimation process improves.

(iii) Testing Joint Restrictions on α and β

As a logical progression in the hypothesis testing framework Johansen and Juselius (1990) develop another likelihood ratio test in which restrictions are imposed on both α and β. Specifically, the ECM paramterisation of the VAR is estimated under the hypothesis that, $\alpha = \mathbf{A}\psi$ and $\beta = \mathbf{H}\phi$. A model embodying both sets of restrictions is then compared to the unrestricted long run matrix Π and a likelihood ratio statistic computed according to (VII.20) to test whether the remaining coefficients estimated under the full set of restrictions is consistent with the original unrestricted specification, such that

$H_0 : \Pi = \mathbf{A}\psi\phi'\mathbf{H}'$

and where linear trends are found to be absent in the integrated variables,

$H_0 : \Pi = \mathbf{A}\psi\phi'\mathbf{H}', \ \mu = \alpha\beta_0'$

where β_0' is an $(r * 1)$ vector that allows for a constant in the cointegrating relations but restricts the time trend to be absent.

VII.(iv) Cointegration in the Research Strategy - A Digression

Whilst the measurement and testing of economic theory is the econometrician's *raison d'etre* he has frequently been accused of the inability to distinguish between competing theories, or uncover the *real* processes at work that theory attempts to model. Indeed, it is commonly suggested that econometrics has led to the proliferation of theories, all with 'significant' *t* ratios 'high' R^2s and valid interpretations. Consequently, when first reported in the literature, cointegration ignited considerable interest in an audience that was much wider than that which typically received developments in econometrics. The primary reason for this was the belief that cointegration could bridge the gap between economic theory and empirical observation, allowing the applied econometrician to test, in a coherent way, the multitude of hypotheses suggested by economic theory. The zest with which the techniques were initially greeted and applied, has subsequently mellowed despite a much richer understanding of the theoretical foundations of cointegrated processes. In part this reflects the naive optimism of the techniques potential and the realization of the limitations and pitfalls of the statistical procedure. Aside from the practical difficulties encountered in the estimation and testing of cointegrating vectors, (such as the low power of some of the test procedures, small sample bias and fragility of the tests in the presence of structural breaks) cointegration offers many opportunities. Rather than symbolizing some holy grail of econometrics cointegration is now regarded to assume the more humble mantel of an effective selection tool in models comprising integrated variables. Certainly, this is the spirit with which it is used in the econometric methodology propounded by 'The LSE School' of which Professor Hendry is the primary exponent.

As a tool of model selection cointegration allows the analyst to address interesting questions such as the existence of long run equilibria posited by theory, what variables may legitimately form an equilibrium relationship, the number of such relationships implied by the data and the nature of the dynamic behaviour in which the equilibrium relationships are shrowded. Obviously, cointegration is not endowed with the ability to identify *the* true model since *all* models, by definition, merely represent simplifications of a hugely complex underlying data generating process. In this sense, to use cointegration to *validate* any particular model endows the technique with a power that it does not possess. Nevertheless, as a means of testing the *adequacy* of a proposed model cointegration is particularly useful. Viewed in this light cointegration is little more than a general specification test which serves to reduce the number of competing theories and their associated (spurious) regression statistics. In addition, because cointegration effectively tests the model specification it requires the anlayst to base empirical models more rigidly in theory, thereby avoiding what may be termed 'kitchen-sink' econometrics in which a whole host of factors are included in a regression based on illegitmate t values with the result that a high R^2 is obtained.

However, because cointegration was frequently perceived as something much grander, extravagant claims concerning the validation or refutation of particular theories invited considerable criticism, such as Darnell and Evans (1990). It appears though that much of the criticism is directed not so much at the technique itself but rather at the naive and unquestioning way in which cointegration results were interpreted. Thus whilst critics are correct in stating that finding no cointegration does not in itself represent sufficient evidence to refute a theory, (specification of maintained model and alternative hypothesis or measurement errors in the data being equally likely explanations) where cointegration is found it suggests that the model under scrutiny is consonant with the data and as such is an adequate simplification of the relationship at hand. As with all statistical techniques inference is only conditional on the framework in which testing takes place and moreover the results are only as good as the data with which a hypothesis is actually tested.

VII.(v). The Present Value Model

In this section we briefly develop land price equations to be estimated within the VAR. Recall that the present value rule for land price determination is,

$$P_t = \delta \sum_{j=0}^{\infty} \delta^j E_t[R_t] \qquad \text{(VII.23)}$$

where δ = 1/(1 + r).That is, land price is the expected present value of an infinite stream of future rents. For simplicity we will adopt the special case of (VII.23) where rents are expected to continue at their present level for ever. In this case,

$$E_t\,[R_{t+j}] = E_t[R_t]$$

for all $j > 0$. Combined with naive expectations (where $E_t\,[R_t] = R_{t-1}$), this implies

$$P_t = CR_{t-1}$$

where $C = 1/r$ is the capitalization rate. This special case embodying the capitalization of constant expected rent into price is appealing in the present context. Specifically, it might be expected that there is a long run tendency for land price to be tied to its capitalized rent. Indeed, in the case of a fixed rent, R^*, then the long run equilibrium price, P^*, is given by:

$$P^* = CR^* \qquad \text{(VII.24)}$$

where the long run elasticity of price in respect of a permanent change in rent is unity. Applying natural logarithms to (VII.24) yields

$$\ln P^* = \ln C + \ln R^* \qquad \text{(VII.25)}$$

which can be estimated by ordinary least squares.

In the short run, land prices and rents may diverge and the dynamic adjustment of price to rent may be represented, (provided that rents and land prices are cointegrated) by an error correction model. The specification of the dynamics of the error correction model is data determined, but using the form that is estimated in the empirical section yields,:

$$\Delta \ln P_t = a_1 \Delta \ln R_{t-1} + a_2 \Delta \ln P_{t-1} - \lambda(\ln P_{t-2} - \ln R_{t-2} - \ln C) + \varepsilon_t \qquad \text{(VII.26)}$$

This theory is basically microeconomic in nature. However, it may also be relevant to enquire into the relationship between land values and institutional and macroeconomic factors. Peters (1966) emphasizes factors such as inflation hedging, interest rates, speculation, capital taxation and amalgamation demand as playing important roles in the determination of land prices. From a time series perspective the last three are troublesome because realistic measurement is difficult, if not impossible. The effect of interest rates has been examined in Chapter IV where it was concluded that the real rate of interest has no discernible effect on real land prices.[17] The results seem to suggest that participants in the land market use a constant rate of interest to discount future returns because of the long term nature of investment in land and the sizeable transactions costs that are incurred.

However, since land serves as an asset for wealth holding, it may be that participants in the market perceive it to be a preferred form of wealth in periods of high inflation *viz a viz* other similar assets, such as stocks and shares, and thus acquire land as a hedge against inflation. This rationale owes as much to historical precedent and psychological factors as it does to economic theory. Consequently, formalising the hedging philosophy is difficult, despite that fact it is a widely acknowledged motivation for acquisition in the UK. It is apparent that land is perceived to be capable of holding its value during inflationary periods and thus provides a 'gilt-edged' means of acquiring indebtedness and a more stable form of security for loans. An indebted land owner may gain from inflation since his equity may grow faster than the rate of inflation. The hedging argument is a self fulfilling prophecy since if enough participants believe land provides better security during inflationary periods, more land is purchased for that reason, which in turn maintains a buoyant demand and thus price. Consequnetly we will also examine whether changes in the general level of prices affect the real price of land. Other macro and institutional considerations such as changes in capital taxation and property rights however are ignored.

The models (VII.25) and (VII.26) may be augmented quite simply to allow inflation effects on real land prices. If land is an inflation hedge so that at least some agents shift the composition of their wealth portfolio into land when inflation is rapid, the equilibrium relationship (VII.25) may be augmented as :

$$\ln P^* = \ln C + \ln R^* + \beta \Delta \ln F^* \qquad \text{(VII.27)}$$

where $\Delta \ln F^*$ is a fixed rate of inflation.Similarly, the ECM is augmented as,

$$\Delta \ln P_t = a_1 \Delta \ln R_{t-1} + a_2 \Delta \ln P_{t-1} + a_3 \Delta^2 \ln F_{t-1} - \lambda(\ln P_{t-2} - \ln R_{t-2} - \ln C - \beta \Delta \ln F_{t-2}) + \varepsilon_t \qquad \text{(VII.28)}$$

with β being the long run elasticity of land price to a steady inflation rate.

[17] Estimation using the cointegration methodolgy set out in this Chapter also supports that conclusion and results have not been included in the interest of brevity.

These models now form the basis of the estimation exercise to which the remainder of the Chapter is dedicated.

VII.(vi) Empirical Testing of the Present Value Hypothesis

The empirical investigation begins with the definitions of the data used to test the hypothesis of cointegration and then proceeds to estimate a VAR for the bivariate case and a trivariate case where the basic relationship is augmented by inflation. Finally, a long historical data set is used to test the same hypothesis.

(a) The Empirical Data[18] :

$\ln P20_t$:The log of average price of all land sold over 20 hectares in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1946 to 1989.

$\ln PX_t$:The log of average price of a sample of farm sold at auction over 5 hectares in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1871 to 1990.

$\ln RN_t$:The log of average rent paid on tenanted farms that have undergone a rent increase in the past year in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1946 to 1990.

$\ln RH_t$:The log of average rent of agricultural land in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1871 to 1990.

$\ln F_t$:The log of the Gross Domestic Product Deflator, 1871 to 1990. Base year 1990.

Recall that Chapter VI established that the land price and rent series are non-stationary I(1) processes in (the log of the) levels and stationary I(0) processes when expressed in first differences, *i.e.* $\ln P20_t \sim I(1)$, $\ln RN_t \sim I(1)$, $\Delta\ln P20_t \sim I(0)$, $\Delta\ln RN_t \sim I(0)$.
The (log of the) GDP deflator is integrated of order two so that inflation is a non-stationary I(1) process and the change in inflation is a stationary I(0) process, *i.e.* $\ln F_t \sim I(2)$, hence $\Delta\ln F_t \sim I(1)$ $\Delta^2\ln F_t \sim I(0)$

18 See the Data Appendix for a detailed explanation of these series. Any dummy variables that are included are additive (not multiplicative) and are defined with the integer one in the year that they operate and zeros elsewhere.

(b) The Bivariate case :

(i) The Johansen Method

Prior to the estimation of the VAR it is necessary to determine whether linear trends are present in the variables (in levels) of the VAR and also the order k of the VAR itself. As the $\ln RN_t$ and $\ln P20_t$ time series are moving upwards over time a constant is initially included although this will be tested formally later. Determining the order of the VAR can be achieved simply by estimating the n equations of the VAR separately for various orders of k and testing the residuals from each equation for normality and serial correlation that are required given that ε_t in (VII.8) and (VII.9) are Guassian. The most parsimonious (lowest k) set of n equations to yield stationary residuals denotes the order that will be used to estimate the VAR. The Parametrisation (VII.9) is used in preference to (VII.8) since all variables will be I(0) in the presence of cointegration and thus standard critical values may be used for inference.[19]

For the bivariate model this necessitates two equations in error correcting form in which k was initially set to 4 with appropriate dummy variables, *i.e.*

$$\Delta lnP_t = \mu + \sum_{i=1}^{k-1} \Delta lnP_{t-i} + \sum_{i=1}^{k-1} \Delta lnRN_{t-i} + lnP_{t-k} + lnRN_{t-k} + D_t$$

$$\Delta lnRN_t = \mu + \sum_{i=1}^{k-1} \Delta lnP_{t-i} + \sum_{i=1}^{k-1} \Delta lnRN_{t-i} + lnP_{t-k} + lnRN_{t-k} + D_t$$

Pretesting indicates that the residuals of each pair of regressions remained stationary when $k > 1$ entailing a VAR(2) system represents an adequate representation of the data. Table VII.1 reports the results for the models in which $k = 1, 2$.

From the table the VAR(1) errors do not appear to deviate significantly from normality since the J-B statistic for each (which is based on the skewness and kurtosis of an empirical distribution) does not exceed the 5% critical value. Visual inspection of a histogram of the residuals (not shown) also bears this out. The residuals are however serially correlated as indicated by the Q^* statistics at 1, 5 and 10 lags. Recall from Chapter VI that both the first difference of the rent and land price series were AR(2) and thus it is of no surprise that the residuals in the VAR(1) model are serially correlated. The residuals from the VAR(2) model comply with the n.i.i.d. requirement of the estimation and on the basis of the statistics presented in the Table VII.1 and by visual inspection of a histogram and ACF (not shown here) this model can now be assumed to

19 Equation (VII.9) also minimises the deliterious effects of multicolinearity, which *a priori*, would be significant in (VII.8) due to the presence of lagged variables.

be an adequate representation of the data generation process.

Table VII.1 : Some Test Statistics for the niid Assumption for the Residuals in (VII.9) with k = 1 and k = 2 in the Bivariate Model

	B-J	S	EK	Q*(1)	Q*(5)	Q*(10)
$k = 1$						
ΔP_t	1.89	-0.29	0.86	1.14	8.71	20.65
ΔR_t	4.00	-0.65	0.74	11.25	11.56	26.97
$k = 2$						
ΔP_t	0.04	0.23	-0.08	0.10	2.61	9.43
ΔR_t	3.13	-0.16	1.30	0.28	4.56	7.46
5% CV	**5.99**			**3.84**	**11.07**	**18.30**

where J-B is the Jarque-Bera (1980) statistic approx distributed as χ^2 (2) under the null of normality
S is the coefficient of skewness which is zero for the normal distribution
EK is the coefficient of excess kurtosis which is zero for the normal distribution
$Q^*(k)$ is the Ljung-Box (1978) statistic for serial correlation in the residuals, approx distributed as a χ^2 (k) under the null of no serial correlation. 95% critical Values are in bold where they apply.

Following these results it is assumed that the VAR(2) of equation (VII.8) with an unrestricted constant and additive dummy variables for 1972 and 1974 is an adequate description of the data generating process. Reparametising the system into the ECM formulation given by (VII.9) and applying maximum likelihood yields estimates of the long run matrix $\Pi = \alpha\beta'$ which are reported in Table VII.3.

The interpretation of the results is made easier if we establish the number of distinct cointegrating vectors given by the rank (r) of Π. Table VII.2 reports the trace (*Trace*) and maximal eigenvalue (λ_{max}) statistics for the bivariate VAR(2) model with 95% and 90% critical values for each statistic. Both statistics are unable to reject the null of no cointegrating vectors implying that there is not one linear combination of rents and land prices that is I(0) from which we can establish that rents and land prices are not cointegrated. Estimating the VAR(2) system in which the constant term in (VII.9) is restricted leads to the same conclusion so results have not been presented.

Table VII.2 : Trace and Maximal Eigenvlaue Statistics for the Bivariate VAR(2) Model

		Trace	95%	90%			λ_{max}	95%	90%
H_0	H_1				H_0	H_1			
$r \leq 0$	$r \geq 1$	9.74	15.41	13.32	$r = 0$	$r = 1$	18.17	14.07	12.07
$r \leq 1$	$r \geq 2$	1.56	3.76	2.89	$r = 1$	$r = 2$	1.56	3.76	2.68

Table VII.3 : The Eigenvalues $\hat{\lambda}$ and Eigenvectors β_i with Loading Vectors α_i in the Bivariate Model

Eigenvalues					
$\hat{\lambda}$	0.181	0.037			
	Eigenvectors β_i			Loading Vectors α_i	
ln*P20*	-0.806	0.161	ln*P20*	0.102	-0.0125
	(-1.000)	(-1.000)		(0.081)	(0.020)
ln*RN*	1.248	0.390	ln*RN*	-0.080	-0.039
	(1.547)	(-2.425)		(-0.065)	(0.006)

Note: The figures in parentheses represent the coefficients in the cointegrating vectors normalised on the coefficient on ln$P20_{t-2}$ being -1.

Whilst this result is sufficient to preclude the need to analyse the Π matrix in any detail it is interesting to note that had either of the candidate cointegrating vectors of β yielded a cointegrating relationship then β_1, the vector associated with the highest eigenvector would have implied a long run relationship of the form,

$$(-\ln P20 + 1.547\ln RN) \quad \text{or} \quad \ln P20 = +\,1.547\ln RN$$

and the second candidate cointegrating vector β_2 implies,

$$(-\ln P20 + 0.390\ln RN) \quad \text{or} \quad \ln P20 = +\,0.390\ln RN$$

The sign of the elasticity coefficient between rents and land prices in both vectors is postive although neither is particularly close to unity as implied by present value theory. A quick glance at the loading vectors also supports the findings above in that all the normalised loading coefficients are very close to zero. Given that the linear combinations of rents and land prices is I(1) then the loading coefficients could not feasibly assume any other value since the dependent variable in each equation is a stationary I(0) process.

We may also test for cointegration using residuals from a static regression as proposed by Engle and Granger. Applying OLS yields,

$$\ln P20_t = 2.02 + 1.77 \ln RN_t$$

$$\bar{R}^2 : 0.71 \qquad \text{CRDW} : 0.48 \qquad \text{ADF}(1) : -2.55$$

The signs of the estimated coefficents are consistent with *a priori* expectations and all variables are statistically significant at the 5% level.[20] Critical values of the CRDW and ADF(1) tests at the 5% (10%) level are 1.03 (0.83) and -3.67 (-3.28) suggesting that the null of no cointegration cannot be rejected. Consequently, the empirics suggest that land prices and rents alone do not constitute a cointegrating vector, however, the statistics are encouraging enough to suggest that the bivariate model may simply need augmenting by one or more variables in order to satisfy the requirements of cointegration.[21]

(c) The Trivariate Model

As a result we resume the empirical analysis with the inclusion of inflation. As stated earlier the GDP deflator index (expressed in natural logs) over the current sample is integrate of order two so that first differencing yields an I(1) series that measures the rate of growth of the deflator, *i.e.* the rate of inflation. We will begin by using the Engle and Granger two stage procedure and then use the Johansen method.

Pretesting suggests a static cointegrating regression of the form,

$$\ln P20 = 2.24 + 1.29 \ln RN + 2.44 \Delta \ln F$$

$$\bar{R}^2 : 0.78 \qquad \text{CRDW} : 0.92 \qquad \text{ADF}(1) : -5.28$$

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20 Note however that inferences based on the t statistics from the cointegrating regression are conditional on the presence of cointegration. As a result some researchers prefer not to report t statistics.

21 Hallam *et al* (1992) arrive at a similar conclusion for the bivariate case despite using slighlty different basic data.

The inclusion of inflation has reduced the coefficient on rents slightly and marginally increased the explanatory power of the equation. More importantly, the CRDW has risen considerably and suggests, along with the ADF statistic (which has 5% and 10% critical values of -3.67 and -3.28 respectively) that we are able to reject the null of no cointegration[22] This evidence suggests that an I(0) combination of I(1) variables has been identifed and this implies cointegration. This may now be investigated more thoroughly in the VAR using the Johansen method.

Again, the first step is to ascertain the order of the trivariate VAR. Assuming that a VAR(4) is more than adequate to induce white noise residuals we then test sucessively more parsimonious speifications of the VAR. The three equation system with k = 4, 3, 2, 1 is thus,

$$\Delta lnP_t = \mu + \sum_{i=1}^{k-1} \Delta lnP_{t-i} + \sum_{i=1}^{k-1} \Delta lnRN_{t-i} + \sum_{i=1}^{k-1} \Delta^2 lnF_{t-i} + lnP_{t-k} + lnRN_{t-k} + \Delta lnF_{t-k} + D_t$$

$$\Delta lnP_t = \mu + \sum_{i=1}^{k-1} \Delta lnP_{t-i} + \sum_{i=1}^{k-1} \Delta lnRN_{t-i} + \sum_{i=1}^{k-1} \Delta^2 lnF_{t-i} + lnP_{t-k} + lnRN_{t-k} + \Delta lnF_{t-k} + D_t$$

$$\Delta^2 lnF_t = \mu + \sum_{i=1}^{k-1} \Delta lnP_{t-i} + \sum_{i=1}^{k-1} \Delta lnRN_{t-i} + \sum_{i=1}^{k-1} \Delta^2 lnF_{t-i} + lnP_{t-k} + lnRN_{t-k} + \Delta lnF_{t-k} + D_t$$

Table VII.4 reports statistics for normality and independence for the VAR(1) and VAR(2) specifications of the system. With a VAR(1) specification the B-J statistic for normality of the residuals from rents and inflation looks a little suspect and serial correlation appears to be present in the residuals from rent and possibly land price equations. These features are corrected in the VAR(2) system. Consequently, a VAR(2) system of the three I(1) variables with an unrestricted constant and additive dummy variable for 1972 are maintained as an adequate description of the data generating process of equation (VII.8).

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22 From Table A1 in the Appendix to this chapter critical values for a trivariate I(1) regression are not given although by looking at the other critical values in the table it seems likely that the CRDW critical value at even the 1% level is considerable below the test statistic computed here.

Table VII.4 : Some Test Statistics for the niid Assumption for the Residuals in (VII.9) with k = 1 and k = 2 for the Trivariate Model

	B-J	S	EK	Q*(1)	Q*(5)	Q*(10)
$k = 1$						
$\Delta \ln P_t$	0.65	0.31	0.05	2.02	3.71	15.43
$\Delta \ln R_t$	3.23	-0.61	0.60	10.98	11.45	28.43
$\Delta^2 \ln F_t$	4.40	0.79	0.04	0.34	0.83	3.92
$k = 2$						
$\Delta \ln P_t$	1.83	0.30	0.85	0.09	3.26	12.14
$\Delta \ln R_t$	0.33	0.08	0.41	0.14	3.06	8.47
$\Delta^2 \ln F_t$	1.52	0.43	-0.39	0.22	3.31	12.72
90% CV	**4.60**			**2.71**	**9.24**	**15.99**
95% CV	**5.99**			**3.84**	**11.07**	**18.30**

Notes : Same as for Table VII.1

This system is then formulated as an ECM given by (VII.9). Applying maximum likelihood yields estimates of the long run matrix $\Pi = \alpha\beta'$ and this is tested for cointegration, the result being presented in Table VII.5.

Table VII.5 : Trace and Maximal Eigenvlaue Statistics for the Trivariate VAR(2) Model

H_0	H_1	*Trace*	95%	90%	H_0	H_1	λ_{max}	95%	90%
$r \leq 0$	$r \geq 1$	33.11	20.97	18.60	$r = 0$	$r = 1$	44.58	29.68	26.79
$r \leq 1$	$r \geq 2$	8.56	14.07	12.07	$r = 1$	$r = 2$	11.46	15.41	13.33
$r \leq 2$	$r \geq 3$	2.91	3.76	2.68	$r = 2$	$r = 3$	2.91	3.76	2.68

From Table VII.5 it is clear that the inclusion of inflation has resulted in a marked increase in the trace and maximal eigenvalue tests for cointegration. Both test statistics strongly reject the null hypothesis of no cointegrating vectors and cannot reject the hypothesis that there is no more than one cointergating vector at the 95% confidence level. Curiously, both the test statistics reject the null of two cointegrating vectors in favour of three cointegrating vectors at the 90% confidence level. However, given that each hypothesis concerning r is strictly conditional upon the results from the previous hypotheses (and that these clearly signalled the presence of a unique cointegrating vector) we may treat this slightly anomolous result as spurious. A plot of the residuals from all three cointegrating vectors supports this view in that only one of the vectors in combination with X_t yields stationary residuals, the other two exhibiting distinct non-stationary behaviour. It is therefore concluded that there is only one cointegrating vector in the data.

Before we analyse the estimates of the long run matrix $\Pi = \alpha\beta'$ in detail it is appropriate to test whether the constant term in the ECM specification of the VAR should be restricted as discussed above. Using eigenvalues from the restricted and unrestricted models yields a test statistic computed from (VII.19) as,

$$= -40\{\ln(0.976) + \ln(0.999)\}$$
$$= 1.01$$

which cannot reject the restriction under the null since the χ^2 (2) critical value at the 5% significance level is 5.99. Consequently, exclusion of the constant in (VII.9) is supported by the data. Re-estimating the VAR with this restriction yields the trace and maximal eigenvalue statistics reported in Table VII.6 which now clearly demonstrate that there is only one cointegrating vector, as intuition led us to believe.

Table VII.6 : Trace and Maximal Eigenvlaue Statistics for the Trivariate VAR(2) Model with Restricted Constant

		Trace	95%	90%			λ_{max}	95%	90%
H_0	H_1				H_0	H_1			
$r \leq 0$	$r \geq 1$	46.03	34.91	32.00	$r = 0$	$r = 1$	33.22	22.00	19.77
$r \leq 1$	$r \geq 2$	12.81	19.96	17.85	$r = 1$	$r = 2$	9.90	15.67	13.75
$r \leq 2$	$r \geq 3$	2.91	9.24	7.53	$r = 2$	$r = 3$	2.91	9.24	7.52

We may now proceed with the interpretation and hypothesis testing using the restricted (constant excluded) model. Table VII.7 reports all the candidate cointegrating vectors and their loadings. Since only a single cointegrating vector β_1 has been identified we may disregard the remaining vectors, (although all cointegrating vectors have been reported for completeness). This automatically entails that only the first loading vector, α_1 is important in this system in order for $\Pi = \alpha\beta'$ to be conformable. Notice that the coefficients in the other loading vectors are virtually zero, as we would expect given that only a single I(0) cointegrating vector exists.

The single cointegrating vector implies a long run relationship between land prices, rents and inflation such that, $(-\ln P20 + 1.177\ln RN + 4.190\Delta\ln F)$ implying that,

$$\ln P20 = 2.568 + 1.174\ln RN + 4.211\ \Delta\ln F \qquad \text{(VII.29)}$$

Since all the variables are expressed in natural logarithms the coefficients in (VII.29) are elasticities. Of specific interest is the rent elasticity since present value theory dictates that this should be unity. This will be tested formally below.

Table VII.7 : Estimates of the Cointegrating Vectors β_i and Loading Vector α_i in the Trivariate Model

Eigenvalues							
$\hat{\lambda}$	0.564	0.219	0.070	0.000			
Eigenvectors				Loading Vectors			
	β_1	β_2	β_3		α_1	α_2	α_3
$\ln P20$	-1.085	-0.085	-0.062	$\ln P20$	0.508	-0.088	0.110
	(-1.000)	(-1.000)	(-1.000)		(0.551)	(-0.008)	(0.007)
$\ln RN$	-1.277	0.562	-0.364	$\ln RN$	0.074	-0.127	0.000
	(1.177)	(6.545)	(-5.889)		(0.081)	(-0.011)	(0.000)
$\Delta\ln F$	-4.545	-2.781	-1.690	$\Delta\ln F$	-0.106	-0.067	0.023
	(4.190)	(-32.428)	(-27.339)		(-0.115)	(0.006)	(0.001)
Constant	2.785	-1.657	2.225	-	-	-	-
	(2.568)	(-19.320)	(35.988)	-	-	-	-

Note: The figures in parentheses represent the coefficients in the cointegrating vectors normalised on the coefficient on $\ln P20$ being -1.

We may interpret the normalised loading vector $\alpha_1 = (0.551 \quad 0.081 \quad -0.115)$ as measuring the extent to which disequilibrium, or excess demand for land enters into the three equations in the system. The numerical value of each coefficient denotes the speed of adjustment towards the equilibrium state, so that a low coefficent implies slow adjustment and a high coefficent rapid adjustment. Hence, the cointegrating relationship, $\beta' X_t$ = (-ln*P20* + 1.174ln*RN* + 4.211 Δln*F*) will have a coefficient of 0.551 in the land price equation, 0.081 in the rent equation and -0.115 in the inflation equation. The signs of the loading coefficients are of the correct sign in the land price and inflation equations, in that movements of land price and inflation from their equilibrium values are being corrected, however the coefficient in the rent equation runs counter to such an interpretation implying that disequilibrium is *compounded*, although the estimate (0.086) is so small in the rent equation (and for that matter in the inflation equation as well) that it may simply mean that changes in rents (and inflation) are exogenous to the system and thus our estimate of the error correcting coefficient is in fact an estimate of zero.

Focussing on the land price equation: if average land price is above its equilibrium level so there is excess demand for land then $\beta' X_t$ = (-ln*P20* + 1.174ln*RN* + 4.211 Δln*F*) will be negative and there is a downward correction in land prices given that the normalised loading coefficient is positive. Conversely, if land price was below it equilibrium level then $\beta' X_t$ is positive implying that an upward pressure on land prices will be present. In either case the size of the loading coefficient (0.551) implies that 50% of any disequilibrium pricing is being corrected in any one year.

A number of interesting hypotheses emerge now we have identified a single cointegrating vector. First, we may wish to test whether the hypothesis of unit elasticity between rents and land prices implied by theory is supported by the data; second, whether the loading coefficients in the rent and inflation equations are zero, since this would imply that these variables are exogenous to the remaining variables in the VAR, in this case land prices. If these two loading coefficient are zero, this would allow us to estimate the long run relationship in a single equation with land price as the dependent variable. Third, we may wish to test whether the long run relationship obtained from the Engle and Granger approach spans the cointegrating space identified using the Johansen procedure.

In order to investigate whether the unit elasticity hypothesis can be maintained between rents and land prices we test whether the coefficients of rent and land price in the cointegrating vector are of equal and opposite sign, *i.e.*,

$H_0 : \beta_1 = -\beta_2$

against the alternative,

$H_0 : \beta_1 \neq -\beta_2$

Here, we formulate the null as,

$$H = \begin{bmatrix} -1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{ and } \phi = \begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{bmatrix}$$

which yields a cointegrating vector $\beta' = (-\phi_1 \;\; \phi_1 \;\; \phi_2 \;\; \phi_3)$ to be estimated by the data. Combining the cointegrating vector with X_{t-2} yields a long run relationship ($-\phi_1 \ln P20 + \phi_1 \ln RN + \phi_2 \Delta \ln F + \phi_3$) which having normalised on land prices gives,

$$(-\ln P20 + \ln RN + \phi_2/\phi_1 \Delta \ln F + \phi_3/\phi_1)$$

The β matrix under this restriction is estimated as,

$$\begin{bmatrix} -1.0228 \\ (-1.0000) \\ 1.0228 \\ (1.0000) \\ 4.8213 \\ (4.7140) \\ 3.3936 \\ (3.3181) \end{bmatrix}$$

where the figures in brackets are coefficients normalised on the coefficient on ln*P20* being minus one. Imposing the unit elasticity restriction has increased the normalised coefficient on inflation from 4.190 to 4.714. The likelihood ratio test for the validity of this restriction, given by (VII.20) yields a test statistic of 2.72 which follows a $\chi^2(1)$ distribution under the null. Critical values at the 5% and 10% significance level are 3.84 and 2.71 respectively and thus the test statistic is on the 10% borderline. If we are prepared to assume that the coefficent is not significantly different from one this result implies that the long run unit elasticity of rents to land price is congruent with the data, or more specifically, that the coefficients given above span the cointegrating space.

We may turn our attention to hypotheses concerning the vector of loadings given by α_1 in Table VII.6. Ideally, we wish to test whether the second and third coefficients in this vector are simultaneously zero in the VAR using the tests described above. Unfortunately, tests on the loading vector cannot be conducted with the software currently available, although we may throw some light on this problem by estimating the equations in the VAR separately and looking at the *t* ratio on the loading coefficient in each equation. Re-estimating the three ECM equations of the VAR given by (VII.11) separately using the residuals of the cointegrating vector from the Johansen procedure normalised on land prices suggests that the loading coefficients are statistically significant in the land price and inflation equations but not in the rent equation.[23] This suggests that the long run relationship is not important in determining rents but that it is in determining land prices and inflation. The influence of rents and land prices on inflation at first sight seems somewhat curious, since one might not expect such a small market to have a significant influence on GDP inflation. In the first instance, one might reasonably assume that the small loading coefficient in the inflation equation is simply an estimate of zero although the statistical significance of the coefficient implies this is not the case. In this light plausible explanations should be sought to account for the feedback from the land market to general GDP inflation. Two explanations spring to mind. First, rent and land price trends may be positively correlated with a third variable, whose influence on inflation may, *a priori*, be more powerful. At first glance house prices may seem plausible. Whilst there seems no reason to believe that returns to farming (as embodied in cash rents) and home ownership are correlated it could be that land price and house prices are correlated since investment value is likely to be a motivation for purchase in both markets. Another, and perhaps more plausible reason may lie in the notion that rents and thus land prices embody the price movements for a whole host of commodities such as those which comprise the inputs and outputs to the agricultural sector. Thus if, as the thrust of this thesis suggests, land prices are ultimately determined by agricultural input-output price ratios this second explanation may well be a more credible argument. However, given that single equation estimation of the three equations that make up the VAR ignores any cross equational constraints the result obtained here may be refuted by the more formal methods described in the last section. This is an issue that will be addressed in future research.

The third hypothesis that we may wish to test concerns the comparability of the long run relationship estimated from the Engle and Granger static regression and the maximum likelihood technique of Johansen. As set out in the previous section, we may test whether a set of estimates span the cointegrating space by imposing restrictions on the estimated β matrix. The estimates of the static regression were,

$$\ln P20 = 2.24 + 1.29 \ln RN + 2.44 \Delta \ln F$$

Imposing the restriction that under the null $\beta = \mathrm{H}\phi$, *i.e.*,

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[23] The respective t ratios are -4.62, -1.49 and 3.32.

$$\beta = \begin{bmatrix} -1 & 0 \\ 1.29 & 0 \\ 2.44 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix}$$

the VAR is estimated. This yields a new set of eigenvalues which are substituted into (VII.20) gives a test statistic of 11.06. Under the null the statistic folows a c2(3)_ distribution and has 5% and 10% critical values of 7.81 and 9.34 respectively. Consequently the estimates of the Engle and Granger cointegrating regression do not span the cointegrating space identified using the Johansen procedure. Two reasons may account for the discrepancy. First, it may be that single equation estimation is inappropriate, as implied by the exogeneity results above. Second, the exclusion of the short run dynamics in the Engle and Granger approach may have a non-trivial effect on the estimation of the parameters in the static regression. Whilst this effect diminishes asymptotically, given the relatively small sample size and the large outlying observation for 1972, it may be relevant in this case and indicate the benefits of using the VAR approach in which the dynamics and outliers are taken into account in the estimation of the long run relationship.In any case, the message that seems to be emerging is that the static regression does not represent a vaild simplification of the VAR and thus our attention continues to be focussed on the ECM estimated within the VAR framework.[24]

The VAR(2) model of equation (VII.11) estimated using the Johansen procedure (in which the constant has been restricted to enter via the long run relationship only), *i.e.*,

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \Pi X_{t-2} + \Phi Z_t + \varepsilon_t$$

may be written in its full form as,

$$\begin{bmatrix} \Delta \ln P20_t \\ \Delta \ln RN_t \\ \Delta^2 \ln F_t \end{bmatrix} = \begin{bmatrix} 0.034 & 1.373 & 1.693 \\ -0.020 & 0.648 & 0.181 \\ 0.045 & -0.065 & -0.416 \end{bmatrix} \begin{bmatrix} \Delta \ln P20_{t-1} \\ \Delta \ln RN_{t-1} \\ \Delta^2 \ln F_{t-1} \end{bmatrix} + \begin{bmatrix} 0.487 \\ -0.045 \\ 0.035 \end{bmatrix} Z_t$$

$$+ \begin{bmatrix} -0.551 & 0.648 & 2.307 & 1.414 \\ -0.081 & 0.095 & 0.3339 & 0.208 \\ 0.115 & -0.136 & -0.483 & -0.296 \end{bmatrix} \begin{bmatrix} \ln P20_{t-2} \\ \ln RN_{t-2} \\ \Delta \ln F_{t-2} \\ 1 \end{bmatrix}$$

where Z_t is a dummy variable for 1972 and the (3 * 4) matrix of coefficients on the second line is the long run matrix Π, the first row and column of which contains the

24 Further testing is required in order to have confidence in the assertion and will be conducted when the software becomes available.

(unnormalised) cointegrating vector and loading vector respectively.

(d) Interpreting the Land Price Error Correction Model

Focussing on the land price ECM, that has been estimated in the unrestricted VAR(2) above, we have a long run or cointegrating relationship given by,

$$\ln P20 = 2.568 + 1.177\ln RN + 4.119\Delta\ln F \qquad \text{(VII.30)}$$

Antilogging (VII.30) we have,

$$P20 = 13.03 * RN^{1.177} * e^{\Delta\ln F4.119} \qquad \text{(VII.31)}$$

Recall that the constant term of the cointegrating vector represents the log of the real capitalisation rate of annual rents into land values. Denoting the long run or equilibrium real discount rate by r then, 1/r = 13.03 implying that r = 1/13.03 = 0.077, *i.e.*the real rate of discount is 7.7% in the land market. Whilst this result is plausible it appears to be rather high. Note however that the unit elasticity coefficient between rent and land prices could not be rejected at the 5% level in the VAR implying that 1.177 is a plausible estimate of unity. The long run cointegrating relationship estimated in the VAR under the unit elasticity restriction was,

$$\ln P20 = 3.318 + \ln RN + 4.7140\Delta\ln F \qquad \text{(VII.32)}$$

Antilogging (VII.32) we have,

$$P20 = 27.61 * RN * e^{\Delta\ln F4.119} \qquad \text{(VII.33)}$$

from which the long run real rate of discount r = 1/27.61 = 0.036, *i.e.* 3.6%. This lower figure seems more likely, and accords well with real rates of discount obtained in Chapter IV that were estimated to be around 3% and also those estimated by Burt (1986) in his study of the land market in the United States, which were around 4%. Furthermore, (VII.33) implies a long run inflation elasticity of 0.31 at the mean values, suggesting that in the long run real land prices are affected little by changes in inflation.[25]

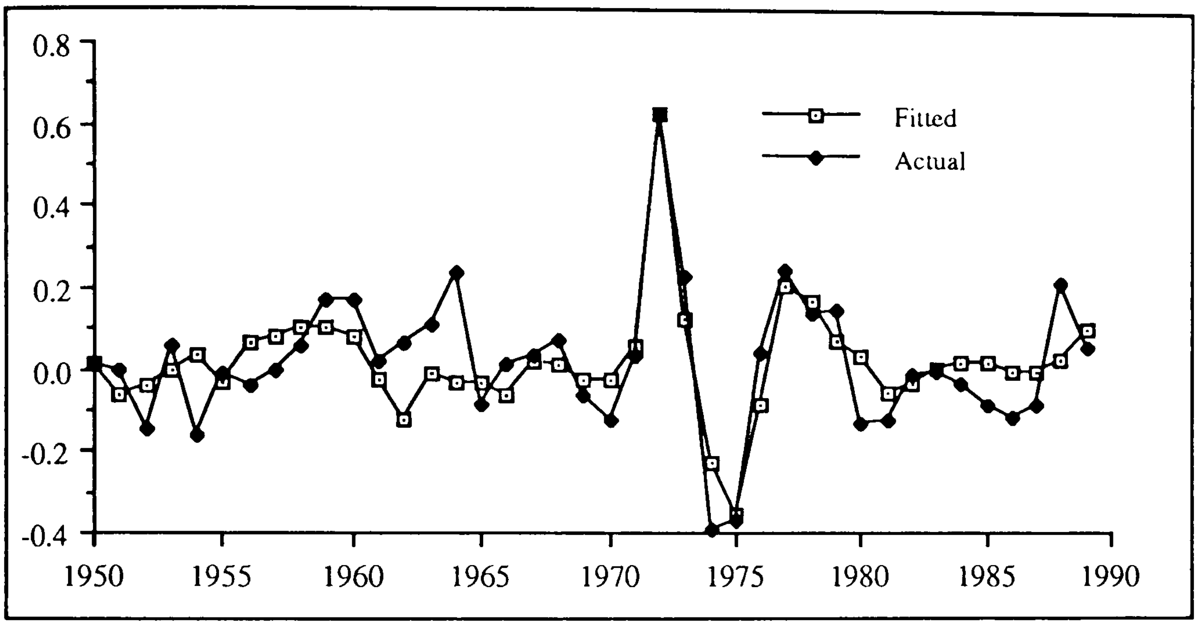
Using the estimate of the long run relationship given by (VII.32) which is denoted by W_t and noting that the coefficient of the explanatory variable $\Delta\ln P20_{t-1}$ in the VAR is simply an estimate of zero we have the final error correction formulation of the land price equation,

$$\underset{}{\Delta\ln P20_t} = \underset{(3.22)}{1.401\Delta\ln RN_{t-1}} + \underset{(2.40)}{1.801\Delta^2\ln F_{t-1}} - \underset{(5.33)}{0.543W_{t-2}} + \underset{(4.60)}{0.505Z_t} \qquad \text{(VII.34)}$$

[25] Given that equation (VII.32) is semilogarithmic with respect to inflation, the elasticity of land prices with respect to inflation is calculated as 4.714(0.066) = 0.31, where 0.066 is the mean level of inflation.

Figure VII.1 is a plot of fitted and actual land values using (VII.24) which tracks the growth rate of land prices reasonably well, particularly so given the parsimonious nature of the estimating equation.

Figure VII.1 : Fitted and Actual Values of the ECM for $\Delta lnP20_t$



The coefficient on W_{t-2} in (VII.34) represents the degree to which disequilibrium prices are adjusted in the following year: hence on average approximately half of any disequilibrium pricing is corrected for in any one year, *i.e* the half life of the adjustment process is about one. Bearing in mind that the point estimate has a 95% confidence interval of 0.34 to 0.74 the half life is around 2 years and 9 months respectively.[26]

Turning now to the dynamic behaviour of land prices in response to changes in rents and inflation, the point estimates of equation (VII.34) imply that on average land prices initially overshoot the equilibrium value in response to changes in (lagged) rents and (lagged) changes in inflation. Whilst an *ex post* rationalisation of dynamic responses is invariably conjectural, it seems plausible that the initial overshooting with respect to inflation, as implied by the coefficient of 1.801 in (VII.34), reflects the speculative behaviour of institutional investors, who are invariably interested in farmland as an

26 In order to accomplish 95% of any disequilibrium takes four years when the adjustment coefficient is 0.551; seven and a half years at 0.34; and two years at 0.74.

inflation hedge; or in other words, the real capital gain on land *viz-a-viz* other assets. Given that even marginal changes to the investment portfolios of the large institutional investors can have significant effects on the average price of farmland (See Munton 1975) the speculative nature of this demand may well induce a transient over-reaction in land prices. The model suggests that if there is a 1% rise (fall) in the rate of inflation, *ceteris paribus,* land prices rise in the following year by 1.8% overshooting the long run level which is only 0.3% above (below) the original equilibrium. If inflation is maintained at its new higher level then, *ceteris paribus,* land price falls in response to the disequilibrium pricing until it is some 0.3% higher than the previous equilibrium; a process that will take around three years.

The affect of real rent changes on land prices in the short run (as given by the coefficient of 1.401) is sufficiently close to the long run response (of one) to indicate that the apparent overshoot is merely due to sampling error, and thus it seems reasonable to infer that short and long run effects to real rent changes are the same.[27]

(e) Cointegration in the Historical Time Series

We now proceed to examine whether the same relationship that is identified over the post-war period holds over the much larger sample spanned by the Oxford Institute land price series. The sample comprises 120 observations over the years 1871 to 1990 and is thus nearly three times as long as the MAFF based data used previously. From a methodological point of view, the use of long time series for the purposes of estimation is beneficial although in practise such series are frequently quite troublesome since they span a number of volatile periods in economic history. Here, there is the Great Depression of UK agriculture in the 1880s, the commodity price collapse in the early 1920s, two World Wars, the Great Depression as well as the oil price shock and land price boom in the 1970s. These 'unusual' events produce large numbers of outliers with the result that the empirical distribution of each series is charactersied by long tails. This has implications for the statistical procedures which assume that the frequency distributions are normal. Here, judicious use of dummy variables induces normality in the landprice and rent series although this is not possible to do the same for inflation which remains non-normally distributed in VARs upto 6 lags in length. Table VII.8 reports some tests for normality and independence for the VAR(2) specification, which will be adopted in the estimation despite violating the normality assumption since it is the most parsimonious VAR to induce normally distributed independent residuals in the

27 OLS estimation of (20) cannot reject the hypothesis that 1.401 is significantly different from one.

land price and rent series. The $\Delta \ln P_t$ regression includes a dummy for 1972; the $\Delta \ln R_t$ regression uses dummies for 1917, 1921, 1922, 1935 and 1936; and the $\Delta^2 \ln F_t$ regression uses dummies for 1917, 1921, 1922 and 1975.

The non-normality of the inflation variable is evident from the Jarque-Bera test statistic of 18.98 in Table VII.8.

Table VII.8 : Some Test Statistics for the niid Assumption for the Residuals in (5) with k = 2 for the Trivariate Model

	B-J	S	EK	Q*(1)	Q*(5)	Q*(10)
$\Delta \ln PX_t$	3.08	-0.18	0.71	0.22	4.28	12.61
$\Delta \ln RH_t$	1.09	-0.13	0.38	0.26	2.15	9.18
$\Delta^2 \ln F_t$	18.98	-0.10	1.96	0.50	3.86	7.09
90% CV	**4.60**			**2.71**	**9.24**	**15.99**
95% CV	**5.99**			**3.84**	**11.07**	**18.30**

where J-B is the Jarque-Bera (1980) statistic approx distributed as χ^2 (2) under the null of normality
S is the coefficient of skewness which is zero for the normal distribution
EK is the coefficient of excess kurtosis which is zero for the normal distribution
Q^*(k) is the Ljung-Box (1978) statistic for serial correlation in the residuals, approx distributed as a χ^2 (k) under the null of no serial correlation. 5% and 10% critical values are in bold where they apply.

The non-normality is almost entirely due to excess kurtosis, as we might have expected given the discussion above. *A priori,* one would expect that the test statistics for cointegration and parameter estimates would be more robust in the presence of excess kurtosis than skewness, since kurtosis should only affect the variances of the estimates whereas skew would imply bias aswell. However, an examination of the behaviour of the cointegrating test statistics in the presence of departures from the nid assumptions has not yet been published, thus the results should be treated with some caution.

We begin by testing for the presence of linear trend in the variables expressed in levels. The test statistic using (VII.19) is calculated as,

$$= -117\{\ln(0.753/0.757) + \ln(0.890/0.893) + \ln(0.953/0.963)\}$$
$$= 2.68$$

which is distributed as χ^2 (2) under the null of no linear trends. The 5% critical value is 5.99 hence we cannot reject the null. The test statistics for cointegration in the VAR where the constant is restricted solely to the cointegrating vector are reported in Table VII.9. At the 95% confidence level the trace and maximal eigenvalue statistics suggest that a single cointegrating vector is present, although the null hypothesis of two cointegrating vectors is rejected at the 90% level. However, a simple inspection of the residuals from each of the cointegrating vectors confirms the presence of a single cointegrating vector since β_1 is the only vector with anything like stationary residuals.

Table VII.9 : Trace and Maximal Eigenvlaue Statistics for the Trivariate VAR(2) (Restricted Constant) Model

H_0	H_1	*Trace*	95%	90%	H_0	H_1	λ_{max}	95%	90%
$r \leq 0$	$r \geq 1$	52.90	34.91	32.00	$r = 0$	$r = 1$	33.23	22.00	19.77
$r \leq 1$	$r \geq 2$	19.67	19.96	17.85	$r = 1$	$r = 2$	13.98	15.67	13.75
$r \leq 2$	$r \geq 3$	5.69	9.24	7.53	$r = 2$	$r = 3$	5.69	9.24	7.53

Table VII.10 reports the decomposition of the long run matrix $\Pi = \alpha\beta'$ for the single cointegrating vector that has been identified above. Focussing on β_1 it is interesting to note that whilst the inflation coefficient is over three times the size of the coefficent estimated over the shorter period, the normalised coefficient on the rent variable (1.18) is close to unity and almost identical to the estimate generated using the shorter time series. Estimation of the coinegrating vector subject to the unity elasticity restriction yields,

$$(-\ln PX + \ln RH + 11.66\Delta \ln F)$$

Testing whether this restricted vector spans the cointegrating space yields a test statistic of 0.670 which has a $\chi^2(1)$ 5% critical value 3.84 implying that the restriction is consonant with the longer data series used here as well.

Table VII.10 : Estimates of the Cointegrating Vector β_i and Loading Vector α_i in the Trivariate Model

Eigenvalue $\hat{\lambda}$ = 0.243	Eigenvector β_1	Loading Vector α_1
ln*PX*	0.240	-0.253
	(-1.000)	(0.061)
ln*RH*	-0.282	-0.009
	(1.177)	(0.002)
Δln*F*	-3.061	0.130
	(12.76)	(-0.031)
Constant	-0.571	-
	(2.383)	-

Note: The figures in parentheses represent the coefficients in the cointegrating vectors normalised on the coefficient on ln*P20* being -1.

In addition we may test whether the coefficients estimated from the MAFF series are consistent with the data used here. The null hypothesis of equivalence was rejected with a test statistic of 20.38 which follows a $\chi^2(3)$ distribution under the null - the 5% critical value being 7.81. This result is not too surprising given the macroeconomic instability and institutional changes that have taken place between the sample periods. The stability of the VAR and the effects of the institutional and macroeconomic change during the earlier part of this long sample clearly requires further investigation and there seems little virtue in detailed examination of the VAR unless these factors are properly addressed. Supporting this view is the very low adjustment coefficient in the land price equation estimated at 0.061, one-ninth of its value in the shorter series and is only significantly different from zero at the 7% level. As a result we will leave the cointegration analysis of the longer time series for future research since a proper examination of issues such as a structural stabililty and violations of normality in the VAR are beyond the scope of the present study.

VII.(vii) A Summary of the Results

Cointegration seeks to determine whether a set of variables are linked together in the long run, as perhaps economic theory or intuition suggest they should. The technique of cointegration and related concepts such as stationarity, the order of integration and error correction models serve as useful tools in the estimation of economic relationships, since they help select from a host of potentially important variables and inter-relationships those which can plausibly exist; discarding all others as spurious, or more likely, incomplete explanations of the real world. Furthermore, by incorporating an estimate of a cointegrating relationship within an error correction model we are able to attempt to disentangle short run influences from this underlying behaviour of the variables.

Using two approaches proposed by Engle-Granger and Johansen, the empirical analysis suggests that the simple bivariate present value model of land prices is under-parameterised and does not form a cointegrating relationship. Consequently, this result implies that land prices in England and Wales are not solely explained by their 'agricultural earning potential'. However, if this relationship is augmented with inflation, the hypothesis of cointegration is supported. Hence, over the post-war period the I(1) variables - land prices, rents and inflation form a long run relationship, in that there is a linear combination of them that is I(0). Using this model the unit elasticity hypothesis between annual returns (rents) and asset value (land prices) is confirmed to lie within the cointegrating space and a long run real rate of discount estimated at 3.6%. The short run dynamic behaviour of land prices with respect to rents is such that changes in rents are immediately translated into proportionate changes in prices. In effect, the short run response to rents changes is the long run response. In contrast, land prices initially over-react to the rate of inflation in the economy since the long run inflation elasticity is estimated at 0.31, implying that agricultural land prices are inflation inelastic. Finally, whilst there is evidence to suggest that rents are exogenous to land prices, inflation appears to be endogenous implying that single equation estimation of the VAR is inappropriate. Whilst some of these results are echoed using a much longer sample, the possiblity of structural change and violation of the assumptions of the statistical analysis undermine the validity of the results and a detailed examination of this series is left for future research.

Appendix I :Summary Tabulations of Cointegration Tests

Table A1: Critical values of the CRDW Test Statistic

sample size	AR(1) process 1%	5%	10%	Higher Order Systems 1%	5%	10%
Bivariate Cointegrating Regression						
50	1.00	0.78	0.69	1.49	1.03	0.83
100	0.51	0.39	0.32	0.46	0.28	0.21
200	0.29	0.20	0.16	0.13	0.08	0.06
Trivariate Cointegrating Regression						
100	0.49	0.37	0.31	-	-	-

Sources : Engle and Yoo (1987), Hall (1986)

Notes

When the variables in the cointegrating regression are assumed to be AR(1) processes, use the critical values on the left hand side of the table and for higher order processes use those on the right.

Table A2: Critical values of the ADF Test Statistic

Maintained model : $\Delta\hat{\varepsilon}_t = \phi\hat{\varepsilon}_{t-1} + \upsilon_t$

Number of Variables	Sample Size	Significance Level 1%	5%	10%
2	50	4.32	3.67	3.28
	100	4.07	3.37	3.03
	200	4.00	3.37	3.02
3	50	4.84	4.11	3.73
	100	5.45	3.93	3.59
	200	4.35	3.78	3.47
4	50	4.94	4.35	4.02
	100	4.75	4.22	3.89
	200	4.70	4.18	3.89
5	50	5.41	4.76	4.42
	100	5.18	4.58	4.26
	200	5.02	4.48	4.18

Source: Engle and Yoo (1987, p.157)

Table A3: Critical values of the ADF Test Statistic

Maintained Model : $\Delta\hat{\varepsilon}_t = \phi\hat{\varepsilon}_{t-1} + \sum_{i=1}^{4} \hat{\delta}_i \Delta\hat{\varepsilon}_{t-i} + \upsilon_t$

Number of Variables	Sample Size	Significance Level		
		1%	5%	10%
2	50	4.12	3.29	2.90
	100	3.73	3.17	2.91
	200	3.78	3.25	2.98
3	50	4.45	3.75	3.36
	100	4.22	3.62	3.32
	200	4.34	3.78	3.51
4	50	4.61	3.98	3.67
	100	4.61	4.02	3.71
	200	4.72	4.13	3.83
5	50	4.80	4.15	3.85
	100	4.98	4.36	4.06
	200	4.97	4.43	4.14

Source: Engle and Yoo (1987, p.158)

Table A4: Critical Values for Johansen Procedure (no Linear Trends)

Maintained model: $\Delta x_t = \Gamma_1 \Delta x_{t-1} + \ldots + \Gamma_{k-1}\Delta x_{t-k+1} + \Gamma_k x_{t-k} + \varepsilon_t$

n - r	*Trace Statistic*			*Maximum Eigenvalue Statistic*		
	90%	95%	99%	90%	95%	99%
1	7.56	9.09	12.74	7.56	9.09	12.74
2	17.96	20.17	24.99	13.78	15.75	19.83
3	32.09	35.07	40.20	19.80	21.89	26.41
4	49.93	53.35	60.05	25.61	28.17	33.12
5	71.47	75.33	82.97	31.59	33.40	39.67

Source:Johansen and Juselius (1990, Table A3)

Table A5: Critical Values for Johansen Procedure (Linear trends)

Maintained model: $\Delta x_t = \mu + \Gamma_1 \Delta x_{t-1} + \ldots + \Gamma_{k-1} \Delta x_{t-k+1} + \Gamma_k x_{t-k} + \varepsilon_t$

r	*Trace Statistic*			*Maximum Eigenvalue Statistic*		
	90%	95%	99%	90%	95%	99%
1	6.69	8.08	11.58	6.69	8.08	11.58
2	15.58	17.84	21.96	12.78	14.60	18.78
3	28.44	31.56	37.29	18.60	21.28	26.15
4	45.25	48.42	55.55	24.92	27.34	32.62
5	65.96	69.98	77.91	30.82	33.26	38.86

Source:Johansen and Juselius (1990, Table A2)

Appendix II : Maximum Likelihood Estimation of the VAR

The method of estimation aims to obtain maximum likelihood estimates of α,β and Ω in equation (VII.8) To do this the likelihood function is initially concentrated with respect to the *free* parameters, - those parameters which cointegration does not impose restrictions on - namely the coefficients of μ, Φ and Γ_i, (i = 1, 2, . . ., k-1) by regressing,

$\Delta \boldsymbol{X}_t$ on ΔX_{t-1}, ΔX_{t-2}, ΔX_{t-k+1}, constant and $\mathbf{Z}_t$.

and

X_{t-k} on ΔX_{t-1}, ΔX_{t-2}, ΔX_{t-k+1}, constant and $\mathbf{Z}_t$.

giving residual vectors $\mathbf{R}_{0t}$ and $\mathbf{R}_{kt}$ respectively. The likelihood function can then be written as being proportional to,

$$L(\alpha, \beta, \Omega) = |\Omega|^{-T/2} \exp\left\{ -\frac{1}{2} \sum_{t=1}^{T} (R_{0t} + \alpha\beta' R_{kt})' \Omega^{-1} (R_{0t} + \alpha\beta' R_{kt}) \right\} \tag{A2.1}$$

Regressing $\mathbf{R}_{0t}$ on $-\beta'$ $\mathbf{R}_{kt}$ allows (A2.1) to be maximised over α and Ω for a fixed β. Thus, establishing the first order conditions,

$$\frac{\partial \ln L}{\partial \alpha} = \frac{\partial \ln L}{\partial \Omega} = 0$$

expressions for $\hat{\alpha}(\beta)$ and $\hat{\Omega}(\beta)$ are given as,

$$\hat{\alpha}(\beta) = -S_{0k}\beta(\beta' S_{kk}\beta)^{-1} \tag{A2.2}$$

and

$$\hat{\Omega}(\beta) = S_{00} - S_{0k}\beta(\beta' S_{kk}\beta)^{-1}\beta' S_{k0} \tag{A2.3}$$

which are expressed in terms of the product moment matrices of the residual vectors which are calculated as,

$$S_{ij} = T^{-1}\sum_{t=1}^{T} R_{it} R_{jt}' \qquad i, j = 0, k$$

Substituting (A2.2) and (A2.3) into (A2.1) the concentrated likelihood function collapses to,

$$L(\beta) = \left|\hat{\Omega}(\beta)\right|^{-T/2} = \left|S_{00} - S_{0k}\beta(\beta' S_{kk}\beta)^{-1}\beta' S_{k0}\right|^{-T/2} \tag{A2.4}$$

entailing that maximising (A2.4) with respect to β is equivalent to minimising $\left|\hat{\Omega}(\beta)\right|$.

The estimation of β proceeds by proving that

$$|S_{00} - S_{0k}\beta(\beta' S_{kk}\beta)^{-1}\beta' S_{k0}| = \frac{|\beta' S_{kk}\beta - S_{k0} S_{00}^{-1} S_{0k}\beta|}{|\beta' S_{kk}\beta|}$$

and noting that

$$\frac{|\beta' S_{kk}\beta - S_{k0} S_{00}^{-1} S_{0k}\beta|}{|\beta' S_{kk}\beta|}$$

may be minimised by solving the generalised eigenvalue problem,

$$|\lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k}| = 0$$

This solution gives n ordered eigenvalues $\hat{\lambda}_1 > \hat{\lambda}_2 > \ldots > \hat{\lambda}_n$ of $S_{k0}\ S_{00}^{-1}\ S_{0k}$ with respect to S_{kk} and n corresponding eigenvectors $\hat{V} = (\hat{v}_1, \hat{v}_2, \ldots, \hat{v}_n)$ normalised such that $\hat{V}' S_{kk} \hat{V} = I$ where the maximum likelihood estimates of the matrix β, are the first r eigenvectors of $S_{k0}\ S_{00}^{-1}\ S_{0k}$ with respect to S_{kk} *i.e.* $\hat{\beta} = (\hat{v}_1, \hat{v}_2, \ldots, \hat{v}_r)$ under the null $\Pi = \alpha\beta'$.

In order to obtain estimates of α and Ω the estimate of β is substituted back into (A2.2) and (A2.3). The maximised likelihood function becomes,

$$L_{max}^{-2/T} = |\hat{\Omega}(\beta)| = |S_{00}| \prod_{i=1}^{r}(1 - \hat{\lambda}_i) \qquad \text{(A2.5)}$$

which may be compared to the likelihood obtained in the absence of the constraint that $\Pi = \alpha\beta'$, in which case $r = n$ and $\beta = \mathbf{I}$. Substituting these equalities into expressions for $\hat{\alpha}(\beta)$ and $\hat{\Omega}(\beta)$ the maximised likelihood becomes,

$$L_{max}^{-2/T} = |S_{00}| \prod_{i=1}^{n}(1 - \hat{\lambda}_i) \qquad \text{(A2.6)}$$

The ratio of the two likelihoods, in (A2.5) and (A2.6) provides a simple test statistic (called the *trace statistic*) for the number of cointegrating vectors and takes the form,

$$-2\ln(Q) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i)$$

This likelihood ratio statistic tests that there at most r cointegrating vectors, where $\hat{\lambda}_i$ $i = r + 1$ to n are the $n - r$ smallest eigenvalues.

In a similar vein a second statistic for the number of cointegrating vectors may be constructed, (called the *maximal eigenvalue statistic*) in which the likelihood under the null of r cointegrating vectors is compared to that when there are $r + 1$, and is given by,

$$-2\ln(Q) = -T\ln(1 - \hat{\lambda}_{r+1})$$

The critical values of these tests are not distributed as χ^2 even asymptotically but as multivariate versions of the Dickey-Fuller distribution, although critical values have been tabulated by monte carlo simulation and are presented in Johansen and Juselius (1990). Test statistics larger than the appropriate critical value signal a rejection of the respective null hypotheses.

Chapter VIII
Univariate Forecasting Models

VIII.(i) Introduction

The econometric models presented so far have attempted to estimate the parameters of a structural model using explanatory variables posited by economic theory. Whilst such structural econometric models illuminate the mechanics of economic relationships and allow for the testing of hypotheses arising from them, such models are frequently impotent for the purpose of forecasting the variable of interest, since it is generally necessary to obtain forecasts of each of the explanatory variables that also appear in the model. Not only does this impose considerable demands on resources but also implies that errors in forecasting the explanatory variables are subsequently compounded into the forecast of the variable of primary interest. As a result specific models are developed for the purpose of forecasting to which attention now turns.

In contrast to econometric models, those used for forecasting neither possess an economic structure nor explanatory variables but attempt to 'explain' the series of interest purely in terms of its past behaviour. Forecasting models fall into one of two categories : deterministic and stochastic, although the former class of models will not be considered here due to their inherent deficiencies. [1]

Stochastic time-series models develop from the presumption that the series of interest has been generated (or may be approximated) by some form of random or stochastic process possessing a definite structure. Using the only realisation of the series available, (the sample data), this structure may be identified and its parameters estimated, so that future values may then be forecast purely from the series past behaviour, obviating the need for explanatory variables. The methodology adopted in this chapter was first proposed by Box and Jenkins (1970) and uses a tractable class of

1 Deterministic forecasting tools include models of Classical Decomposition and the simple extrapolation and moving average models . Whilst quick and easy to implement their rather *ad hoc* and deterministic nature are disquieting features and limits their applicability to situations in which time and expertise is lacking. However, their most serious drawback relates to the fact that because of their deterministic nature, standard errors and confidence intervals are not generated. Clearly, where policy making is concerned, margins of error are frequently as important as the point estimates produced. For an introductory review of these deterministic models see, Pindyck and Rubinfeld (1981).

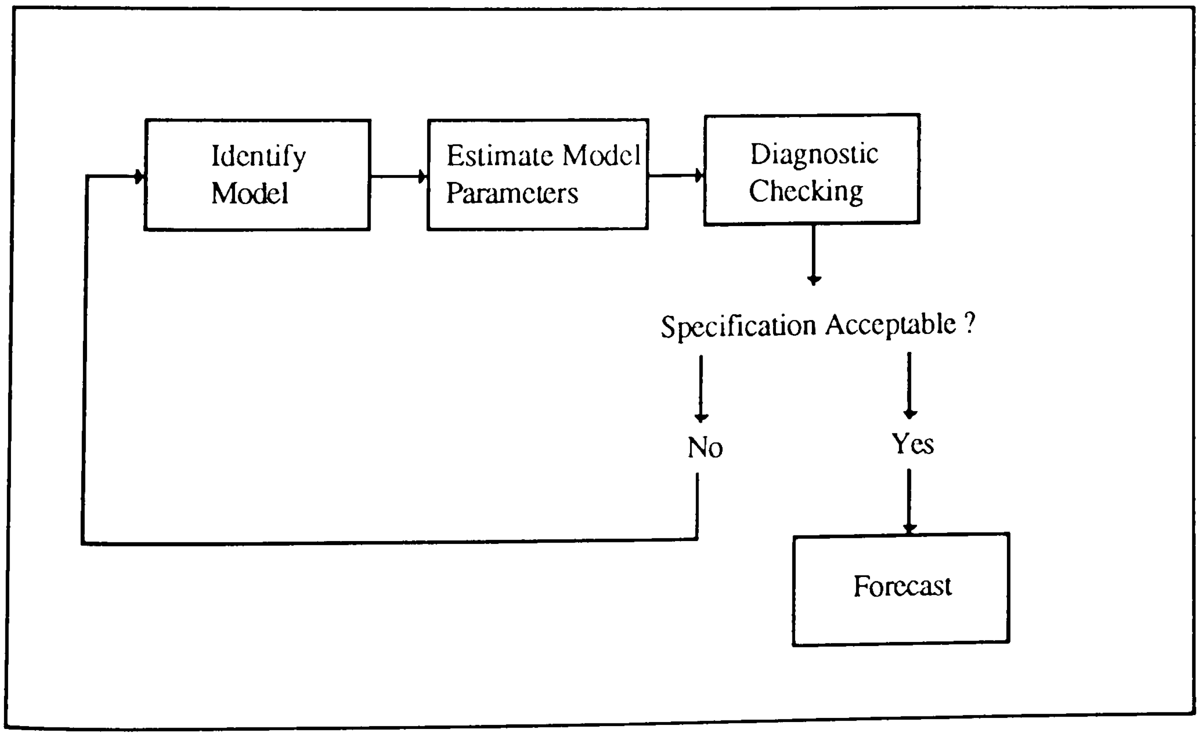
linear models for the analysis of univariate time series, called integrated autoregressive moving average or ARIMA models. Despite having little or no economic interpretation ARIMA models describe the properties of a time series sufficiently well to yield forecasting models that typically perform well over short forecasting horizons.

This Chapter contains ten Sections and one Appendix. Section (ii) gives an overview of the steps involved in ARIMA modelling and in Section (iii) the characteristics of some parsimonious ARIMA are discussed. Sections (iv) to (vii) explore each of the steps introduced in Section (ii), namely, identification, estimation, diagnostic checking and forecasting. Sections (viii) and (ix) contain the empirical analysis and finally some concluding remarks are made in Section (x). The Appendix to this Chapter is a simulation exercise in which identification of the linear models introduced in section (iii) is attempted using artificially generated data.

VIII.(ii) The ARIMA Methodology

Box and Jenkins (1970) propose a model building strategy that is illustrated in Figure VIII.1. It comprises four sequentially discrete but closely inter-related stages, namely identification, parameter estimation, diagnostic checking and forecasting.

Figure VIII.1 : The Box-Jenkins Strategy



Clearly, the object of the exercise is to produce a set of forecasts h periods into the future. However, the forecasters first task is to identify the structure of the process that is believed to be generating the data. Once a model or estimate of this structure is determined, the parameters of the model are then estimated using the sample data so as to minimise the sum of squared residuals, in a manner analogous to regression. Following the estimation exercise a number of diagnostic tests are performed to ensure that the model chosen is an acceptable representation of the process generating the data. Should the diagnostic testing suggest that the model is an inadequate representation, the identification stage is repeated and a new estimate of the structure identified and estimated. Once an adequate specification has been identified and estimated the model is then used to produce forecasts.

(a) The Autocorrelation and Partial Autocorrelation Functions

In order to explore the characteristics of different stochastic models it is necessary to begin by discussing the autocorrelation function (ACF) and the partial autocorrelation function (PACF) - which are used as important tools for identifying the most appropriate model of an empirical time series. The ACF was introduced in Chapter VI where it was examined in some detail with respect to stationarity. To recap, the ACF describes the degree of association or the nature of the bonding between observations in the same time series and is computed as,

$$\tau_k = \frac{\gamma_k}{\gamma_0} = \frac{\mathrm{cov}(Y_t, Y_{t-k})}{\sqrt{\mathrm{var}(Y_t)\ \mathrm{var}(Y_{t-k})}}$$

where,

$$\mathrm{cov}(Y, Y_{t-k}) = \mathrm{E}[(Y_t - \mu)(Y_{t-k} - \mu)] = \gamma_k$$

and,

$$\mathrm{var}(Y_t) = \mathrm{E}[(Y_t - \mu)^2]$$

where μ is the mean of the process. In standardising the covariance between Y_t and Y_{t-k} by the variance of the series, the autocorrelation function generates k autocorrelation coefficients (τ_k) such that, $-1 > \tau_k < +1$. Using estimates of the mean, variance and covariance from the sample of observations available, a sample ACF can be derived. To aid the interpretation of the sample ACF the $\hat{\tau}_k$ are typically plotted against the length of lag k on a correlogram.

In order to introduce some objectivity into the interpretation of the ACF a number of tests have been developed to test for the significance of successive autocorrelation coefficients and most computer packages typically superimpose the standard error bands on the correlogram to aid identification of the number of significant autocorrelations. Barlett (1946) has shown that the standard error of $\hat{\tau}_k$ for a stationary normal process is approximately equal to,

$$\mathrm{SE}(\hat{\tau}_k) = \sqrt{\frac{1}{n}\left[1 + 2\sum_{k=1}^{q} \hat{\tau}_k^2\right]} \qquad \text{(VIII.1)}$$

for lags $k > q$.[2] Consequently, if an autocorrelation coefficient assumes a value greater (in absolute terms) than twice its standard error given by (VIII.1) this suggests that it is significantly different from zero. Testing the significance of $\hat{\tau}_k$ therefore requires the inclusion of all previous autocorrelation coefficients, that is $\hat{\tau}_i$; $i = 1, 2, \ldots k\text{-}1$.

Another tool frequently used in the model identification phase is the partial autocorrelation function (PACF) and the partial autocorrelation coefficients it generates. Since, in time series analysis, a large proportion of the correlation between Y_{t-k} and Y_t may be due to the correlation these variables have with the intervening lags ($Y_{t-1}, Y_{t-2}, \ldots Y_{t-k+1}$) the partial autocorrelation coefficient at lag k, denoted ϕ_k is frequently used to adjust for this correlation as it is a measure of the *extra* information Y_{t-k} contributes to Y_t after the influences of $Y_{t-1}, Y_{t-2}, \ldots Y_{t-k+1}$ have been taken into account. Consequently, partial coefficients are simply the coefficients of a multiple linear autoregression of Y_t on its lagged values, *i.e.*

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_k Y_{t-k}\, \varepsilon_t \qquad \text{(VIII.2)}$$

As the order of the autoregression is unknown, obtaining the partial autocorrelation coefficients requires fitting autoregressive models of increasing order to the sample data: the estimate of the last coefficient in each model gives a measure of the partial autocorrelation. Using a t test, the significance of the k^{th} coefficient in each case can be determined, and hence the correct order of the autoregression.

Alternatively, we may exploit a useful relationship between the partial autocorrelations (ϕ_k) and the autocorrelation coefficients (τ_k). Noting that the autocovariances for lags k in a p^{th} order autoregression are calculated from,

$$\gamma_k = \mathrm{E}\left[Y_{t-k}(\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + \varepsilon_t)\right]$$

then, letting $k = 0, 1, \ldots, p$ results in $p + 1$ difference equations that may be solved

2 If the sample size T is large the sample estimates of τ_k will be approximately normally distributed with standard error $T^{-1/2}$. This large sample approximation is used in Appendix I to calculate the significance of coefficients in both the ACFs and PACFs.

simultaneously for the autocovariances $\gamma_0, \gamma_1, \ldots, \gamma_p$ to yield,

$$\gamma_0 = \phi_1 \gamma_1 + \phi_2 \gamma_2 + \ldots + \phi_p \gamma_p + \sigma_\varepsilon^2$$

$$\gamma_1 = \phi_1 \gamma_0 + \phi_2 \gamma_1 + \ldots + \phi_p \gamma_{p-1} + \sigma_\varepsilon^2$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\gamma_p = \phi_1 \gamma_{p-1} + \phi_2 \gamma_{p-2} + \ldots + \phi_p \gamma_0$$

and for lags k greater than p the autocovariances follow the equation,

$$\gamma_k = \phi_1 \gamma_{k-1} + \phi_2 \gamma_{k-2} + \ldots + \phi_p \gamma_{k-p} \qquad \text{(VIII.3)}$$

If these equations are now divided by γ_0 we are left with a set of p equations called the *Yule-Walker equations* that determine the first p values of the autocorrelation function,

$$\tau_1 = \phi_1 + \phi_2 \tau_1 + \ldots + \phi_p \tau_{p-1}$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\tau_p = \phi_1 \tau_{p-1} + \phi_2 \tau_{p-2} + \ldots + \phi_p$$

and from (VIII.3) we have the autocorrelation coefficients for lags k greater than p,

$$\tau_k = \phi_1 \tau_{k-1} + \phi_2 \tau_{k-2} + \ldots + \phi_p \tau_{k-p}$$

Now, if the autocorrelation coefficients are known or can be estimated from calculation of the sample ACF then the Yule -Walker Equations can be solved to yield estimates of the partial autocorrelation coefficients ($\phi_0, \phi_1, \ldots, \phi_p$). Again however this requires prior knowledge of the order of the autoregression p which will not be known. Hence, a recursive approach is necessary in which we solve the Yule-Walker equations for successive values of p until the ϕ_{p+1} coefficient is insignificantly different from zero. Hence, assuming that $p = 1$, the Yule-Walker equations are solved, resulting in $\phi_1 = \tau_1$. If ϕ_1 is significantly different from zero then the autoregressive process must be at least of order one. The procedure is then repeated under the assumption that $p = 2$, and the Yule-Walker equations solved to yield values of ϕ_1, and ϕ_2. If the estimate of ϕ_2 is significantly different from zero then the process is at least of order 2, although if it is not, it can be concluded that $p = 1$. In practice the recursion continues k times so that k partial autocorrelations have been generated, although only the first p of them will be significantly different from zero. Using the sample of data at hand estimates of the coefficients above may be produced. Again, the estimated coefficients of the sample PACF, $\hat{\phi}_k$ are plotted against lag k on a graph similar to the correlogram - the partial correlogram.

In fact the above computation is simplified by using a recursion proposed by Durbin

(1960). Here, estimates of the ϕ_k coefficients in the equations that make up (VIII.2) may be derived using the following updating equations, where hats denote sample estimates, $\phi_k = \phi_{kk}$ and ϕ_{kj} denotes the other ϕ_k's so that for each equation j = 1,2, . . . , k-1.

$$\hat{\phi}_{kk} = \frac{\hat{\tau}_k - \sum_{j=1}^{k=-1} \hat{\phi}_{k-1,j}\, \hat{\tau}_{k-j}}{1 - \sum_{j=1}^{k=-1} \hat{\phi}_{k-1,j}\, \hat{\tau}_j}$$

$$\hat{\phi}_{kj} = \hat{\phi}_{k-1,j} - \hat{\phi}_{kk}\, \hat{\phi}_{k-1,k-j} \qquad \text{(VIII.4)}$$

Equation (VIII.4) will be used later to derive the partial autocorrelation coefficients from the models discussed in the following sections.

To aid identification of the order of an autoregressive process we need to test the significance of each estimated partial autocorrelation coefficient, ϕ_k . Quenouille has shown that under the hypothesis that the process is one of pure autoregression of order p, the partial autocorrelation coefficients of order p +1 and above are independently distributed with a standard error given by,

$$\mathrm{SE}(\hat{\phi}_k) = \sqrt{\frac{1}{n}} \qquad \text{for } k > p+1$$

and most computer packages provide the two standard error bands for identification of significant partial autocorrelations.

VIII.(iii) Linear Time Series Models

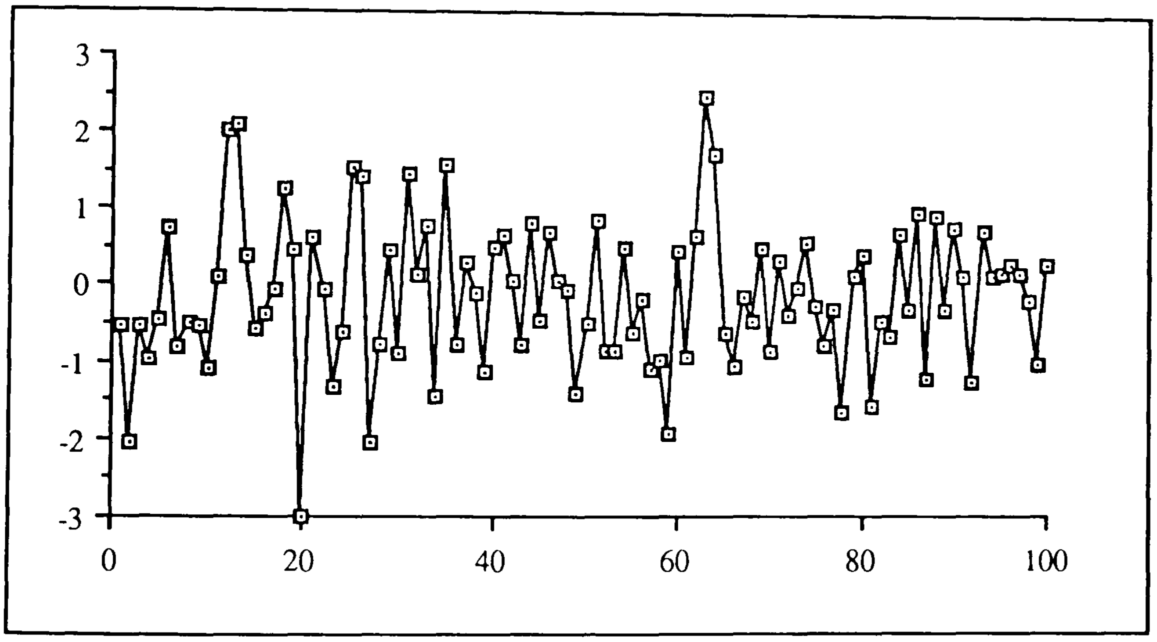
This section describes the three types of linear stochastic models that comprise a general framework for the 'Box-Jenkins' modelling of stationary univariate time series; namely, moving average (MA), autoregressive (AR) and mixed (ARMA) models. The assumption of a linear functional form simplifies the analytical process and facilitates the use of standard statistical theory to produce confidence intervals for the estimated parameters and forecasts. Since linear relationships (involving fixed parameters) are used to estimate the underlying stochastic structure of the data generating process, it follows that the process must exhibit stable time series properties, and thus the series to be modelled must be stationary, as described in Chapter VI. Although we will return to the question of stationarity in Section (d) it is assumed for the time being that all series are stationary.

The simplest stochastic model describes a purely random series, that is,

$$Y_t = \varepsilon_t$$

where ε_t is a white noise process in which every observation is independently and identically distributed through time with zero mean and constant variance, *i.e.* ε_t *i.i.d.*$(0, \sigma_\varepsilon^2)$. Such a series is shown in Figure VIII.2. Since each observation is independent of all others the covariance between any two observations in the series is zero, *i.e.* $\gamma_k = (\varepsilon_t, \varepsilon_{t-k}) = 0$, for all non-zero k. Consequently, knowledge of the past cannot assist in forecasting future values of the series and the best forecast is its mathematical expectation, which is zero.

Figure VIII.2: Time series of an i.i.d.(0,1) Variable



Despite being quite rare in economics the white noise process is of fundamental importance to stochastic modelling as every stochastic series is viewed as being the outcome of a linear transformation of random innovations. Consequently, white noise is perceived as the driving force behind *all* stochastic models since a weighted accumulation of random innovations provide a good representation of many commonly found non-white series as will be demonstrated below. The first step of time series modelling is therefore to identify the linear filter that transforms white process to one that is nonwhite. Attention now focuses on the three classes of linear filters.

(a) Moving Average Models

Given that all stationary stochastic processes can be viewed as being the accumulation of random innovations, the simplest form of linear filter is that represented by the moving average model in which each observation Y_t is generated purely by a weighted average of current and lagged random disturbances. The order (q) of a MA process specifies the number of lagged disturbance terms that affect each observation. Thus the MA(q) process is denoted as,

$$Y_t = \mu + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_q \varepsilon_{t-q} \qquad \text{(VIII.5)}$$

where the parameters of the model, $\theta_1, \ldots \theta_q$ are the weights assigned to the random innovations in the process ε_t and ε_t *i.i.d.*$(0, \sigma_\varepsilon^2)$. Given this structure it is easy to see that all MA processes must be stationary by definition since the mean value of Y_t in (VIII.5) is the constant μ and variance is given by,

$$\begin{aligned}
\text{var}(Y_t) = \gamma_0 &= \text{E}\left[(Y_t - \mu)^2\right] \\
&= \text{E}(\varepsilon_t^2 + \theta_1^2 \varepsilon_{t-1}^2 + \ldots + \theta_q^2 \varepsilon_{t-q}^2 - 2\theta_1 \varepsilon_t \varepsilon_{t-1} - \ldots) \\
&= \sigma_\varepsilon^2 + \theta_1^2 \sigma_\varepsilon^2 + \ldots + \theta_q^2 \sigma_\varepsilon^2 \\
&= \sigma_\varepsilon^2 (1 + \theta_1^2 + \theta_2^2 + \ldots + \theta_q^2)
\end{aligned}$$

which is also a constant. The covariance of Y_t is also invariant to time, depending only on the distance between the two observations, k and the order of the MA process, q,

$$\gamma_k = (\theta_k + \theta_1 \theta_{k+1} + \ldots + \theta_{q-k} \theta_q)\sigma_\varepsilon^2 \qquad k = 1, \ldots, q$$

$$\gamma_k = 0 \qquad k > q$$

As a result it is clear that any MA process satisfies the conditions of stationarity discussed at some length in Chapter VI.

For simplicity the MA(q) is frequently written in the form,

$$Y_t = \theta(\text{B})\varepsilon_t$$

where B represents a polynomial of order q *i.e,*

$$\theta(\text{B}) = 1 - \theta_1 \text{B} - \theta_2 \text{B}^2 - \ldots - \theta_q \text{B}^q$$

and is called the moving average operator. Furthermore it is sometimes necessary to express the moving average process in autoregressive form *i.e.*

$$\varepsilon_t = \theta^{-1}(\text{B})Y_t$$

that is,

$$\varepsilon_t = Y_t + \theta_1^{-1} Y_{t-1} + \theta_2^{-1} Y_{t-2} + \ldots + \theta_q^{-1} Y_{t-q}$$

This now implies that for every moving average process there is a unique autocorrelation function. However, this may not necessarily be the case unless certain restrictions are imposed on the MA parameters; where these conditions are satisfied the MA process is said to be *invertible*. It will suffice to state here that imposition of the invertibility constraint ensures that there is a unique moving average process for a given autocorrelation and partial autocorrelation function.

It is now appropriate to consider some simple moving average processes and in particular analyse their mean, variance and autocorrelation function. These statistics represent artefacts that may be analysed to aid identification of the process generating the data at hand. In Appendix I the ACF and PACF of the processes reviewed below are examined to identify the order of the process from a sample of observations which have been generated artificially from known data generating processes. It is fortunate that in practice one is only concerned with MA models of low order, typically 1 or 2 and so the presentation of MA models will be confined to these two processes.

(i) Moving Average Process of Order 1 :MA(1)

The MA(1) process is expressed by the equation,

$$Y_t = \mu + \varepsilon_t - \theta_1 \varepsilon_{t-1} \qquad \text{(VIII.6)}$$

Dwelling on (VIII.6) for a moment it is evident that as θ_1 approaches -1 the series assumes a smooth appearance, whereas when θ_1 tends toward unity the series will appear even more erratic than a random series. It is clear that this process has mean μ and variance given by,

$$\begin{aligned} \text{var}(Y_t) = \gamma_0 &= E\left[(Y_t - \mu)^2\right] \\ &= E(\varepsilon_t^2 + \theta_1^2 \varepsilon_{t-1}^2 - 2\theta_1 \varepsilon_t \varepsilon_{t-1}) \\ &= \sigma^2(1 + \theta_1^2) \end{aligned}$$

Its autocovariance at lag one is,

$$\begin{aligned} \gamma_1 &= E\left[(Y_t - \mu)(Y_t - \mu)\right] \\ &= E\left[(\varepsilon_t - \theta_1 \varepsilon_{t-1})(\varepsilon_{t-1} - \theta_1 \varepsilon_{t-2})\right] \\ &= -\theta_1 \sigma^2 \end{aligned}$$

and in general for a k lag displacement in time it is,

$$\begin{aligned} \gamma_k &= E\left[(\varepsilon_t - \theta_1 \varepsilon_{t-1})(\varepsilon_{t-k} - \theta_1 \varepsilon_{t-k-1})\right] \\ &= 0 \qquad \text{for } k > 1 \end{aligned}$$

Recalling that the autocorrelation function for a stationary process is simply the autocovariance at lag k divided by the variance, the ACF of a MA(1) process is,

$$\tau_k = \frac{\gamma_k}{\gamma_0} = \frac{-\theta_1}{1+\theta_1^2} \qquad k = 1$$
$$= 0 \qquad \text{for } k > 1$$

It is evident therefore that the MA(1) process has a covariance and thus ACF that vanishes to zero for lags greater than one, so that the process has a *memory* of only one period. As a result Y_t is correlated with Y_{t-1} and Y_{t+1} but no other observation in the series, so that events occurring more than one period ago are irrelevant to the current observation. The fact that the autocorrelation function cuts-off at lag one is a useful artefact that can be detected simply by observing the correlogram. Notice however that the solution of τ_1 above is a quadratic in θ_1 and hence may be rewritten as the quadratic equation,

$$\theta_1^2 + \frac{\theta_1}{\tau_1} + 1 = 0$$

so that a given value of τ_1 will be associated with two different values of the parameter θ_1. In order to ensure that the autocorrelation function implies a unique value of θ_1 and hence a unique data generating process, it is necessary to invoke the invertibility condition, which for the MA(1) model is simply $-1 < \theta_1 < 1$.[3]

Focussing on the ACF for the theoretical MA(1) process it is evident that substituting values of θ_1 with the range admissible for invertibility imposes bounds in which τ_1 may lie: specifically, $-0.5 < \tau_1 < 0.5$

It should also be noted that the PACF for the MA(1) process may be derived as,

$$\phi_k = \frac{-\theta_1(1-\theta_1^2)}{\left[1-\theta_1^{2(k+1)}\right]}$$

which although not easily apparent, results in a exponential decline to zero as k increases, in stark contrast to the sharp cut-off exhibited by the ACF for this process. (See Appendix I).

(ii) Moving Average Process of Order two : MA(2)

The MA(2) process is expressed as,

$$Y_t = \mu + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2}$$

3 Also note that an important reason for restricting attention to invertible processes is that non-invertible processes give rise to inefficient forecasts. See Harvey (1981) pp.161 for a discussion of this point.

with mean μ and variance $\sigma^2(1 + \theta_1^2 + \theta_2^2)$ and covariance at lag one given by,

$$\begin{aligned}\gamma_1 &= \mathrm{E}\left[(\varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2})(\varepsilon_{t-1} - \theta_1 \varepsilon_{t-2} - \theta_2 \varepsilon_{t-3})\right] \\ &= -\theta_1 \sigma^2 + \theta_1 \theta_2 \sigma^2 \\ &= -\theta_1 (1 - \theta_2)\sigma^2\end{aligned}$$

and at lag two by,

$$\begin{aligned}\gamma_2 &= \mathrm{E}\left[(\varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2})(\varepsilon_{t-2} - \theta_1 \varepsilon_{t-3} - \theta_2 \varepsilon_{t-4})\right] \\ &= -\theta_2 \sigma^2\end{aligned}$$

and $\gamma_k = 0$ for k > 2.

From the above equations we may calculate the autocorrelation function of an MA(2) as,

$$\tau_1 = \frac{-\theta_1 (1 - \theta_2)}{1 + \theta_1^2 + \theta_2^2}$$

$$\tau_2 = \frac{-\theta_2}{1 + \theta_1^2 + \theta_2^2}$$

$$\tau_3 = 0 \qquad k > 2$$

From the autocovariance and ACF it is clear that the MA(2) process has a memory of two periods so that the current observation of Y_t is influenced only by the observations in Y_{t-1} and Y_{t-2}. More generally it can be shown that an MA(q) process has a memory of precisely q periods with an autocorrelation function such that,

$$\begin{aligned}\tau_k &= \frac{-\theta_k + \theta_1 \theta_{k+1} + \ldots + \theta_{q-k} \theta_q}{1 + \theta_1^2 + \theta_2^2 + \ldots + \theta_q^2} \qquad & k = 1, \ldots, q \\ &= 0 & k > q\end{aligned}$$

so that the autocorrelation function cuts off at lag q. Indeed, the ACF can be a valuable tool in the identification of the order of moving average processes, exhibiting significant spikes for the first k autocorrelations on the correlogram. As in the MA(1) case the PACF does not exhibit a 'cut-off' but declines steadily to zero as k increases. This systematic decline of MA processes is a general trait and will be portrayed by any MA(q) process. See Appendix I.

The restrictions that need to be imposed on the parameters of the MA(2) model to ensure invertibility may be summarised as,

$$\theta_1 + \theta_2 < 1$$
$$\theta_2 - \theta_1 < 1$$
$$-1 < \theta_2 < 1$$

(b) Autoregressive Models

An alternative class of linear stochastic models is the autoregressive process in which the current observation is dependent upon its past and a unknown noise term. In general the autoregressive model of order p, AR(p) is given by,

$$Y_t = \mu + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ . \ . \ . \ + \phi_p Y_{t-p} + \varepsilon_t \qquad \text{(VIII.7)}$$

where the noise component ε_t is assumed white noise, such that ε_t i.i.d.(0, σ^2). Assuming that μ is zero, (VIII.7) may be more succinctly expressed by,

$$\phi(\mathrm{B})Y_t = \varepsilon_t$$

where $\phi(\mathrm{B})Y_t$ is the autoregressive operator since (VIII.7) can be rearranged to give,

$$Y_t - \phi_1 Y_{t-1} - \phi_2 Y_{t-2} - \ . \ . \ . \ - \phi_p Y_{t-p} = \varepsilon_t$$
$$(1 - \phi_1 \mathrm{B} - \phi_2 \mathrm{B}^2 - \ . \ . \ . \ - \phi_p \mathrm{B}^p) = \varepsilon_t$$

MA processes are always stationary but must satisfy conditions for invertibility, whereas AR processes are always invertible but must fulfill conditions to ensure stationarity. As with moving average processes it is seldom necessary to employ a high order AR process to model an empirical series and consequently our discussion of autoregressive processes is limited to second order processes.

(i) Autoregressive Processes of Order One : AR(1)

Here, the process generating Y_t is given as,

$$Y_t = \delta + \phi_1 Y_{t-1} + \varepsilon_t \qquad \text{(VIII.8)}$$

and if stationary the mean of the process should be invariant to time so that,

$$\mathrm{E}[Y_t] = \mathrm{E}[Y_{t-1}] = \mu$$

and thus,

$$\mu = \frac{\delta}{1 - \theta_1}$$

From (VIII.8) it can be inferred that when ϕ_1 is positive, Y_t will evolve as a relatively smooth series (compared to white noise) although this will not be the case where ϕ_1 is negative. From (VIII.8) it is also clear that a sufficient condition for stationarity is simply that $-1 < \phi_1 < 1$ for if $|\phi_1| > 1$ the process would be explosive, exhibiting trending over time.[4] The variance of this process is[5],

$$\gamma_0 = \mathrm{E}[Y_t^2] = \mathrm{E}\left[(\phi_1 Y_{t-1} + \varepsilon_t)^2\right]$$
$$= \mathrm{E}\left[\phi_1^2 Y_{t-1}^2 + \varepsilon_t^2 + 2\phi_1 Y_{t-1}\varepsilon_t\right] = \phi_1^2\gamma_0 + \sigma^2$$
$$= \frac{\sigma^2}{1-\phi_1^2}$$

The covariance at lag 1 of Y_t about its mean is then,

$$\gamma_1 = \mathrm{E}\left[Y_{t-1}(\phi_1 Y_{t-1} + \varepsilon_t)\right] = \phi_1\gamma_0$$
$$= \frac{\phi_1\sigma^2}{1-\phi_1^2}$$

and at lag 2 is,

$$\gamma_2 = \mathrm{E}\left[Y_{t-2}(\phi_1^2 Y_{t-2} + \phi_1\varepsilon_t + \phi_1\varepsilon_{t-1})\right] = \phi_1^2\gamma_0$$
$$= \frac{\phi_1^2\sigma^2}{1-\phi_1^2}$$

In a similar fashion it is easy to see that the k lag covariance of Y_t is,

$$\gamma_k = \phi_1^k\gamma_0$$
$$= \frac{\phi_1^k\sigma^2}{1-\phi_1^2}$$

and the autocorrelation function for the AR(1) process is thus,

$$\tau_k = \frac{\gamma_k}{\gamma_0} = \phi_1^k$$

and hence declines geometrically from unity : in a monotonic fashion if $\phi > 0$ and in a oscillatory manner if $\phi < 0$. Moreover, this implies that an AR(1) process possesses an infinite memory suggesting that the current value of Y_t depends on all past values, although the weight given to past observations declines geometrically. This can be demonstrated directly by substitution of past values into (VIII.8), giving,

$$Y_t = \phi_1 Y_{t-1} + \varepsilon_t$$
$$= \phi_1(\phi_1 Y_{t-2} + \varepsilon_{t-1}) + \varepsilon_t$$
$$= \phi_1^2 Y_{t-2} + \phi_1\varepsilon_{t-1} + \varepsilon_t$$

Repeated substitution for Y_t in this manner yields,

$$Y_t = \varepsilon_t + \phi_1\varepsilon_{t-1} + \ldots + \phi_1^k\varepsilon_{t-k} + \phi^{k+1}Y_{t-k-1} \qquad \text{(VIII.9)}$$

If this substitution is continued, then in the limit, the last term in (VIII.9) becomes

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[4] Note however that any autoregressive process is invertible.

[5] Assuming $\delta = 0$, implies the process has a zero mean and simplifies the following derivation although does not affect the outcome of the results

negligible leaving,

$$Y_t = \sum_{k=0}^{\infty} \phi_1^k \varepsilon_{t-k}$$

which is an MA(∞) process. Following this reasoning any stationary AR(1) process has an infinite order moving average representation. More generally it can be shown that for any stationary AR(p) process there exists an equivalent MA process of infinite order. The converse is also true, in that any invertible MA(q) process has an equivalent AR(∞) representation.[6]

Returning to the AR(1) process we may use equation (VIII.4) to determine the partial autocorrelation function for this process which yields,

$$\begin{aligned} \hat{\phi}_{kk} &= \hat{\tau}_1 \qquad k = 1 \\ &= 0 \qquad k > 1 \end{aligned}$$

implying that the PACF cuts-off after lag one.

(ii) Autoregressive Process of Order 2 : AR(2)

Here the process generating the data is given by,

$$Y_t = \delta + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \varepsilon_t$$

and has a mean,

$$\mu = \frac{\delta}{1 - \phi_1 - \phi_2}$$

Assuming that $d = 0$ to simplify the derivation, the variance of this process is given by,

$$\begin{aligned} \gamma_0 &= \mathrm{E}\left[Y_t(\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \varepsilon_t)\right] \\ &= \phi_1 \gamma_1 + \phi_2 \gamma_2 + \sigma^2 \end{aligned}$$

and covariances,

$$\begin{aligned} \gamma_1 &= \mathrm{E}\left[Y_{t-1}(\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \varepsilon_t)\right] \\ &= \phi_1 \gamma_0 + \phi_2 \gamma_1 \\ \gamma_2 &= \mathrm{E}\left[Y_{t-2}(\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \varepsilon_t)\right] \\ &= \phi_1 \gamma_1 + \phi_2 \gamma_0 \end{aligned}$$

and in general, for $k > 2$,

$$\begin{aligned} \gamma_k &= \mathrm{E}\left[Y_{t-k}(\phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \varepsilon_t)\right] \\ &= \phi_1 \gamma_{k-1} + \phi_{k-2} \gamma_0 \end{aligned}$$

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6 For further details and derivations of these statements see Box and Jenkins, (1970).

Solving these equations simultaneously yields an expression for γ_0 purely in terms of ϕ_1, ϕ_2 and σ^2, from which γ_1 and then all other covariances may then be determined. Dividing γ_k by γ_0 reveals the k autocorrelations of the AR(2) process. However, we may circumvent these derivations by noting that the autocorrelation function can be determined directly from the Yule Walker equation,

$$\tau_k = \phi_1 \tau_{k-1} + \phi_2 \tau_{k-2}$$

Putting $k = 1$ into this equation yields

$$\tau_1 = \phi_1 \tau_0 + \phi_2 \tau_{-1}$$

Noting from above that $\tau_0 = 1$, $\tau_1 = \phi_1$ and the symmetry of the autocorrelation coefficients such that $\tau_1 = \tau_{-1}$ then,

$$\tau_1 = \frac{\phi_1}{1-\phi_2}$$

For $k = 2$,

$$\tau_2 = \frac{\phi_1^2}{1-\phi_2} + \phi_2$$

and in general the theoretical autocorrelation function takes the form,

$$\begin{aligned} \tau_k &= \frac{\phi_1}{1-\phi_2} && k = 1 \\ &= \phi_1 \tau_{k-1} + \phi_2 \tau_{k-2} && k > 1 \end{aligned}$$

Using equation (VIII.4) we may derive the partial autocorrelation function for the AR(2) process, which assumes the form,

$$\begin{aligned} \phi_{11} &= \tau_1 = \frac{\phi_1}{1-\phi_2} \\ \phi_{22} &= \frac{\tau_2 - \tau_1^2}{1-\tau_1} \\ \phi_{kk} &= 0 \qquad k > 2 \end{aligned}$$

which implies that there is a cut-off at lag 2 in the partial autocorrelation function of the AR(2) process. Furthermore, this result holds for the general AR(p) case in that the PACF cuts off at the p^{th} lag and that the PACF can be a useful tool in determining the correct order of an autoregressive process.

Stationarity in the AR(2) model, which must be achieved in order to obtain the results outlined above may be summarised as,

$$\phi_1 + \phi_2 < 1$$
$$\phi_2 - \phi_1 < 1$$
$$-1 < \phi_2 < 1$$

which are identical to the invertibility conditions imposed on the parameters of the MA(2) process.

(c) Mixed Processes :ARMA(*p*,*q*)

In practice many of the series encountered in economics do not have either a pure moving average nor pure autoregressive representation since they have both AR and MA characteristics. In such circumstances it will be necessary to develop a mixed or hybrid model, which captures these different characteristics; the ARMA process. In cases where a large number of parameters are needed to estimate a pure MA or AR model, a hybrid model of low order MA and AR processes frequently leads to a more parsimonious representation. Parsimony is an advantage where data is scarce, since fewer parameters have to be estimated from a given sample size, implying that those estimates will be more efficient, (have lower variance).

Generally the mixed ARMA(*p*,*q*) processes assumes the form,

$$Y_t = \delta + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_q \varepsilon_{t-q} \qquad \text{(VIII.10)}$$

Using the backward shift operator notation introduced earlier, the ARMA (*p*,*q*) may be more succinctly written as,[7]

$$\phi(B)Y_t = \theta(B)\varepsilon_t$$
$$Y_t = \frac{\theta(B)}{\phi(B)}\varepsilon_t$$

so that the process Y_t is the product of a ratio of the two polynomials and the white noise that drives the process.[8] In practice, low order ARMA processes characterise empirical time series sufficiently well to limit consideration to the processes where $p,q \leq 2$. To begin, a few salient points will be made about the ARMA(*p*,*q*) process followed by a look at the ARMA(1,1) model.

In order for the ARMA(*p*,*q*) process to exhibit time invariant first and second moments and yield a unique ACF and PACF it must be stationary and invertible; or rather the AR part of the process must be stationary and the MA part of the process must be

7 The constant term present in (VIII.10) is omitted here to ease exposition.

8 Alternatively, the process may be expressed as, $\varepsilon_t = \phi(B)\theta(B)^{-1}Y_t$.

invertible. In order for

$$Y_t = \phi(\mathrm{B})^{-1}\theta(\mathrm{B})\varepsilon_t$$

to be stationary $\phi(\mathrm{B})^{-1}$ must converge requiring the roots of the characteristic equation,

$$\begin{aligned}\phi(\mathrm{B}) &= 0 \\ &= 1 - \phi_1 \mathrm{B} - \phi_2 \mathrm{B}^2 - \ldots - \phi_p \mathrm{B}^p = 0\end{aligned}$$

must all lie *outside* the unit circle, *i.e.* the solutions $\mathrm{B}_1, \mathrm{B}_2, \ldots \mathrm{B}_p$ must all be greater than one. In an analogous fashion, the MA part of the process must be invertible so that the process can be inverted into a purely autoregressive representation,

$$\varepsilon_t = Y_t \phi(\mathrm{B})\theta(\mathrm{B})^{-1}$$

This requires that the roots to the characteristic equation

$$\begin{aligned}\theta(\mathrm{B}) &= 0 \\ &= 1 - \theta_1 \mathrm{B} - \theta_2 \mathrm{B}^2 - \ldots - \theta_q \mathrm{B}^q = 0\end{aligned}$$

must all lie outside the unit circle, so that the solutions $\mathrm{B}_1, \mathrm{B}_2, \ldots \mathrm{B}_q$ must all be greater than one.

Returning to (VIII.10) and taking expectations yields the mean of the ARMA process given by,

$$\mu = \frac{\delta}{1 - \phi_1 - \phi_2 \ldots - \phi_p}$$

Now, the variances, covariances and autocorrelation functions of ARMA(p,q) processes are solutions to difference equations that cannot be readily solved by inspection (see Box and Jenkins) although it is useful to note that,

$$\gamma_k = \phi_1 \gamma_{k-1} + \phi_2 \gamma_{k-2} + \ldots + \phi_p \gamma_{k-p} \qquad k > q$$

which implies that,

$$\tau_k = \phi_1 \tau_{k-1} + \phi_2 \tau_{k-2} + \ldots + \phi_p \tau_{k-p} \qquad k > q$$

Recalling that q is the memory of the MA part of the process it is therefore true that for any ARMA(p,q) its ACF (and autocovariances) will eventually (*i.e.*for lags $k > q - p$) follow the same pattern as that of a pure AR(p) process, being described by combinations of damped exponentials and/or damped sine waves. This however is not the case for the first q lags which are determined by the magnitudes of both the AR and MA parameters.

In an analogous fashion it can be shown that the PACF of any ARMA(p,q) process eventually, (*i.e.*for lags $k > p - q$) behaves like that of a pure MA(q) process. However, for $k \leq p - q$ the PACF does not follow this pattern, it being a combination of both the MA and AR parameters. The conditions for stationarity and invertibility in mixed processes are those that apply to the appropriate order of pure AR and MA processes.

(i) The ARMA (1,1) Process

This process is described by,

$$Y_t - \phi_1 Y_{t-1} = \varepsilon_t - \theta_1 \varepsilon_{t-1}$$

or alternatively,

$$(1 - \phi_1 \mathrm{B})Y_t = (1 - \theta_1 \mathrm{B})\varepsilon_t$$

and the process will be invertible (AR terms do not affect invertibility) and stationary (MA term do not affect stationarity) when

$$-1 < \phi_1 < 1$$
$$-1 < \theta_1 < 1$$

so that the roots of $\phi(\mathrm{B})$ and $\theta(\mathrm{B})$ lie outside the unit circle.

For this simple ARMA process we may calculate its mean, variance and autocovariance relatively easily. The mean is given by,

$$\mu = \frac{\delta}{1 - \phi_1}$$

Setting $\delta = 0$ for convenience (although the same results are achieved using deviations from a non-zero mean), the variance is given as,

$$\gamma_0 = \mathrm{E}\left[(\phi_1 Y_{t-1} + \varepsilon_t - \theta_1 \varepsilon_{t-1})\right]$$
$$= \phi_1^2 \gamma_0 - 2\phi_1 \theta_1 \mathrm{E}\left[Y_{t-1} \varepsilon_{t-1}\right] + \sigma^2 + \theta_1^2 \sigma^2$$

and since $\mathrm{E}(Y_{t-1}\varepsilon_{t-1}) = \sigma^2$, this gives,

$$\gamma_0 (1 - \phi_1^2) = \sigma^2 (1 + \theta_1^2 - 2\phi_1 \theta_1)$$
$$\gamma_0 = \frac{1 + \theta_1^2 - 2\phi_1 \theta_1}{1 - \phi_1^2} \sigma^2$$

The autocovariance at lag one is thus,

$$\gamma_1 = E\left[Y_{t-1}(\phi_1 Y_{t-1} + \varepsilon_t - \theta_1 \varepsilon_{t-1})\right]$$
$$= \phi_1 \gamma_0 - \theta_1 \sigma^2$$

and on substitution for γ_0 yields,

$$= \frac{(1-\phi_1\theta_1)(\phi_1-\theta_1)}{1-\phi_1^2}\sigma^2$$

Similarly the autocovariance at lag two is,

$$\gamma_2 = E\left[Y_{t-2}(\phi_1 Y_{t-1} + \varepsilon_t - \theta_1 \varepsilon_{t-1})\right]$$
$$= \phi_1 \gamma_1$$

and for all other autocovariances,

$$\gamma_k = \phi_1 \gamma_{k-1} \qquad k > 1$$

The autocorrelation function can now be derived as,

$$\tau_1 = \frac{\gamma_1}{\gamma_0} = \frac{(1-\phi_1\theta_1)(\phi_1-\theta_1)}{1+\theta_1^2 - 2\phi_1\theta_1}$$

and for displacement k greater than one,

$$\tau_k = \phi_1 \tau_{k-1} \qquad k > 1$$

Focussing on the autocorrelation results for a moment the above results demonstrate that the autocorrelation function begins at its starting value τ_1 which is a function of both the AR and MA parameters and then decays geometrically in contrast to the AR(1) process which decays geometrically from τ_0. This reflects the fact that the moving average part of the ARMA(1,1) process only has a memory of one so that after the first lag the process has an autocorrelation function exactly the same as a pure AR(1) process.

Having mentioned above that the PACF of an ARMA(p,q) is determined by the MA part of the process at displacements $k > p - q$ it is clear that in the ARMA(1,1) case the PACF behaves in exactly the same way as an MA(1) given that $\phi_{11} = \tau_1$ so that the PACF is dominated by a damped exponential whose form is determined by the sign of q_1.

(d) Modelling Non-Stationary Time Series

The previous treatment of the linear stochastic models discussed so far has been restricted to stationary processes. As discussed in Chapters VI and VII such processes are rare in economics but may be converted to stationarity by application of the appropriate transformation. In the series used here it was found that all series are integrated processes of order one, I(1) and therefore require differencing to achieve a stationary mean. In addition the original series require a logarithmic transformation to stabilize their respective variances for reasons explained in Chapter VI. In general, the order of integration is included in the description of time series model, entailing the general notation of a process : ARIMA (p,d,q), where d indicates the number of times the series must be differenced to achieve stationarity. The series used here are consequently ARIMA $(p,1,q)$ processes. For convenience the following development will be in terms of w_t where $w_t = \Delta^d Y_t$ and d is the number of times the original series Y_t must be differenced to obtain stationarity.

VII.(iv) The Identification Process

Since Box and Jenkins' pioneering work on ARIMA modelling a number of attempts have been made to automate and/or simplify the task of identifying the most appropriate specification of an empirical time series. Indeed, using the 'Box-Jenkins approach' to time series modelling requires a good deal of discretion and experience on behalf of the analyst to interpret the ACF and PACF of a particular series especially in cases where the series is not one of pure MA or AR. Even in circumstances where the data has been generated artificially according to a known specification, identifying that specification from the ACF and PACF alone requires considerable expertise and frequently few clear signals emerge from the identification process, (see Appendix I). In light of this a substantial amount of research has been undertaken to develop criteria to aid the analyst in the identification of the most appropriate model for a time series. Shibata (1985) has provided a survey of model selection criteria and two of the most popular statistics are briefly reviewed here : the Akaike (1974) information criterion (AIC) and the BIC developed independently by Rissanen (1978) and Schwarz (1978).

Akaike's AIC, was one of the earliest selection criteria developed and is defined as,

$$\mathrm{AIC}(p,q) = \ln\hat{\sigma}^2 + 2(p+q)T^{-1}$$

where $\hat{\sigma}^2$ is the estimate of the error variance of the ARMA (p,q) fitted to a stationary time series of length T. The BIC is defined as,

$$\mathrm{BIC}(p,q) = \ln\hat{\sigma}^2 + (p+q)T^{-1}\ln T$$

Notice that both criteria incorporate the estimated error variance plus an extra term to penalise for the number of parameters relative to the size of sample and it is in this penalty that most model selection criteria differ. The aim is to find the ARMA (p,q) model that minimises the value of the criterion so that a model with an AIC of -7.45 would be preferred to a rival model with an AIC of -7.29.

Clearly, the model with the lowest AIC or BIC cannot automatically be regarded as the 'true' model for the true model may not have been included in the set of models under examination. Consequently, it is 'good practice' to estimate a number of models and compare the diagnostic test statistics from each. In circumstances where two (or more) selection criteria favour different model specifications Hannan (1980) has shown that if the true orders (p_*,q_*) are contained within the set P,Q where $P = \{1,2, \ldots p\}$ and $Q = \{1,2, \ldots, q\}$ then the orders of p and q chosen by each criterion (p_x,q_x) will never be smaller than the true orders (p_*,q_*), *i.e.* $p_x \geq p_*$ and $q_x \geq q_*$ as T tends to infinity. However, because BIC is *strongly consistent* in that it determines the true model asymptotically, it will give the true orders of p and q in large samples whereas the AIC does not have this property. Both statistics are reported in the empirical work because Hannan's results can be used to help infer the true orders of an ARMA model. For example, if AIC and BIC select the same model then this suggests the model should be preferred, although it still may be over-parameterised. If the AIC selects a (say) ARMA(3,1) and the BIC selects an ARMA (2,1) the results taken together are suggestive of an ARMA (2,1) model generating the data. In practice however one would seldom base any decision on any single criterion but rather assess the evidence from a wide range of sources such as ACF and PACF, information criteria and ancillary diagnostic checks. Furthermore, given that the sample sizes used in the empirical analysis are relatively small the principle of parsimony will also weigh quite heavily in the final choice of model.

VIII.(v) Estimation of an ARIMA (p,d,q) Model

Having identified a plausible specification of the model (*i.e.* determined appropriate values of p,d and q) the next task is to estimate the numerical values of the autoregressive and moving average parameters of the unknown data generation process $(\hat{\phi}_1, \hat{\phi}_2, \ldots, \hat{\phi}_p, \hat{\theta}_1, \hat{\theta}_2, \ldots, \hat{\theta}_q)$ using the sample data. Recalling that w_t is the stationary series of interest, we start with the model,

$$\hat{\phi}(B)w_t = \hat{\theta}(B)\hat{\varepsilon}_t \qquad \text{(VIII.11)}$$

Rearranging (VIII.11) in terms of its driving process, the random innovations yields,[9]

$$\hat{\varepsilon}_t = \hat{\theta}^{-1}(B)\hat{\phi}(B)w_t \tag{VIII.12}$$

Box and Jenkins propose a maximum likelihood estimation routine that yields a vector of AR parameters $\hat{\phi}$ and a vector of MA parameters $\hat{\theta}$ that minimise the sum of the squared errors,

$$S\left(\hat{\phi}, \hat{\theta}\right) = \sum \hat{\varepsilon}_t^2 \qquad \text{where } \hat{\varepsilon}_t = \hat{\theta}^{-1}(B)\hat{\phi}(B)w_t \tag{VIII.13}$$

which is equivalent to choosing parameter values that minimise the sum of the squared differences between the actual time series and the fitted values, *i.e.*$(w_t - \hat{w}_t)^2$

The theoretical development of the estimation routine need not concern us although it should be apparent that where MA parameters are present in (VIII.11) a non-linear procedure is required since (VIII.13) is clearly non-linear in the parameters. The estimation procedure begins by linearising (VIII.12) around an initial guess of the parameters of $\hat{\phi}$ and $\hat{\theta}$ and a linear regression is performed and least squares estimates obtained. These estimates are then substituted back into (VIII.12) and a new linearisation is made around them. Another linear regression is then performed and a second set of $\hat{\phi}$ and $\hat{\theta}$ are obtained. The process is repeated in an iterative fashion until the estimates stabilise or *converge* on specific values in repeated iterations. When convergence has been attained standard errors of the estimates are calculated from the final linearisation, from which *t*-statistics and an R^2 can be derived.[10]

Whilst it is not necessary to understand the mechanics of the estimation in detail an appreciation of its iterative nature is important because there is no guarantee that the estimates will converge.[11] Furthermore, multiple solutions may exist in the 'parameter space' so that convergence may only imply the discovery of a local and not 'global' optimum. In either case a new set of initial values must be given to ensure convergence and if multiple solutions are found to exist the set of parameters chosen should be those corresponding to the solution that gives the smallest value of the sum of squared

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9 Clearly, in order to conduct this rearrangement, $\theta(B)$ must be invertible.

10 It should be noted that *t*-statistics and R^2 only have a limited meaning for they apply to the last linearisation of the non-linear model, not to the non-linear model itself. Consequently, despite obtaining a low R^2 for the last linearisation the actual non-linear model may well possess impressive predictive power.

11 Divergence of the parameter estimates after successive iterations is most likely where there are a large number of AR and MA parameters to estimate with a relatively small data set.

residuals. This discussion emphasises the need to provide starting values that are close to the true parameter values - or rather those implied by a global optimum. If the process is autoregressive then the Yule-Walker equations can provide a useful estimate (the so-called Yule-Walker estimates) of the p autoregressive parameters. Recall from Section (iii) above that the theoretical ACF for the AR(1) process at lag k is,

$$\tau_k = \frac{\gamma_k}{\gamma_0} = \phi_1^k$$

implying that the AR(1) model has an autoregressive coefficient equal to the autocorrelation coefficient at lag one. Although the theoretical ACF is unknown in practice, we may use $\hat{\tau}_1$ from the sample ACF as a reasonable first estimate of $\hat{\phi}_1$. For the AR(2) process the Yule-Walker equations may be solved for ϕ_1 and ϕ_2 implying the theoretical relationship,

$$\phi_1 = \frac{\tau_1(1-\tau_1)}{1-\tau_1^2} \qquad \phi_2 = \frac{\tau_2 - \tau_1^2}{1-\tau_1^2}$$

Again, substituting the sample estimates of the autocorrelation coefficients into the above yields Yule-Walker estimates of the AR(2) process which can be used as an initial guess in the estimation procedure.[12]

If the time series contains a MA component then the Yule-Walker equations are non-linear for the parameters of interest although for the simple MA(1) process an easily derived estimate may be inferred. For example the ACF of an MA(1) process is,

$$\tau_1 = \frac{-\theta_1}{1+\theta_1^2} \tag{VIII.14}$$

and zero for all other displacements. Substituting for $\hat{\tau}_1$ and setting (VIII.14) equal to zero we may solve the resulting quadratic. Assuming $\hat{\tau}_1 = 0.4$ the two roots of the quadratic are -2 and -0.5. Since $|\theta_1| < 1$ for the process to be invertible then the later value represents the initial value used in the estimation routine. Unfortunately the Yule - Walker estimates for θ in terms of the theoretical autocorrelation coefficients becomes increasingly difficult for the MA(q) process requiring the solution of q simultaneous non-linear equations.

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12 Note that for higher order AR processes the Yule-Walker estimates become increasingly crude. This reflects the use of the sample as opposed to the theoretical ACF and also becasuse the sample ACF contains much less information than the actual time series. Note that if the process is one of pure autoregression, then a simple linear regression will provide OLS estimates that may be used as starting values. This however is not possible where MA terms are required.

For more complicated ARMA(p,q) processes it becomes necessary to rely on trial and error in practice, comparing the residual sum of squares of each set of initial guesses obtained after convergence. Should convergence not be attained the most likely reason to account for this is an incorrectly identified structure in which case a new structure should be identified and the whole process repeated.

VIII.(vi) Diagnostic Checking

Having conducted the identification and estimation phases of the modelling process it is common to obtain a number of rival specifications that appear to fit the data reasonably well. Choosing between competing models is the next and arguably most important stage in the modelling process and a number of tests and checks have been proposed in the literature to facilitate informed choice. Given that the object of ARMA model building is to transform a presumably autocorrelated observed series into a structureless white noise process, checks of model adequacy revolve around testing whether the residuals of the model,

$$\hat{\varepsilon}_t = \hat{\theta}^{-1}(\mathrm{B})\hat{\phi}(\mathrm{B})w_t$$

mimic the properties of the true data generation process,

$$\varepsilon_t = \theta(\mathrm{B})^{-1}\phi(\mathrm{B})w_t$$

Consequently, the *residuals* of each rival specification should be checked to ascertain whether:

(i) the mean is (approximately) zero

(ii) the variance is (approximately) constant and

(iii) individual errors are uncorrelated.

Feature (i) may be tested by comparing the estimated mean of the residuals ($\bar{\hat{\varepsilon}}$)with its standard error and (ii) may be checked casually by visual inspection of a plot of squared residuals. In practice, most attention focusses on testing for autocorrelation in the residuals of the fitted model.[13] Box and Jenkins recommend as a first check for randomness visual inspection of the ACF from the residuals. Each autocorrelation coefficient of the residuals given by,

13 Another commonly used diagnostic check is that of *overfitting*, where a less parsimonious model is tested under points (i), (ii) amd (iii) and the results compared with its parsimonious rival. Where a number of rival specifications have been selected the overfitting method may well be performed latently in the checking of these rivals.

$$\hat{\tau}_k = \frac{\sum_{t=k+1}^{T} (\hat{\varepsilon}_t - \bar{\hat{\varepsilon}})(\hat{\varepsilon}_{t-k} - \bar{\hat{\varepsilon}})}{\sum_{t=1}^{T} (\hat{\varepsilon}_t - \bar{\hat{\varepsilon}})^2}$$

can then be compared to its standard error under the null of independence ($T^{-1/2}$) as described earlier. However, because the true standard errors are often much smaller for low values of k (see Mills 1990, pp.145) attention focuses on the construction of various *portmanteau* tests which seek to test whether the first m residual autocorrelations are *jointly* insignificantly different from zero. One such test developed by Ljung and Box (1978) is defined as,

$$Q = T(T+2) \sum_{k=1}^{m} (T-k)^{-1} \hat{\tau}_k^2$$

where m begins at one and increases up to the usual limit of $T^{1/2}$. Again the hypothesis tested here is that the first m autocorrelation coefficients are all insignificantly different from zero, so that if the calculated Q statistic exceeds the tabulated value of χ^2 on $(m\text{-}p\text{-}q)$ degrees of freedom, the adequacy of the ARMA (p,q) model that generated the residuals must be cast in doubt. Whilst Monte Carlo experiments have shown that the Q statistic performs better than other portmanteau tests, the power of this test may still be quite low - high values only being found in the presence of severe misspecification. The low power of all portmanteau tests emanates from the absence of explicit formulation of an alternative hypothesis. Whilst this approach may be appropriate given that many different alternative specifications exist, it results in a tendency to accept the null of the portmanteau tests more often than one should. Indeed, a large q statistic indicative of model inadequacy may only occur with a very poor model. As a consequence, it should be echoed that all tests should be interpreted in conjunction with one another, so that it is the *weight* of evidence that leads to adoption or rejection of any particular model rather than any one piece of evidence.[14]

VIII.(vii) Forecasting

Having identified and estimated an ARIMA model and following checks for adequacy of the chosen specification, it is then possible to embark on the object of the entire

[14] Recently, LM tests have been developed (see *inter alia* Mills 1990 for a discussion) in the literature which have much higher power than the portmanteau tests since they are conducted with reference to an explicit alternative hypothesis. Nevertheless, they are labour intensive to compute since a large number of alternative specifications require testing and are not considered any further.

exercise, that being the forecasting of future values of the series. The task of computing forecasts for a given model is essentially quite mechanistic although a number of points need to be bourne in mind before the forecasts are actually computed.

The aim of the preliminary stages of forecasting, namely, identification, estimation and testing is to produce a model that that will be able to predict future values of the series with as little error as possible. Supposing that the observed series $(Y_1, Y_2, \ldots, Y_T)$ is a realisation from the general ARIMA(p,d,q) process,

$$\phi(\mathrm{B})w_t = \theta(\mathrm{B})\varepsilon_t$$

where $w_t = \Delta^d Y_t$, then the forecast of a future value of Y_t l periods into the future denoted $\hat{Y}_{T+l}$ is given by[15]

$$\hat{Y}_{T+l} = \phi(\mathrm{B})^{-1}(1-\mathrm{B})^{-d}\theta(\mathrm{B})\varepsilon_t = \psi(\mathrm{B})\varepsilon_t = \sum_{j=o}^{\infty} \psi_j \varepsilon_{t-j} \qquad \text{(VIII.15)}$$

which is expressed entirely in terms of the random innovations. Noting that (VIII.15) may be written as,

$$\hat{Y}_{T+l} = \psi_0\,\varepsilon_{T+l} + \psi_1\,\varepsilon_{T+l-1} + \ldots + \psi_{l-1}\,\varepsilon_{T+1} + \sum_{j=0}^{\infty} \psi_{l+j}\,\varepsilon_{T-j} \qquad \text{(VIII.16)}$$

which divides the infinite sum of (VIII.15) into two parts, the second part describing all past and present information, and the first set of terms describing future events. As all future innovations are unknown at period T their expected values are substituted in (VIII.16), in which case the forecast boils down to,

$$\hat{Y}_{T+l} = \sum_{j=0}^{\infty} \psi_{l+j}\,\hat{\varepsilon}_{T-j} = \mathrm{E}(Y_{T+l} \,|\, Y_T, \ldots, Y_1)$$

since the conditional expectation of ε_{T+i} given the previous history of ε_t is 0 for i = 1,2, . . .l and the expected values of (ε_T, ε_{T-1}, . . .) are just the observed errors, *i.e.* the residuals from the estimated model. Consequently, the l step ahead forecast is simply the conditional expectation of Y_{T+l} given all past and current observations on Y_t. Moreover, this can be shown to give the optimal forecast, *i.e.* that which produces the minimum forecast error.

The l-step ahead forecast error from the origin T is hence,

$$\varepsilon_{T+l} = (Y_{T+l} - \hat{Y}_{T+l}) = \varepsilon_{T+l} + \psi_1\,\varepsilon_{T+l-1} + \ldots + \psi_{l-1}\,\varepsilon_{t+1} \qquad \text{(VIII.17)}$$

and implies that the forecast $\hat{Y}_{T+l}$ is unbiased since the conditional expectation of (VIII.17) is clearly zero. The forecast error is thus a linear combination of the unknown

[15] T is called the origin of the forecast and l as the lead time.

future innovations. The variance of the forecast error is then,

$$E\left[\varepsilon_{T+l}^2\right] = \sigma^2(1 + \psi_1^2 + \psi_2^2 + \ldots + \psi_{l-1}^2)$$

Using these results it is possible to demonstrate the general procedure for computing a forecast, however the following points should be borne in mind. First the forecast error variance depends on $\psi(B)$ implying that different specifications of the ARIMA model yield different forecast error variances. Second, from (VIII.17) the one-step ahead forecast error will be ε_{T+1} with variance σ^2 and that this will be the case for *any* ARIMA specification. Thus the forecast error variance one period ahead is always the variance of the error term. Third, these results are based on the assumption that the parameters and structure of the underlying data generation process ($\phi_1, \ldots \phi_p$ and $\theta_1, \ldots, \theta_q$) are known with certainty. Clearly this will never be the case in practice so that the actual forecast error variance will be much larger than the quantities calculated using (VIII.17). To determine how much larger, we must use the residuals of the last linearization of the chosen ARIMA specification as an estimate of the true variance σ^2. Even so this estimate must be used cautiously bearing in mind that it is calculated from the final linearisation of what may be a non-linear relationship. As such the estimated variance and standard errors are not 'true' estimates of the actual quantities and for this reason may be ignored in the calculation of the forecast error variance : empirical researches preferring to use the formulation in (VIII.17) despite the fact it is an underestimate of the true value.

(a) Computing Forecasts

The procedure of actually computing a forecast is performed recursively, beginning with the one-step ahead forecast which is substituted into the equation for the two-step ahead forecast and so on until the l step ahead forecast is reached. To begin we write the ARIMA (p,d,q) model including a constant for completeness as,

$$w_t = \phi_1 w_T + \ldots + \phi_p w_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \ldots - \theta_q \varepsilon_{t-q} + \delta$$

where $w_t = \Delta^d Y_t$. To compute the forecast $\hat{Y}_{T+1}$ the process begins by calculating the forecast for w_t, $\hat{w}_{T+1}$ where w_{T+l} is given as,

$$w_{T+1} = \phi_1 w_T + \ldots + \phi_p w_{T-p+1} + \varepsilon_{T+1} - \theta_1 \varepsilon_T - \ldots - \theta_q \varepsilon_{T-q+1} + \delta \qquad \text{(VIII.18)}$$

Taking the conditional expectation of (VIII.18) yields the one-step forecast,

$$\begin{aligned}\hat{w}_{T+1} &= E(w_{T+1} \mid w_T, \ldots) \\ &= \phi_1 w_T + \ldots + \phi_p w_{T-p+1} - \theta_1 \hat{\varepsilon}_T - \ldots - \theta_q \hat{\varepsilon}_{T-q+1} + \delta\end{aligned}$$

where $(\hat{\varepsilon}_T, \hat{\varepsilon}_{T-1} \ldots)$ are the observed residuals and the expected value of $\varepsilon_{T+1} = 0$. This forecast is then used to form the forecast at time T of the series two periods ahead,

$$\hat{w}_{T+2} = E(w_{T+2} \mid w_T, \ldots)$$
$$= \phi_1 \hat{w}_{T+1} + \phi_2 w_T \ldots + \phi_p w_{T-p+2} - \theta_2 \hat{\varepsilon}_T - \ldots - \theta_q \hat{\varepsilon}_{T-q+2} + \delta$$

This recursive procedure is continued until the l^{th} forecast has been made. Thus at each stage, past expectations are replaced with known values of w_t and ε_t and future expectations are replaced with forecast values $\hat{w}_t$ and zero.

Once the stationary series w_t has been forecasted the forecast for the original series Y_t simply involves summing w_t d times so that if w_t is the first difference of Y_t then the l-period forecast of Y_{T+l} is,

$$\hat{Y}_{T+l} = Y_T + \hat{w}_{T+1} + \hat{w}_{T+2} + \ldots + \hat{w}_{T+l}$$

As noted in the introduction, the margin of error of a forecast is as important as the forecast itself and thus it is necessary to calculate confidence intervals within which the true value of the series l periods in the future is believed to lie. Due to the fact that in practice we do not know the parameter values of the true data generating process confidence intervals produced under the assumption that we have estimated the true model will be over-optimistic.[16] Nevertheless, assuming we have identified the true model then the confidence interval of Z standard deviations around a forecast l periods ahead is given by,

$$C_Z = \hat{Y}_{T+l} \pm Z\left(1 + \sum_{j=1}^{l-1} \psi_j^2\right)^{1/2} \hat{\sigma}^2 \quad \text{(VIII.19)}$$

where $\hat{\sigma}^2$ is the variance from the chosen ARIMA model. Equation (VIII.19) indicates that the interval gets larger as the lead time l gets larger and that the exact pattern depends on the parameters in the ARIMA model chosen.

VIII.(viii) The Empirical Analysis - Identification and Estimation

In this section the results from the identification and estimation of the ARIMA models of the three rent series and three land price series will be presented. The forecasts themselves will be presented in the following section. All series are in real terms (1990 prices) and are expressed in logs to stabilise their variances.

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[16] Pindyck and Rubinfeld (1981) suggest a rule of thumb that this is likely to be important where the t-statistics of parameters in the final linearization are less than 5. p.560.

(a). The Average Rent series (1944-90) $\ln R_t$

Recall from Chapter VI that the unit root tests conducted on the average rent series $\ln R_t$ suggested that the series was a non-stationary AR(2) and was a stationary AR(1) series in first differences, *i.e.*

$$lnR_t = (1+\phi)lnR_{t-1} - \phi lnR_{t-2} + \varepsilon_t$$

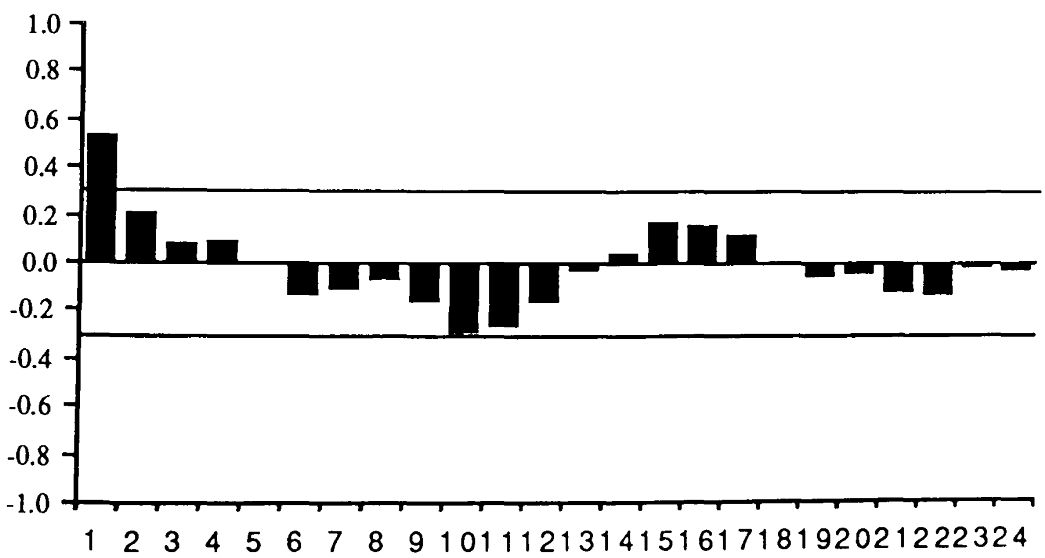
or

$$\Delta lnR_t = \phi\Delta lnR_{t-1} + \varepsilon_t$$

The ACF of $\ln R_t$, exhibits a slow linear decline indicative of the non-stationarity of this series (and hence autoregressive nature of the process - as moving average components are always stationary) and the PACF has two dominant spikes, pointing to a AR(2) process, as suggested by the unit root tests.

In order to identify any moving average components a first step is to produce the ACF and PACF of the first differenced series $\Delta\ln R_t$. These functions are shown in Figures VIII.3 and VIII.4 respectively and suggest that $\Delta\ln R_t$ is a stationary AR(1) process, due to the visible decay of the ACF and a single significant spike at lag one in the PACF, which appears to be randomly distributed thereafter.[17]

Figure VIII.3 : ACF of $\ln R_t$

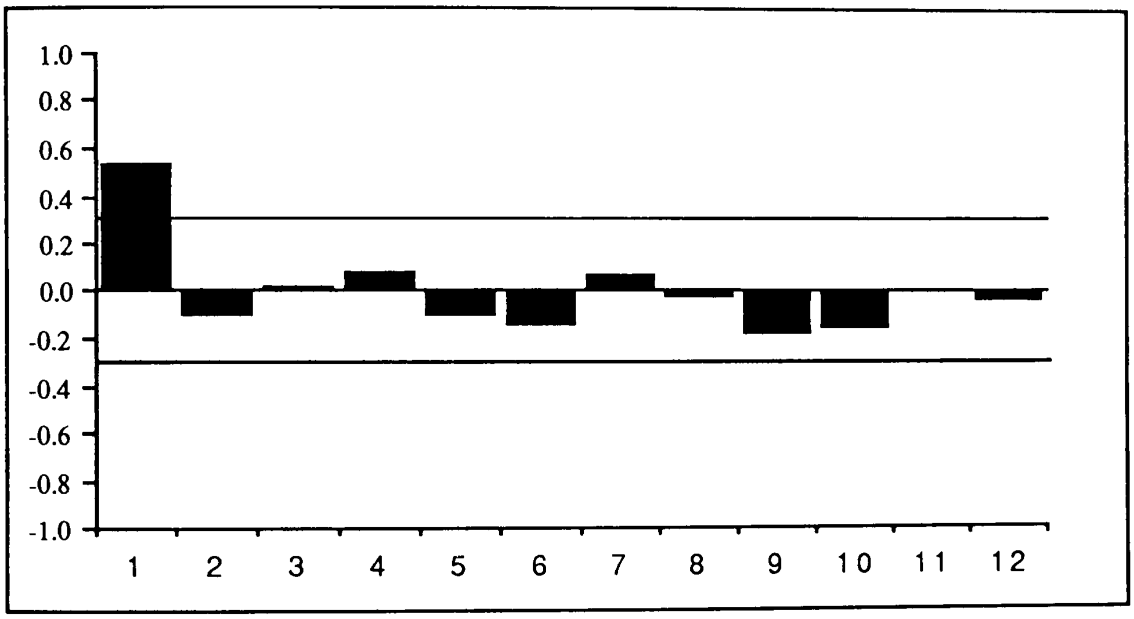


It would be prudent to compare the performance of the ARMA(1,0) model with some alternative specifications. The patterns of the ACF and PACF are also consistent with an ARMA(2,1) process if the PACF is actually declining to zero in a systematic fashion

[17] The horizontal lines represent approximate 95% confidence bands.

rather than distributed randomly. Further, the dominant spike at lag one in the ACF could imply an ARMA(0,1) model although the PACF does not appear to be declining geometrically as required for this process, although with only twelve partial autocorrelations this is difficult to discern. Nevertheless the ARMA(0,1) process will be estimated along with an ARMA(1,1) model for the purpose of comparison between the pure autoregressive and moving average models suggested above.

Figure VIII.4 : PACF of $\ln R_t$



These four rival specifications are estimated and the diagnostic test statistics (discussed earlier) are presented in Table VIII.1. The Q statistic tests the null hypothesis that the first 12 autocorrelation coefficients of the residuals from the estimated model are empirical white noise (adjusted for the degrees of freedom).

Table VIII.1 : Model Selection Criteria for the series $\Delta\ln R_t$

Model	Q(d.f.)	R^2	AIC	BIC
ARMA (1,0)	6.4 (11)	0.31	-6.9194	-6.8784
ARMA (2,1)	6.6 (9)	0.28	-6.7937	-6.6709
ARMA (0,1)	10.0 (11)	0.28	-6.8087	-6.7677
ARMA (1,1)	6.0 (10)	0.30	-6.8524	-6.7705

None of the Q statistics in Table VIII.1 permit rejection of the null at the 5% level although the other diagnostics indicate a preference for the ARMA(1,0) model.[18] Of the candidate models in Table VIII.1 the ARMA (0,1) compares least favourably and may be disregarded on two counts, namely its low R^2 and because the MA parameter in the ARMA(1,1) model is not statistically different from zero, suggesting that it is only the AR component that is driving the $\Delta \ln R_t$ series. The remaining models are estimated as,

$$\Delta lnR_t = \underset{(15.66)}{1.6334\Delta lnR_{t-1}} - \underset{(-6.83)}{0.66002\Delta lnR_{t-2}} + \underset{(23.05)}{0.95417\hat{\varepsilon}_{t-1}} + \varepsilon_t$$

$$\Delta lnR_t = \underset{(5.53)}{0.64252\Delta lnR_{t-1}} + \varepsilon_t$$

Notice that the MA parameter in the ARMA (2,1) model is close to unity. In fact it has a standard error of 0.04140 implying the 95% confidence interval of,

$$0.87137 \leq \theta \leq 1.03697$$

so that we may reasonably expect the coefficient to be an estimate of unity. If this is the case then it follows that the ARMA (2,1) specification is equivalent to an ARMA (1,0) since we may write,

$$\begin{aligned} Y_t &= (1+\phi)Y_{t-1} - \phi Y_{t-2} + \varepsilon_t - \varepsilon_{t-1} \\ Y_t - Y_{t-1} - \phi Y_{t-1} + \phi Y_{t-2} &= \varepsilon_t - \varepsilon_{t-1} \\ (1 - \mathrm{L} - \phi \mathrm{L} + \phi \mathrm{L}^2)Y_t &= (1-\mathrm{L})\varepsilon_t \\ (1-\mathrm{L})(1-\phi \mathrm{L})Y_t &= (1-\mathrm{L})\varepsilon_t \\ (1-\phi \mathrm{L})Y_t &= \varepsilon_t \\ Y_t &= \phi Y_{t-1} + \varepsilon_t \end{aligned}$$

This result indicates the adoption of an ARMA(1,0) model in preference to the ARMA(2,1) model for $\Delta \ln R_t$ on the grounds of parsimony which also accounts for the better AIC and BIC criteria since both diagnostics penalise over-parameterisation. Analysis of the residuals from this model indicate that they are empirical white noise with zero mean and constant variance, as would be expected if the ARMA process was a good approximation to the underlying process actually generating the series.[19] The rent series in levels is consequently best modelled as a stationary ARIMA (1,1,0) process confirming the conclusion of the unit root tests.

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[18] Note that the AIC and BIC with the largest negative number indicates the preferred model.

[19] Using two different starting values of 0.9 and 0.1 in the ARMA (1,0) did not alter the final estimate of the AR parameter estimated by using an starting value of (0.60411) suggested by an OLS autoregression.

(b). The Newly Negotiated Rent Series (1944-1990) lnRN_t

The unit root tests in Chapter VI suggested that this series exhibited similar behaviour to lnR_t in that it was a nonstationary AR(2) in levels and stationary AR(1) process in first differences. The ACF and PACF of the series in levels are almost identical to those for lnR_t although a slightly different picture emerges when the series is differenced. The ACF and PACF for ΔlnRN_t are shown in Figures VIII.5 and VIII.6 respectively.

Figure VIII.5 : ACF of ΔlnRN_t

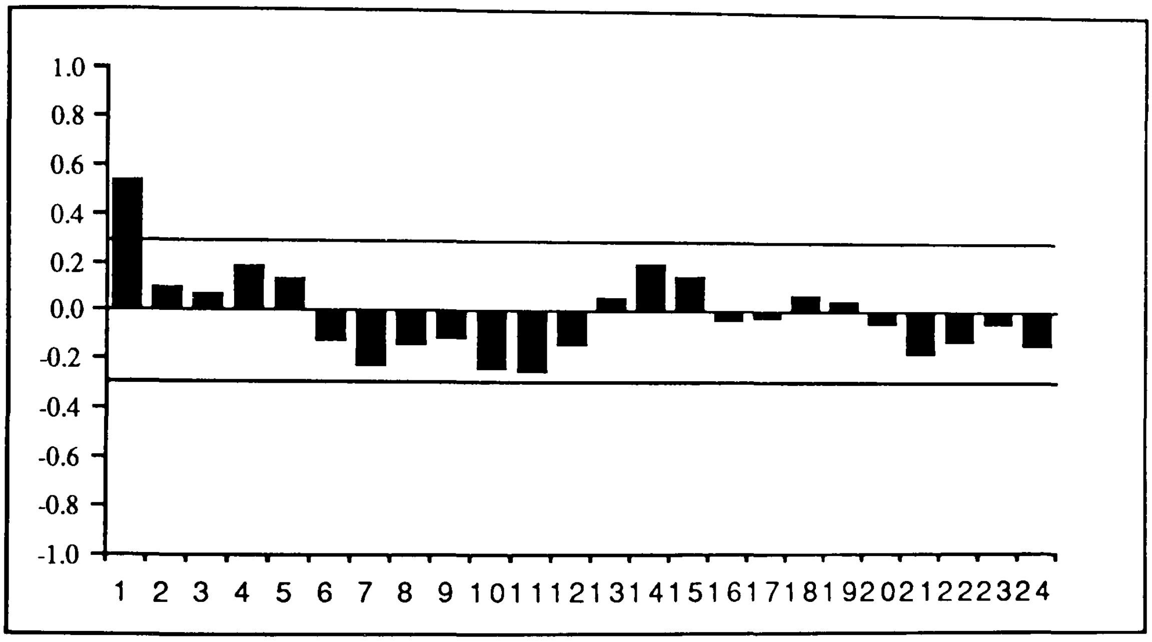
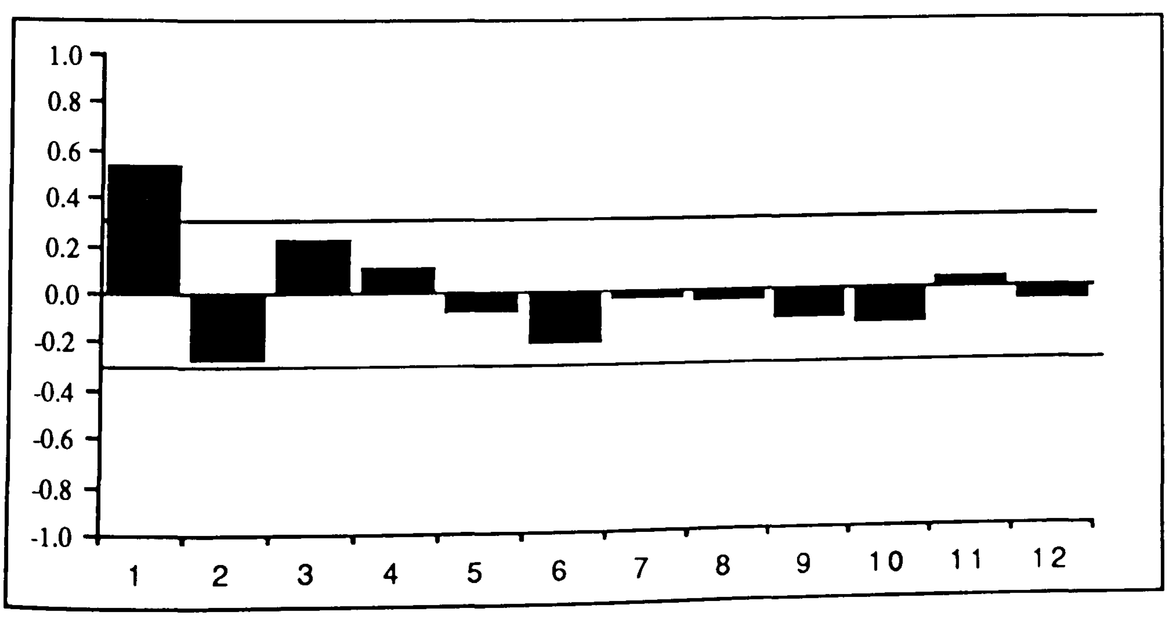


Figure VIII.6 : PACF of ΔlnRN_t



Again the ACF and PACF suggest a number of rival specifications. The significant spike in the ACF and a geometrically declining PACF are indicative of an ARMA (0,1) process. Alternatively, the significant spike in the PACF and declining ACF signal that an AR(1) process might be at work. If the second spike in the PACF is treated as significant (although it is strictly inside the 95% confidence interval for white noise) then the evidence is suggestive of an ARMA (2,1) model as well. For the purpose of comparison an ARMA (1,1) model is also estimated. Diagnostic tests arising from the estimation of these four rival models are presented in Table VIII.2. Pre-testing suggested that a constant term is unnecessary in any of the specifications.

Table VIII.2 : Model Selection Criteria for the series $\Delta \ln RN_t$

Model	Q(d.f.)	R^2	AIC	BIC
ARMA (1,0)	16.8 (11)	0.30	-6.4703	-6.4293
ARMA (2,1)	17.7 (9)	0.26	-6.3449	-6.2220
ARMA (0,1)	9.0 (11)	0.35	-6.5570	-6.5161
ARMA (1,1)	7.4 (10)	0.35	-6.5128	-6.4309

A quick glance at Table VIII.2 reveals that the ARMA (0,1) model is to be preferred, it having a relatively high adjusted R^2 and and smallest AIC and BIC values and a low Q value, well inside the 5% critical value of 19.67. The ARMA (2,1) model has a Q statistic that allows rejection of the null (that the residuals are white noise), and also has a low adjusted R^2 and high AIC and BIC statistics relative to the other models. In fact, this model is also equivalent to the ARMA (1,0) specification since the 95% confidence interval of the MA coefficient encompasses unity, as was demonstrated above. Whilst the ARMA (1,1) and ARMA (0,1) models perform well on the criteria produced in Table VIII.2, as the following equations reveal, the AR coefficient is not statistically different from zero at the 5% level implying that the ARMA (0,1) is the preferred model - as was initially suggested.

$$\underset{}{\Delta lnRN_t} = \underset{(1.33)}{0.27442\Delta lnRN_{t-1}} \underset{(-3.08)}{+0.54769\hat{\varepsilon}_{t-1}} + \varepsilon_t$$

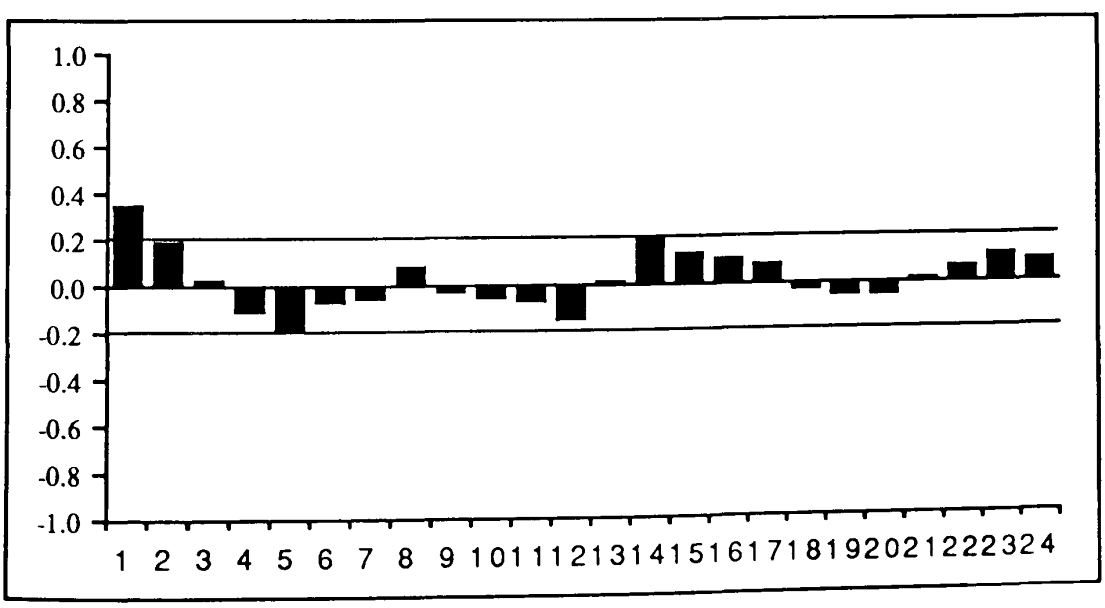
$$\Delta lnRN_t = \underset{(-7.04)}{+0.72200\hat{\varepsilon}_{t-1}} + \varepsilon_t$$

Tests on the residuals of the preferred model also support the adoption of the ARMA (0,1) model for $\Delta \ln RN_t$ and therefore the series expressed in levels, $\ln RN_t$ is best described by an ARIMA (0,1,1). Note that although this result contrasts with the evidence from the unit root tests that implied $\Delta \ln RN_t$ was an AR(1) process this is to be expected since MA processes are always stationary and thus are not directly tested for in such tests, and as mentioned above any MA (1) process has an autoregressive representation. More interestingly, we have shown that the average rent and new rent series appear to be described by two quite different processes.

(c) The Historical Average Rent Series (1871-1990) $\ln RH_t$

The unit root tests implied that $\ln RH_t$ was nonstationary and its first difference $\Delta \ln RH_t$ was a stationary AR(1) process. The ACF and PACF of $\Delta \ln RH_t$ are presented in Figures VIII.7 and VIII.8. The ACF has two significant spikes after which it declines in a sine wave pattern towards zero. The PACF of this series has a single dominant spike after which all coefficients are insignificant (the spike at the 14^{th} lag may reasonably be regarded as spurious). Whilst the presence of a pattern in the ACF is clearly visible it is unclear whether the PACF declines after the first lag in a systematic or random manner and this will require further testing.

Figure VIII.7 : ACF of $\Delta \ln RH_t$



Due to a sine wave decline in the ACF and a single spike in the PACF it seems likely that $\Delta \ln RH_t$ is an ARMA (1,0) if it is reasonable to assume that the PACF is randomly distributed around zero. If this is not the case then a MA model of order one or possibly two is implied given that the ACF has significant spikes at lags one and two. These three rival specifications will be estimated with an ARMA (1,2) and ARMA (1,1) included to aid comparison. Diagnostic tests from the five estimated models are presented in Table VIII.3.

Figure VIII.8 : PACF of $\Delta \ln RH_t$

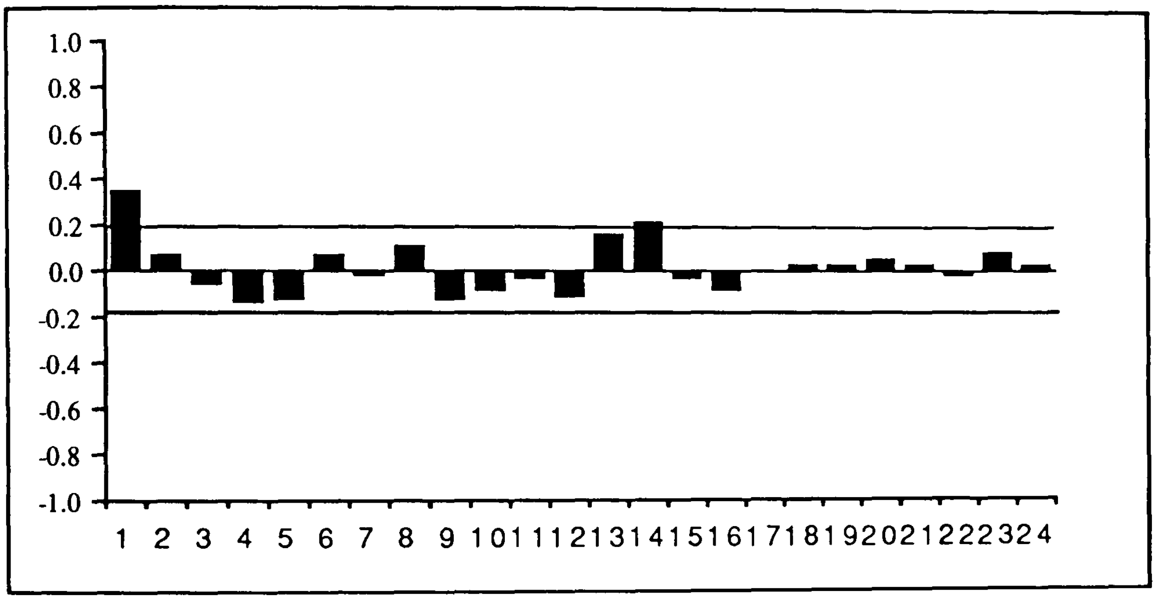


Table VIII.3 : Model Selection Criteria for the series $\Delta \ln RH_t$

Model	Q(d.f.)	R^2	AIC	BIC
ARMA (1,0)	11.2 (11)	0.11	-5.6984	-5.6748
ARMA (0,1)	13.3 (11)	0.09	-5.6718	-5.6482
ARMA (0,2)	10.8 (10)	0.10	-5.6725	-5.6302
ARMA (1,1)	11.5 (10)	0.11	-5.6759	-5.6287
ARMA (1,2)	13.7 (9)	0.07	-5.6220	-5.5512

Inspection of Table VIII.3 reveals that the residuals from all the models are empirical white noise as implied by the Q statistics, although the other criteria suggest that the simple ARMA(1,0) model is to be preferred. The ARMA(1,2) model performs worst of all the models over all the criteria and may be reasonably dismissed as inadequate. The second MA parameter in the ARMA (0,2) is statistically insignificant implying either an

ARMA(1,0) or ARMA (0,1) model both of which have statistically significant parameters. Estimation of an ARMA(1,1) model yields an insignificant MA parameter, implying that the ARMA(1,0) model is to be preferred, a result that supports the inference based solely on the diagnostic tests in the table. A simple t test on the residuals from this model suggest they have zero mean with what appears to be constant variance from casual inspection of the squared residuals.

The results indicate that $\Delta \ln RH_t$ is a stationary ARMA (1,0) process and thus the series expressed in levels, $\ln RH_t$ is an ARIMA (1,1,0), this being the same as the shorter average rent series $\ln R_t$. It is worth noting however that the explanatory power of the model for the historical series is considerably lower than that for the shorter series on average rents. At least two reasons may be put forward to account for this; namely, errors in data which are likely to be non-trivial in the early years of the series (see the Data Appendix on the construction of this series) and also the presence of some very large outlying observations that correspond to the free-fall in farm prices in the early 1920s and the Great Depression in the 1930s. Whilst the errors in the data cannot be rectified, the outlying observations may be filtered out of the data using intervention analysis which will improve the fit and estimation of the ARMA(1,0) model. Whilst it would be possible to identify a new structure for this series in the absence of the outliers, intuition would suggest that this is unlikely given that the first difference of the shorter average rent series ($\Delta \ln R_t$) is also ARMA(1,0).

(d). Average Real Land Price (1944-1989) $\ln P_t$

The ACF and PACF of this series corroborates the findings of the unit root tests since the series has a persistent ACF (indicative of non-stationary) and the PACF has three spikes. If the series in levels is a nonstationary AR(3) then its first difference $\Delta \ln P_t$ should be a stationary AR(2) process, if indeed no MA terms are present. This inference is supported by the ACF and PACF of $\Delta \ln P_t$ shown in Figures VIII.9 and VIII.10.

A dampened sine wave is clearly visible in Figure VIII.9 suggesting a stationary AR process and the two spikes followed by what appear to be random coefficients in the PACF suggest the AR process is of order two. Despite the clear signalling of an ARMA (2,0) process a number of low order models were estimated although the only adequate specifications to emerge from this search were the ARMA (2,0) and the ARMA (1,2) models, diagnostic tests for which are presented in Table 4.

Figure VIII.9 : ACF of $\ln P_t$

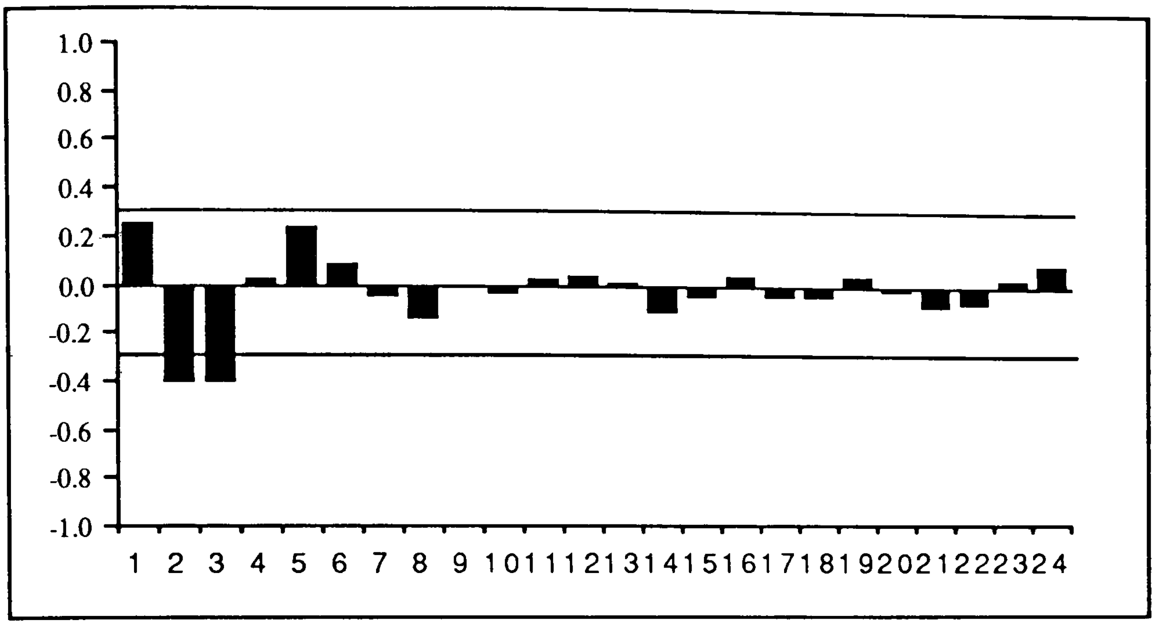


Figure VIII.10 : PACF of $\ln P_t$

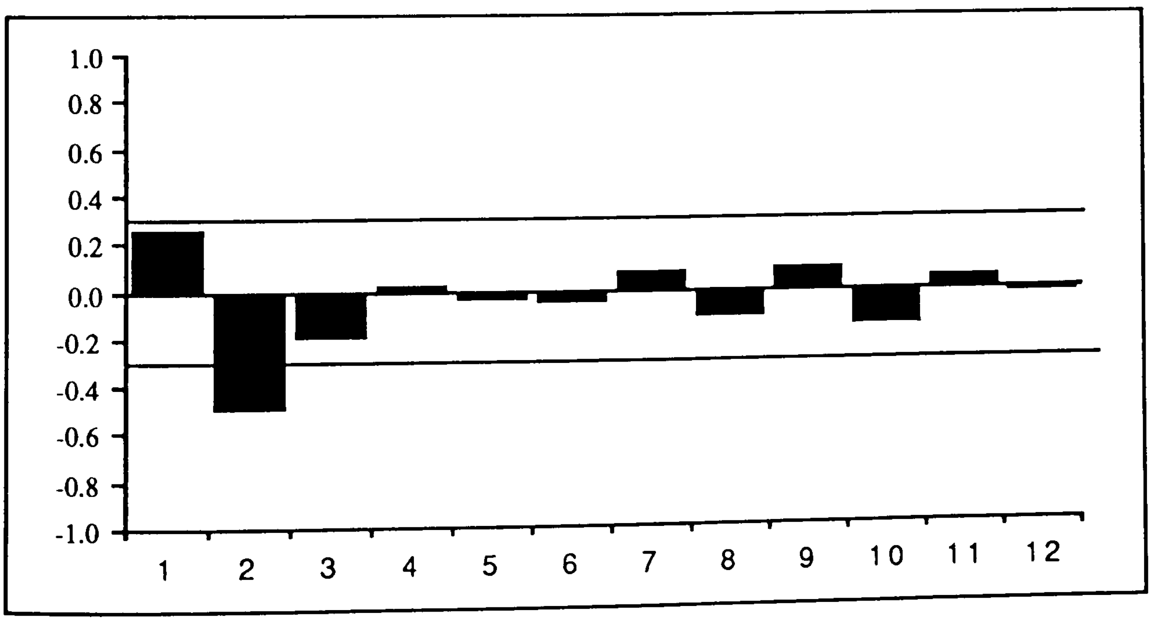


Table VIII.5 : Model Selection Criteria for the series $\Delta \ln P20_t$

Model	Q(d.f.)	R^2	AIC	BIC
ARMA (2,0)	5.2 (10)	0.27	-3.9542	-3.8523
ARMA (1,2)	9.2 (9)	0.17	-3.7408	-3.6180

The tests clearly favour the ARMA (2,0) model which is estimated as,

$$\Delta lnP_t = 0.43754 \Delta lnP_{t-1} - 0.53949 \Delta lnP_{t-2}$$
$$(3.78) \qquad\qquad (-4.14)$$

and therefore the land price series expressed in levels is ARIMA (2,1,0).

(e) Average Real Land Price for >20 hectares (1944-1989) $\ln P20_t$

The ACF and PACF of $\ln P20_t$ confirm the results of the unit root tests, in that the series is a non-stationary AR(3) process since the ACF is persistent and the PACF has three dominant spikes at lags one, two and three. If this inference is true then $\Delta \ln P20_t$ should be a stationary AR(2) process. The ACF and PACF are shown in Figures VIII.11 and VIII.12 respectively.

Figure VIII.11 : ACF of $\ln P20_t$

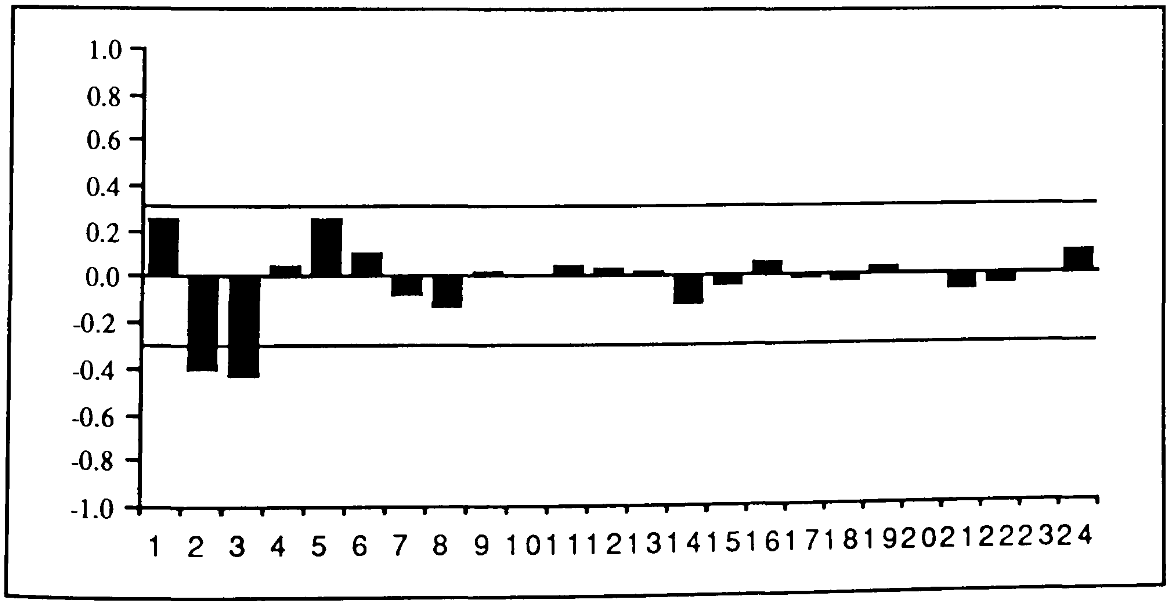
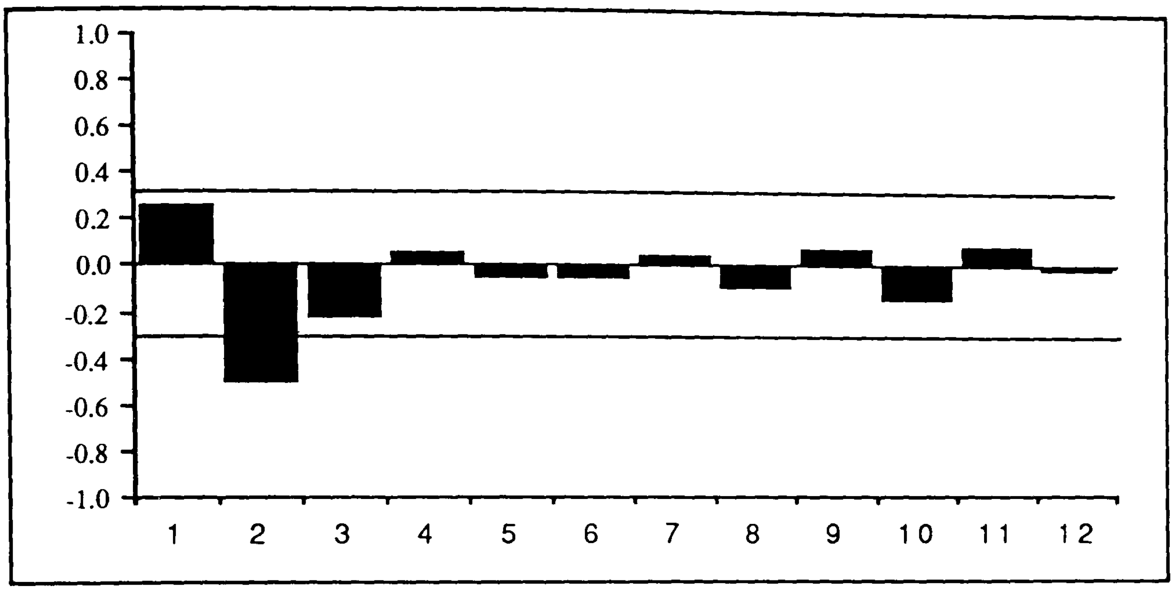


Figure VIII.12 : PACF of ln$P20_t$



Taken together the evidence from the ACF and PACF tend to suggest an autoregressive process of order two or possibly three, if the third coefficient in the PACF is treated as significant. If however the decline of the PACF is viewed as having a cyclical decline then the three spikes in the ACF might suggest a third order moving average process. This seems unlikely given the cyclical decline of the ACF and estimation of various moving average models confirmed that only AR parameters are required. Table VIII.5 shows the diagnostic tests from various AR models.

The Q statistic for the AR(1) model exceeds the 5% critical value and thus allows rejection of the white noise residuals null. The AIC and BIC statistics favour adoption of the AR(2) model although the adjusted R^2 is marginally better for the AR(3) model.

Table VIII.5 : Model Selection Criteria for the series Δln$P20_t$

Model	Q(d.f.)	R^2	AIC	BIC
ARMA (1,0)	22.3 (11)	0.03	-3.6184	-3.5783
ARMA (2,0)	7.0 (10)	0.25	-3.8353	-3.7550
ARMA (3,0)	3.2 (9)	0.26	-3.8004	-3.6799

However, a simple t test on the third AR parameter suggests that it is not significantly different from zero and hence the AR(2) is adopted for $\Delta \ln P20_t$. The model is estimated as,

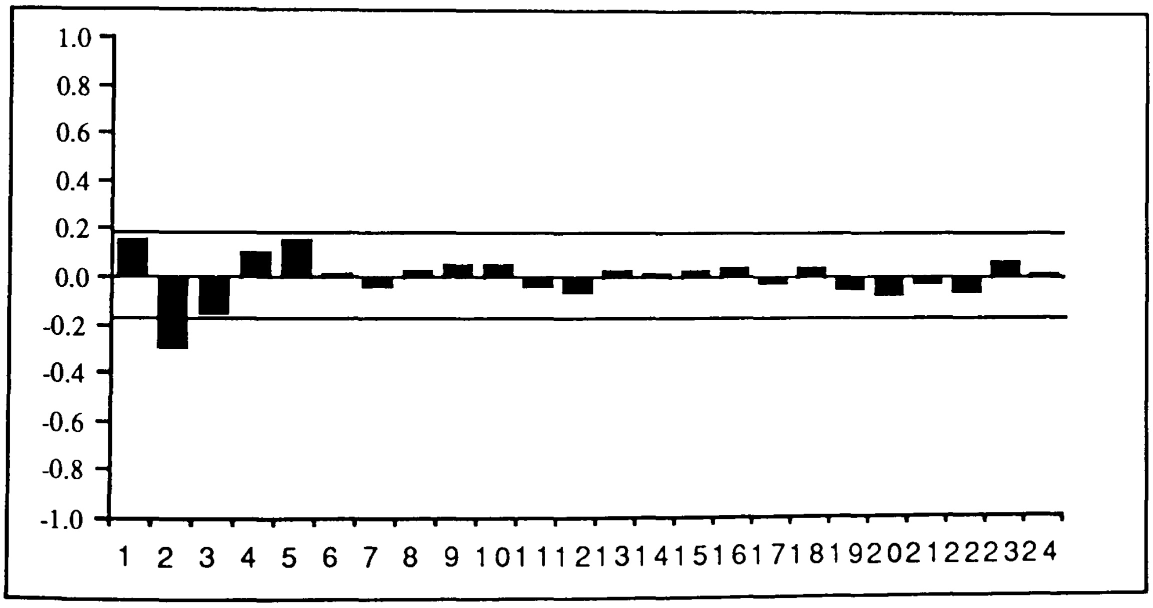
$$\Delta lnP20_t = 0.38437 \Delta lnP20_{t-1} - 0.50709 \Delta lnP20_{t-2}$$
$$(2.91) \qquad\qquad (-3.77)$$

implying that the series expressed in levels, $\ln P20_t$, is ARIMA (2,1,0) as was found for the $\ln P_t$ series.

(f). The Oxford Institute Land Price Series (1859-1990) $\ln PX_t$

As with the other two land price series the unit root tests suggest that the log of the Oxford Institute series $\ln PX_t$ is a nonstationary AR(3) series and a stationary AR(2) in first differences. The ACF and PACF of $\ln PX_t$ bear all the hallmarks of a non-stationary AR(3) but to test for the existence of any MA components the ACF and PACF of $\Delta \ln PX_t$ are presented in Figures VIII.13 and VIII.14.

Figure VIII.13 : ACF of $\Delta \ln PX_t$



The sine wave decay of the ACF does not suggest any MA terms and the random nature of the coefficients of the PACF after the second lag strongly points to a AR(2) process. Estimation of a number of low order models confirms that $\Delta \ln PX_t$ is purely autoregressive in nature and as expected, is best described by a second order model of the form,

$$\Delta \ln PX_t = 0.21219 \Delta \ln PX_{t-1} - 0.32645 \Delta \ln PX_{t-2}$$
$$(2.52) \qquad\qquad (-3.88)$$

and yields diagnostics that are presented in Table VIII.6.

Figure VIII.14 : PACF of $\Delta\ln PX_t$

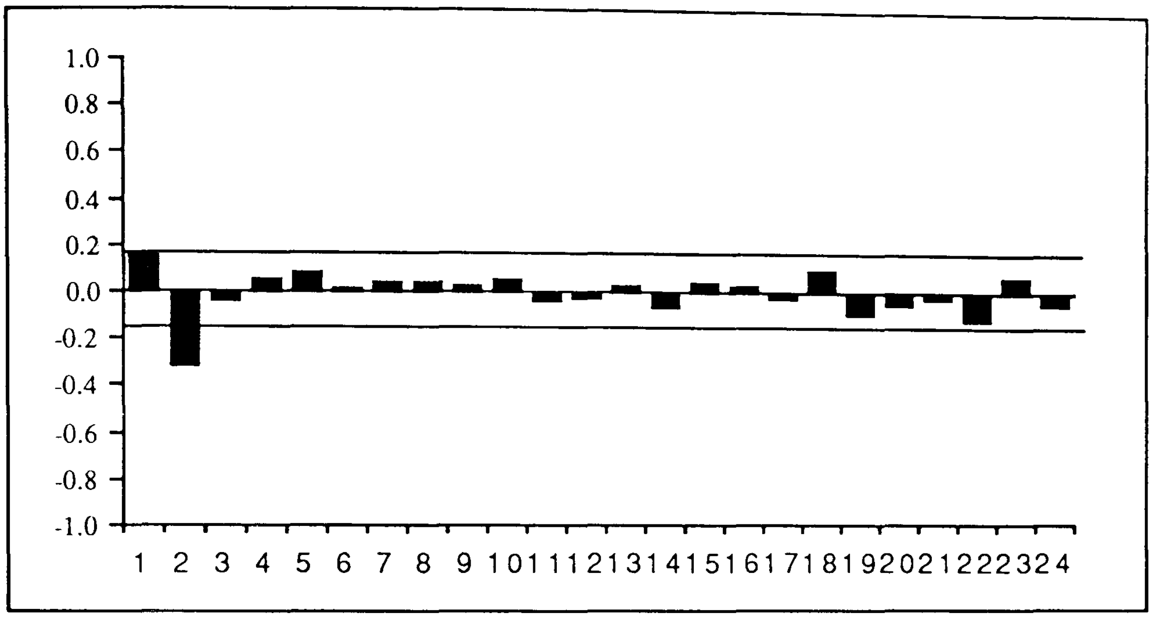


Table 6 : Model Selection Criteria for the series $\Delta\ln PX_t$

Model	Q(d.f.)	R^2	AIC	BIC
ARMA (2,0)	3.1 (10)	0.12	-4.2346	-4.1903

As with the rent series the explanatory power is considerably lower for the longer time series than for the shorter series. Likely explanations follow similar lines as for the long rent series, namely errors in the data towards the beginning of the series (although the land price series should be better in this respect compared to the rent series) and the presence of outliers, which are most significant in the sudden depression of the early 1920s and in the land price boom of the mid-1970s. Nevertheless, some comfort must be derived for identifying a similar structure for all the land price series used, despite their different samples and construction. This similarity of the time series properties of the land price series reinforces the findings in the Data Appendix which indicated that all the land price series appear to behave similarly.

(g). Summary of the Results

Using the time series techniques developed in this chapter the structures of the variables used in this study may be summarized as follows.

Rent Series

$\ln R_t$: ARIMA (1,1,0)

$\ln RN_t$: ARIMA (0,1,1)

$\ln RH_t$: ARIMA (1,1,0)

Land prices

$\ln P_t$: ARIMA (2,1,0)

$\ln P20_t$: ARIMA (2,1,0)

$\ln PX_t$: ARIMA (2,1,0)

VIII.(ix). The Empirical Analysis - Forecasting

Armed with an estimate of the data generating process for each series we can now present the forecasts from each model. All forecasts will be in 1990 price terms and will be computed for a lead time of five years. Generally however, ARIMA forecasts are used only for very short time horizons since forecasts converge to the mean value of the series as the lead time increases, although the time taken to revert to the mean depends upon the specification of the forecasting function. Typically, lead times tend not to be set much longer than the sum of the parameters in the model, *i.e.* $l \sim p + q$. Due to the low order of models estimated here only the one or two step ahead forecasts are of any real meaning.

Forecasts are initially produced using forecasting functions developed for the stationary processes identified in the previous section. Because these stationary series are expressed in first differences of the log of the original series, appropriate transformations have been conducted to show forecasts consistent with the original series.[20]

[20] It should be noted however that if the series forecasted is in log form then simply exponentiating (anti-logging) the forescasts from this model does not give unbiased forecasts of the raw series. It can be shown that the l -step ahead forecast of the raw series is given by,

$Y_{T+l} = \exp(\ln Y_{T+l} + 0.5\sigma_l^2)$ where σ_l^2 is the variance of the forecast error. See Mills (1990) pp.337-338 for further details. Forecasts of the raw series presented here have been adjusted in accordance with this theoretical result.

(a) Forecasts for Average Farm Rents R_t

Forecasts of R_t five periods into the future using the ARIMA (1,1,0) model are reproduced in Table VIII.7 with the associated 95% confidence interval.

Due to the fact that the forecasting model is autoregressive the process has infinite memory so the reversion to the mean of the series is slow and has not been completely achieved with a five period lead time although the tendency is clearly visible. The model forecasts a general decline in the series from the origin (1990); the one step ahead forecast being 3.05% below its previous value. The series is then predicted to fall very slightly over the remainder of the forecasting horizon although given the parsimonious specification of the model and the size of the confidence interval it would be foolhardy to infer too much from the two or more step ahead forecasts.

Table VIII.7 ARIMA Forecasts of R_t (1991-1995) £/ha.

Year	Lower	Forecast	Upper
1991	86.27	91.63	97.23
1992	80.01	89.91	100.69
1993	74.88	88.93	104.84
1994	70.65	88.41	109.28
1995	67.11	88.19	113.82

(b) Forecasts for Newly Negotiated Farm Rents, RN_t

Forecasts of RN_t five periods into the future using the ARIMA (0,1,1) model are reproduced in Table VIII.8 with the associated 95% confidence interval.

Table VIII.8 ARIMA Forecasts of RN_t (1991-1995) £/ha.

Year	Lower	Forecast	Upper
1991	90.86	97.63	104.76
1992	84.67	97.82	112.42
1993	80.89	98.01	117.67
1994	77.99	98.20	122.05
1995	75.58	98.39	125.93

The forecasting model suggests that the one-step ahead forecast (at 1990 prices) is some 1.14% lower than the 1990 value (of 98.76) although the forecasts rise slowly from this value, so that in 1995 rents are only slightly below their 1990 level. However, because forecasts are initially generated for the stationary series, $\Delta \ln RN_t$ using an MA(1) process the l step ahead forecast from this model will be the same as the one step ahead forecast since an MA(1) model only has a memory of one period. This implies that all the forecasts for the original series should also be the same as the one-step ahead forecast. Accounting for the slow rise in the forecasts presented in Table 8 is the adjustment that must be made to the forecasts in logs to obtain optimal predictions of the raw series, as explained in footnote 20. For our purposes here though, the only 'useful' forecast is the one-step ahead forecast given that we have an MA(1) process driving the forecast.

(c) Forecasts for the Historical Rent Series RH_t

Forecasts of RH_t five periods into the future using the ARIMA (1,1,0) model are reproduced in Table VIII.9 with the associated 95% confidence interval.

Table VIII.9 ARIMA Forecasts of RN_t (1991-1995) £/ha.

Year	Lower	Forecast	Upper
1991	83.09	93.05	103.86
1992	76.55	92.76	111.38
1993	71.79	92.88	118.25
1994	68.09	93.17	124.49
1995	65.07	93.50	130.21

The forecasting model suggests that the one step ahead forecast (at 1990 prices) is some 1.5% lower than the 1990 value (of 94.51) and that the rent series continues to fall into 1992 where it bottoms out and begins to rise slowly - although the forecast for 1995 is still 1% below the 1990 level although such medium term forecasts should be treated sceptically for the reasons explained above.

(d) Forecasts for the Average Land price series, P_t

Forecasts of P_t five periods into the future using the ARIMA (2,1,0) model are reproduced in Table VIII.10 with the associated 95% confidence interval. The date of origin (the last available observation of the series) is 1989 for this series.

Table VIII.10 ARIMA Forecasts of P_t (1990-1994) £/Ha.

Year	Lower	Forecast	Upper
1990	3500	4580	5890
1991	2756	4431	6759
1992	2598	4568	7470
1993	2596	4745	7988
1994	2516	4786	8296

The one step ahead forecast from this model predicts a sharp drop in land price from the origin, of some 7.1%. The downward trend continues into 1991 which is 3.3% lower than the forecast for 1990, however the model predicts an upturn in land prices in 1992 rising to a level of £4786 per hectare by 1994, although this is still 2.9% below the 1989 actual value of land in real terms.

(e) Forecasts for the 20 Hectare plus Average Land price series, $P20_t$

Forecasts of P_t five periods into the future from a 1989 origin using the ARIMA (2,1,0) model are reproduced in Table VIII.11 along with the associated 95% confidence interval.

Table VIII.11 ARIMA Forecasts of $P20_t$ (1990-1994) £/Ha.

Year	Lower	Forecast	Upper
1990	3255	4315	5611
1991	2523	4132	6396
1992	2384	4260	7051
1993	2401	4450	7569
1994	2330	4495	7875

The results obtained from this model of $P20_t$ are similar to those from the previous model of P_t.The one step ahead (1990) forecast of this series suggests a sharp drop in land price of around 7.4% followed by another fall of some 4.2% in 1991. Thereafter the series turns up considerably, although the five-step ahead forecast is still some 3.8% below the actual level in 1989.

(f) Forecasts for the Oxford Institute Average Land price series, PX_t
Forecasts of PX_t five periods into the future using the ARIMA (2,1,0) model are reproduced in Table 12 with the associated 95% confidence interval.

Table VIII.12 ARIMA Forecasts of PX_t (1990-1994) £/Ha.

Year	Lower	Forecast	Upper
1990	5044	6400	8007
1991	4451	6508	9195
1992	4342	6775	10091
1993	4197	6839	10546
1994	3986	6822	11325

Using 1989 as the origin of the forecast the model predicts a large fall in land prices of some 9% in 1990. In the following year the model predicts a slight increase of 1.7% in the series which continues until the end of the forecasting horizon in 1994 at which time land prices are about 7.5% above their 1989 value in real terms.

VIII.(x) Conclusion

The object of this chapter has been to develop parsimonious ARIMA models primarily for the purpose of generating forecasts of agricultural rents and land prices. Such models solely comprise autoregressive and/or moving average components of the past history of the series and consequently have greatest predictive power where the data is characterised by repetitive cycles. By implication ARIMA models suffer from the inability to pick up turning points in a series since the models do not incorporate an explanatory structure that is rooted in economic behaviour. One other drawback of this approach is that ARIMA models become increasingly impotent for the purposes of prediction as the forecasting horizon lengthens. This stems from the 'backward-looking' or adaptive nature of the models themselves, in that, such models base forecasts solely on the historical evolution of the series up to that point. Because the importance of contemporaneous information diminishes as we proceed further into the future, forecasts from ARIMA are by necessity short term predictions. Given the parsimonious specifications identified here it is only the one and two step ahead forecasts that can be considered in any way reliable and generally inferences have been confined to this time horizon.

The findings that arise from this modelling are as follows. The forecasting models for the three rent series give consistent predictions in that the one-step ahead forecast from all the models suggests a fall in rent in real terms of the order of 1 to 3 per cent in 1990. The forecasting models of the three land price series are also reasonably consistent although predictions of the model forecasting the Oxford Institute land price series do differ slightly to those from the other models. Whilst all the models predict a large fall in land prices in 1990 (of 7 to 9%) the models of P_t and $P20_t$ suggest that this is followed by a further fall in 1991 of around 3 to 4 per cent after which an upturn is predicted.[21] In slight contrast the Oxford forecasting model predicts that the upturn occurs in 1991 rather than 1992.

However, the generation of forecasts is not the sole reason for the identification and estimation of ARIMA models. It has already been noted that all the land price series are characterised by outlying observations, such as those in the mid-1970s, that are believed to have been caused by accession to the European Community and/or the rapid inflation caused by the oil price shock, yet little formal analysis has been conducted on the precise nature and dynamics of these outliers.

With the aid of an ARIMA model it is possible to investigate these aspects using an *intervention model* and identify the dynamic response of land agents to the unusual conditions that are alleged to have produced the outliers. Secondly, ARIMA models may be combined with regression models that can be used for the purposes of estimation and forecasting. The combination of both approaches into what are called *transfer function models* is frequently superior to either pure regression or ARIMA models. The advantage of combination arises from the complementarity of the two approaches. The inclusion of explanatory variables into an ARIMA model allows the transfer function model to more accurately track turning points in a series yet permits

[21] Due to the fact that values for the Oxford institute series takes much less time to be published a 1990 value for the series is currently available, although this is not so with the satutory series. Recall that the forecast for 1990 was a 9% fall in prices which estimates quite accurately the actual fall which is observed as 9.7% in that year.

more accurate forecasts than a pure regression model. Such areas of investigation are acknowledged but are not within the scope of this present study and will be left for future investigation.

Appendix I : ARMA Model Simulation

In developing forecasting functions for the rent and land price series the properties of a number of simple of linear stochastic processes were examined, namely the ARMA(1,0), ARMA(2,0), ARMA(0,1), ARMA(0,2) and ARMA(1,1). Here, each of these of processes has been simulated according to a known data generation process (which is stationary and/or invertible) and a randomly generated set of errors, denoted ε_t, characterised by zero mean and unit variance. Each of the following models has been generated using this same set of random errors ε_t. The sample size of each model is 100.

The purpose of this Appendix is to illustrate the ACFs and PACFs of those simple linear processes because an acquaintance with some stochastic ACFs and PACFs will be useful before the empirical series on rents and land prices are identified. The Appendix highlights the need for some experience when trying to identify ARMA models using these descriptive tools and underscores the notion that identification may be more of an art than a science. Even in the simple processes presented below the identification is seldom as straightforward as the theoretical derivations of the ACF and PACF suggest.

To aid identification standard error bands have been superimposed to represent the 95% confidence limit for a set of random variables with mean zero. The limits are only approximate and may be estimated more precisely using Barlett's (1946) formula shown in the text.

1.ARMA (0,1)

DGP : $Y_t = \varepsilon_t + 0.75\varepsilon_{t-1}$

The ACF in Figure A1 is dominated by a significant spike at lag 1 and insignificant coefficients thereafter indicative of an MA(1) process. The theoretical derivation of the ACF for this process also implies that the first coefficient on the ACF should lie between -0.5 and 0.5 and this is what we observe. The large spikes at lags 18 and 19 would typically be ignored on the grounds of sampling variability - one in twenty spikes being spuriously 'significant' on average anyway. The PACF should also decline to zero although this is not immediately obvious. Moreover, the first two spikes dominate the PACF and may suggest, when taken by itself, an AR(2) process although when considered with the ACF this would be refuted. Consequently, the true model would most probably have been identified in this instance although the evidence is not as clear-cut as one might like.

Figure A1: A Realisation of a Typical MA(1) Process

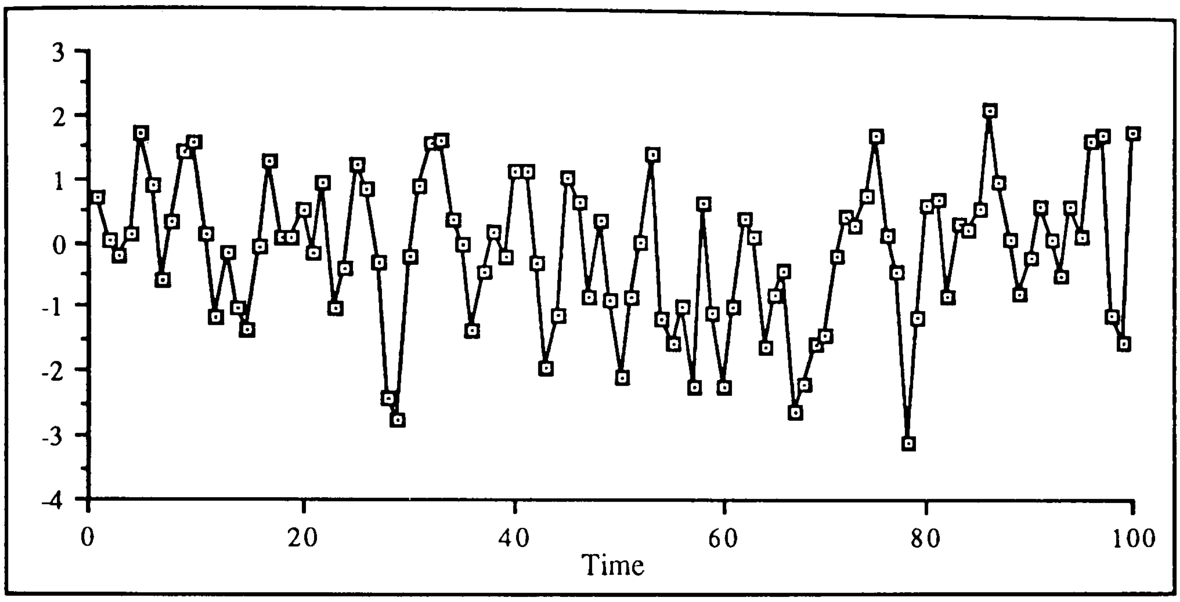


Figure A2: Autocorrelation Function of an MA(1) Process

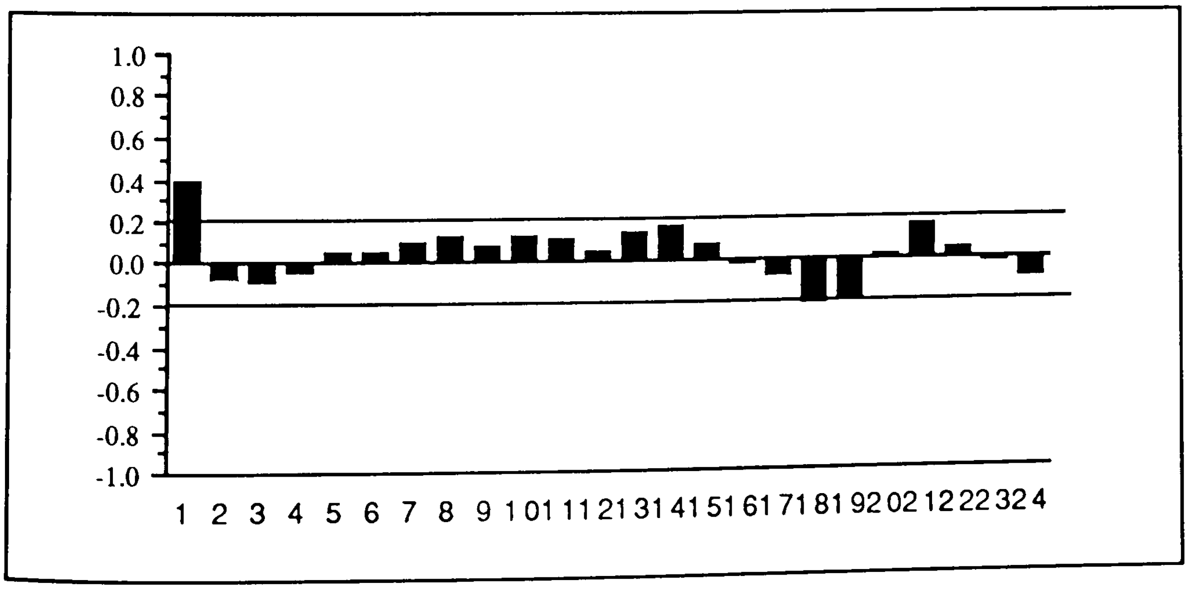
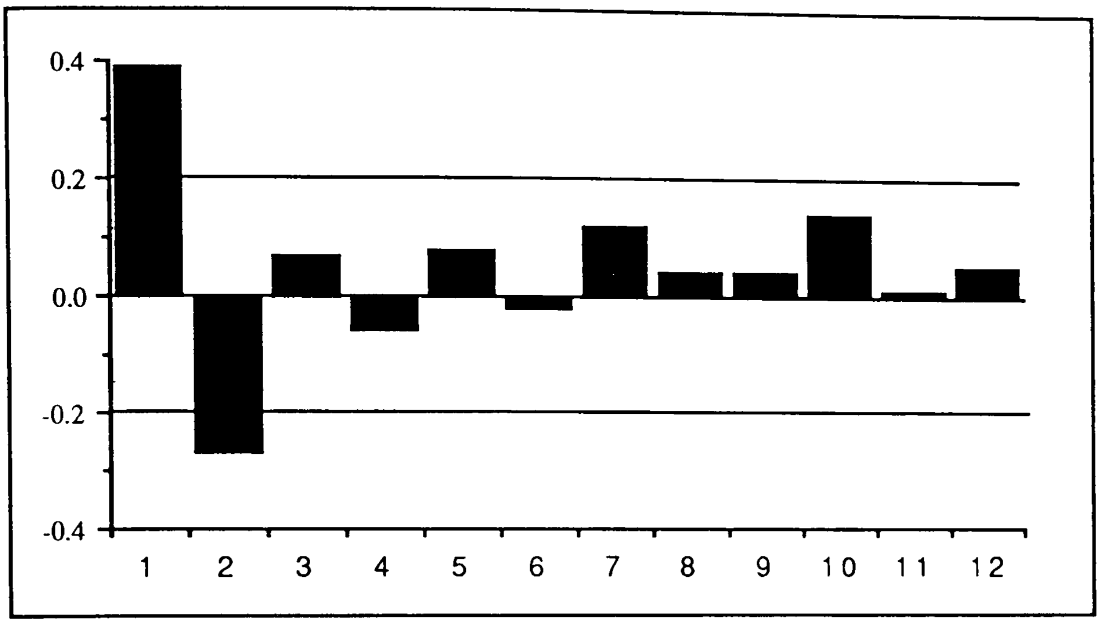


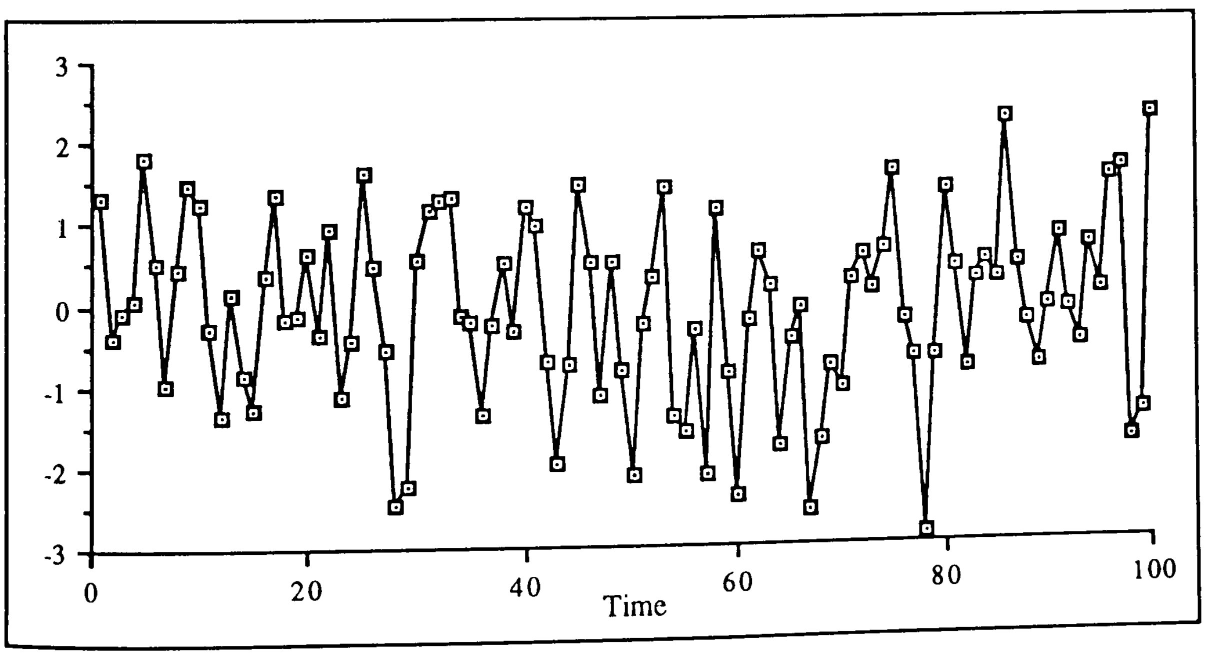
Figure A3: Partial Autocorrelation Function of an MA(1) Process



2. ARMA (0,2)

DGP : $Y_t = \varepsilon_t + 0.6\varepsilon_{t-1} - 0.3\varepsilon_{t-1}$

Figure A4: A Realisation of a Typical MA(2) Process



The ACF in Figure A5 exhibits two clear spikes at lags one and two (all others, around lag twenty could be legitimately disregarded) suggesting the process has a memory of only two periods. The PACF declines to zero quite clearly and there seems little here to dispute the identification of an MA(2) model. The oscillatory nature of the PACF would further imply that the MA parameters assume alternate signs, as indeed they do.

Figure A5: Autocorrelation Function of an MA(1) Process

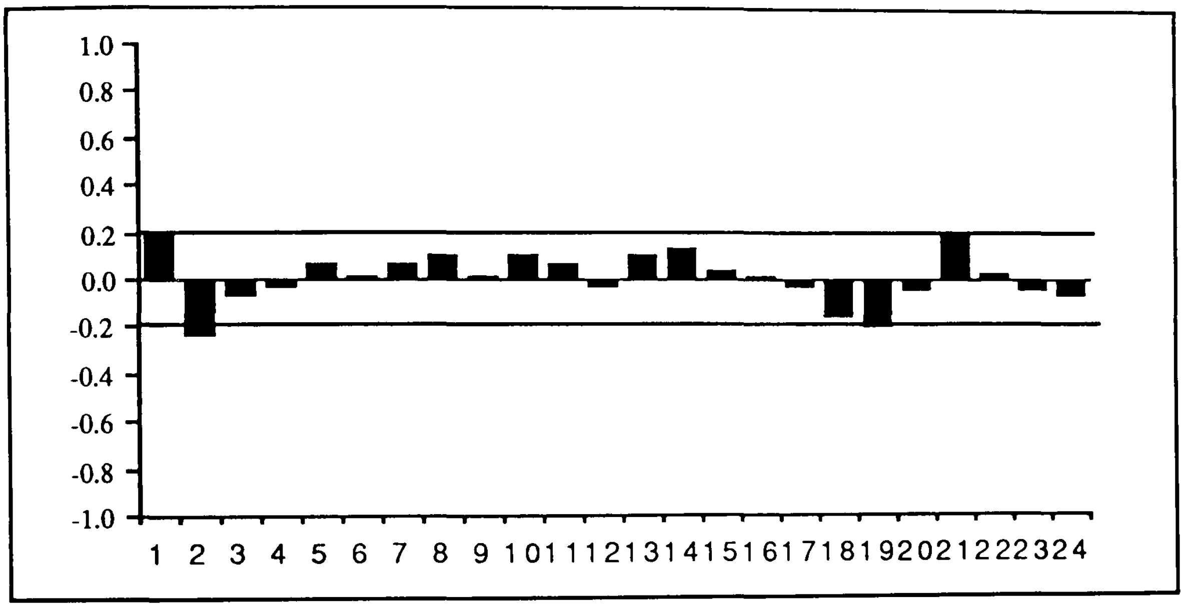
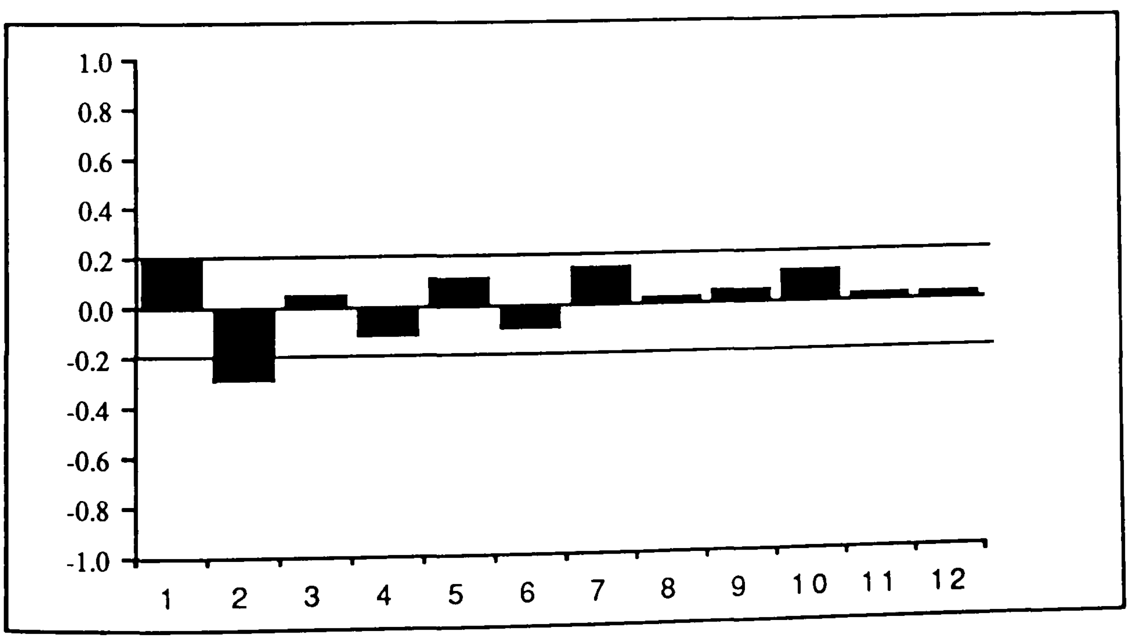


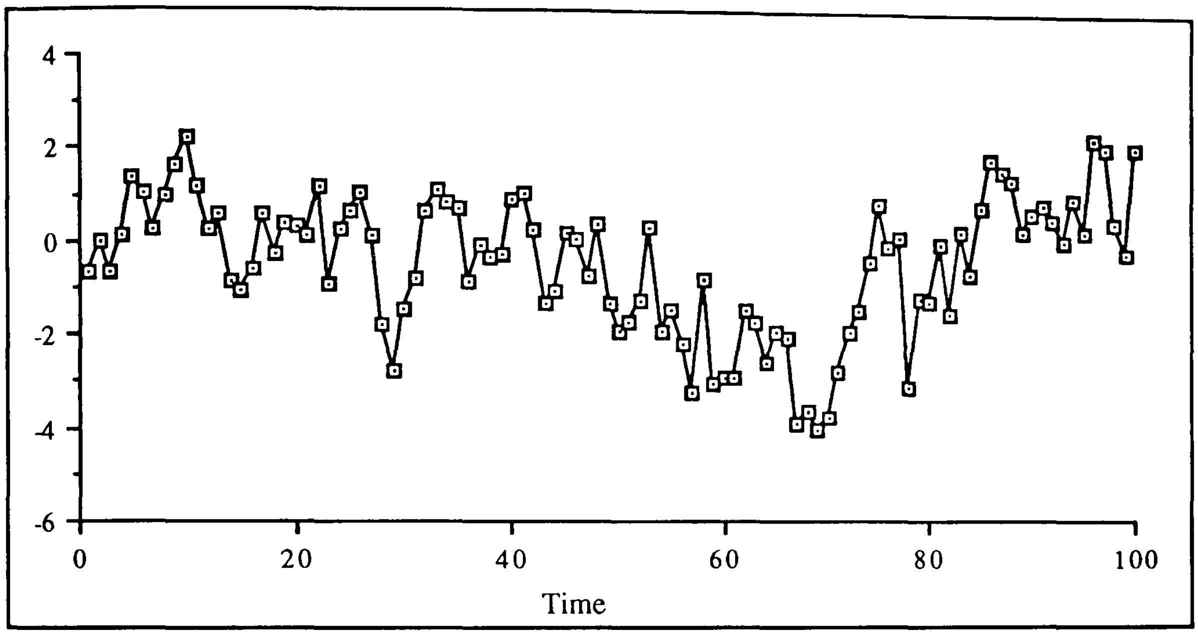
Figure A6: Partial Autocorrelation Function of an MA(1) Process



3.ARMA (1,0)

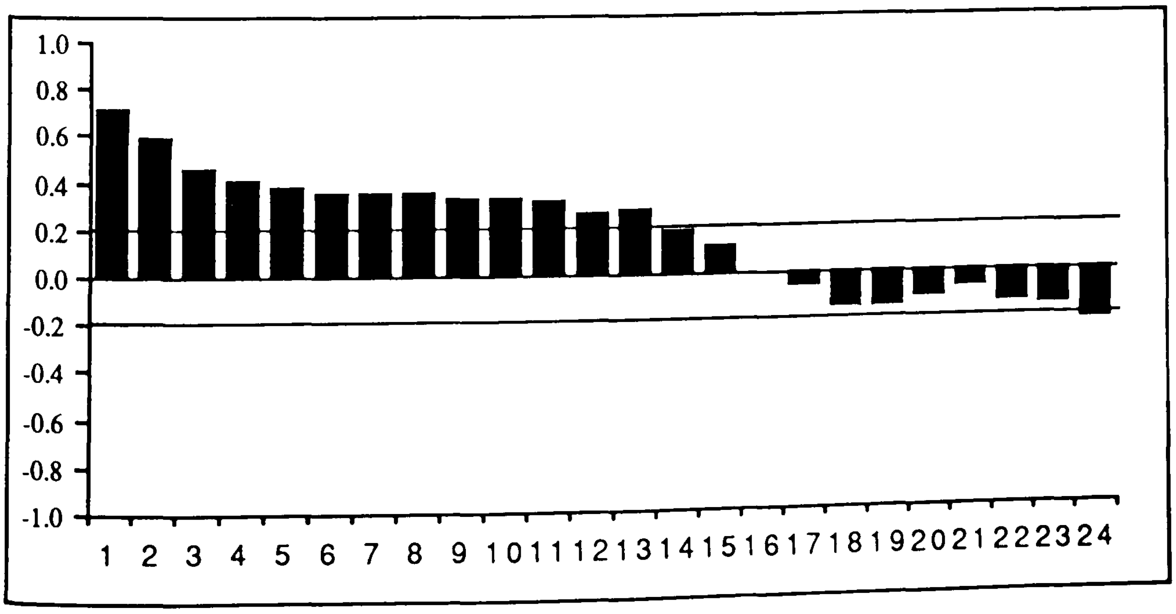
DGP : $Y_t = 0.8Y_{t-1} + \varepsilon_t$

Figure A7: A Realisation of a Typical AR(1) Process



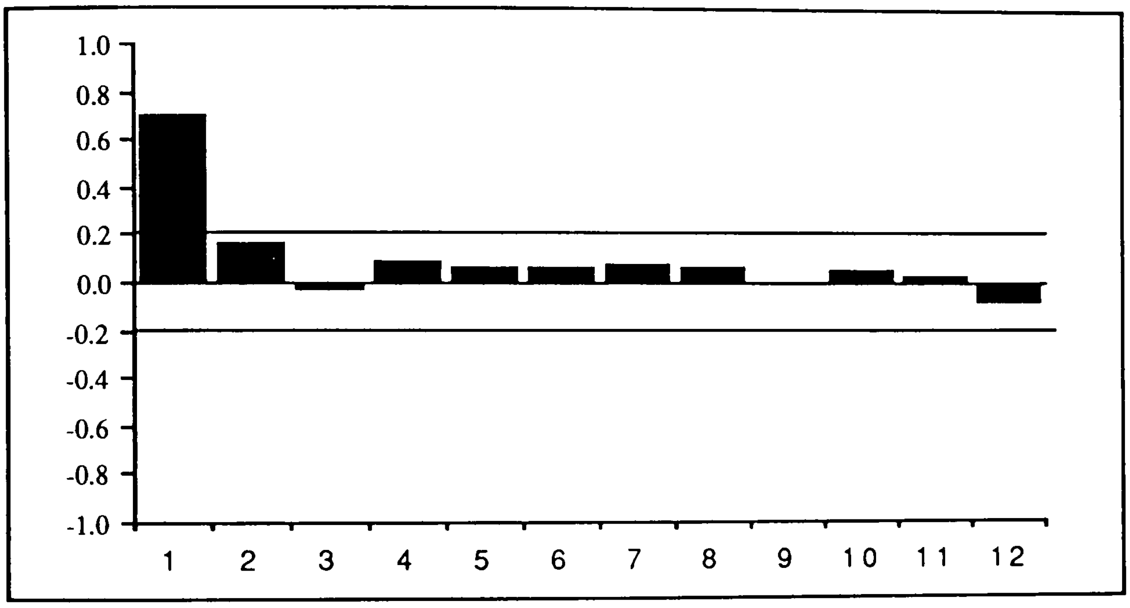
The ACF in Figure A8 is strongly indicative of a process with long memory such as an AR process. The PACF is dominated by a spike at lag one and would probably lead immediately to the identification of the true structure of this process.

Figure A8: Autocorrelation Function of an AR(1) Process



Given the slow linear decline of the ACF *and* the significant spike in the PACF it would be appropriate to infer that that the AR parameter is positive and close to the boundary of stationarity (unity). Indeed the parameter used to generate the process was 0.8.

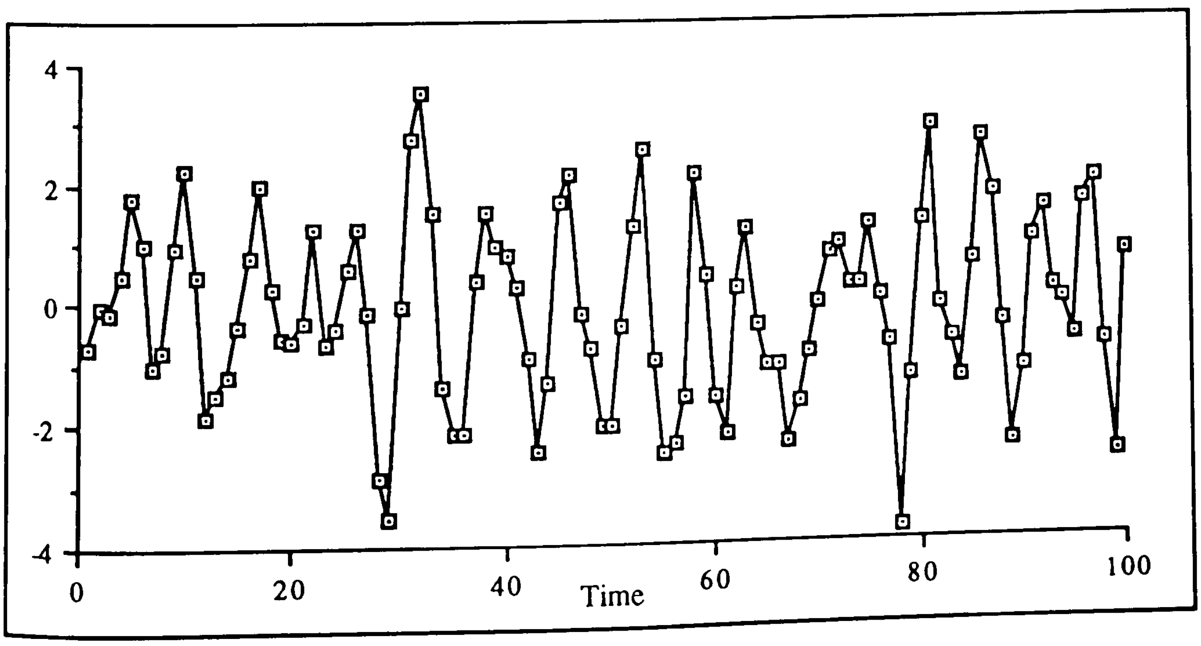
Figure A9: Partial Autocorrelation Function of an AR(1) Process



4.ARMA (2,0)

DGP : $Y_t = -0.7Y_{t-1} + 0.8Y_{t-2} + \varepsilon_t$

Figure A10: A Realisation of a Typical AR(2) Process



The ACF in Figure A11 assumes a sine wave pattern indicating that the process is AR of at least order two. The PACF actually gives a rather misleading picture in that there appear to be three 'significant' spikes in this function. This would lead to the probable adoption of an AR(3) model, although because the third spike on the PACF is close to the 95% confidence level one would be well advised to carry an AR(2) model through to the next stage of the Box-Jenkins process so that a comparison between the rival specifications could be made.

Figure A11: Autocorrelation Function of an AR(2) Process

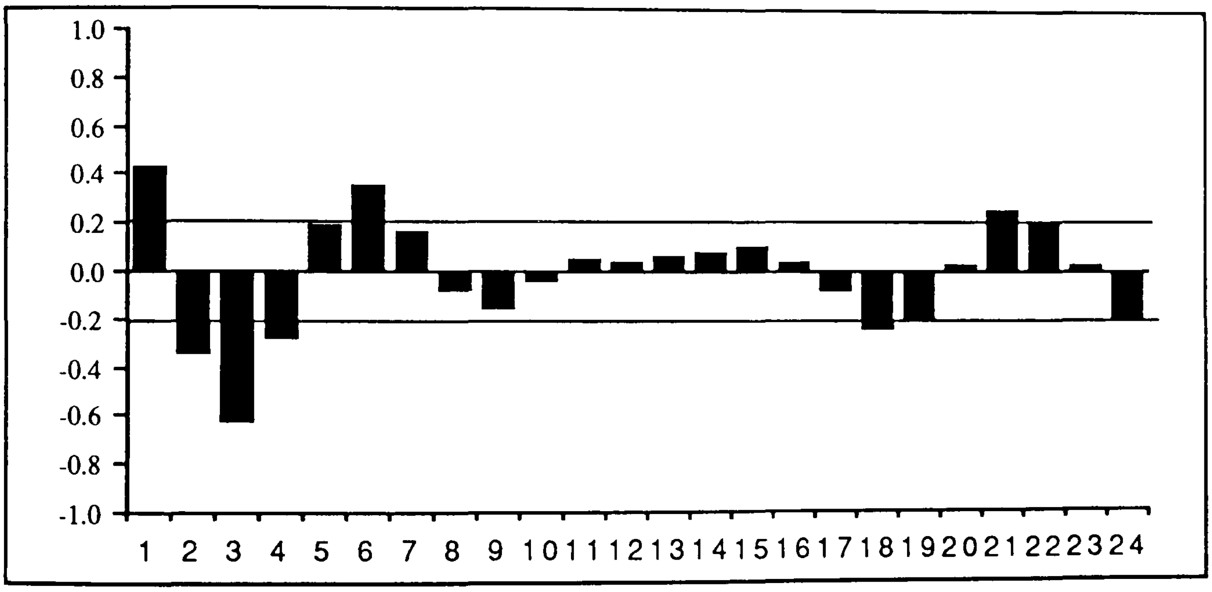
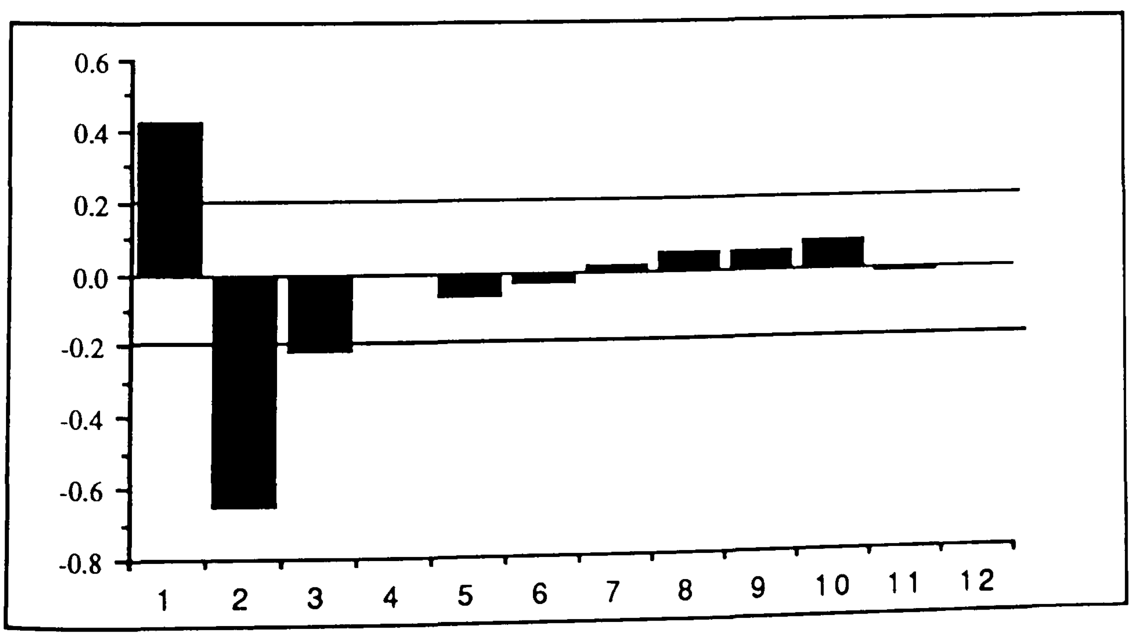


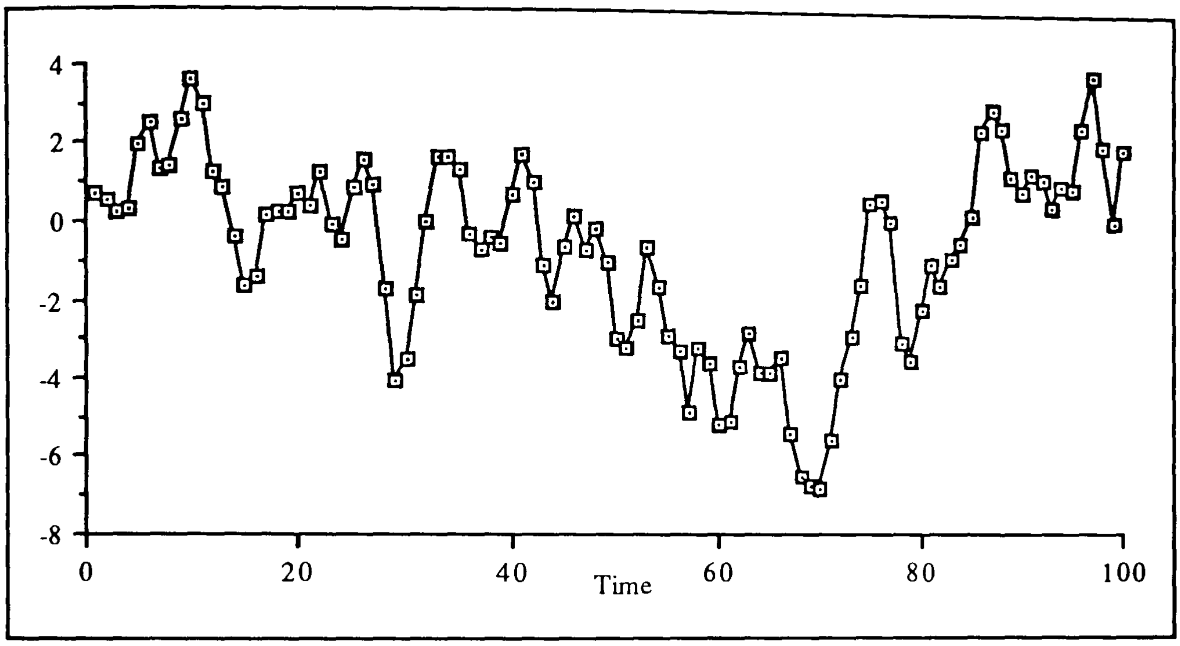
Figure A12: Partial Autocorrelation Function of an AR(2) Process



5. **ARMA (1,1)**

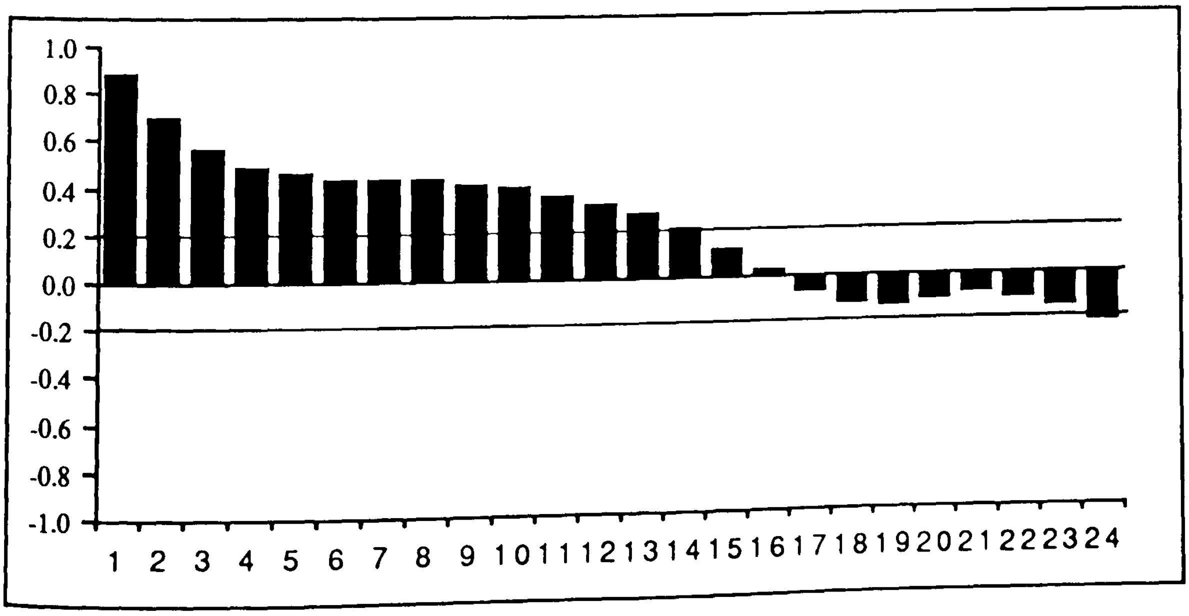
DGP : $Y_t = 0.8Y_{t-1} + 0.8\varepsilon_{t-1} + \varepsilon_t$

Figure A13: A Realisation of a Typical ARMA (1,1) Process



The ACF of this process is clearly dominated by an autoregressive component and the slow linear decline of the ACF suggests a positive and high AR parameter. The PACF of an ARMA(1,1) should behave like a MA(q) process after p-q lags. Whilst this is visible to some extent, in that the PACF does decline to zero, the very significant spike at lag one may also suggest a simple AR(1) model.

Figure A14: Autocorrelation Function of an ARMA (1,1) Process



Chapter IX
Conclusion

IX.(i) A Summary of Results

This thesis has attempted to develop logically deduced empirical models of land price determination that satisfy the requirements of the statistical techniques used in their estimation. In so doing, the investigation has explored the theoretical foundations of asset price determination using present value methods. This approach provides a tractable framework in which pricing equations may be derived and estimated econometrically using time series data. The econometric methodology adopted serves the dual purpose of providing more reliable estimates and giving a greater insight into the economic rationale of econometric models. A number of new results emerge from this investigation that are summarised as follows.

The economic theory of price determination of durable assets establishes a symmetry between potential purchasers and current owners of land, in so far as the factors that influence the demand for an asset will also influence its supply. In a situation where all offer prices and reservation prices are known to the analyst in each period of time the identification of supply and demand curves is feasible. Here, expressions for the equilibrium price and number of transactions that will occur in such a setting have been derived. However, since such information is unavailable in practice, the symmetry of the market entails that the identification of separate demand and supply curves becomes impossible and the analysis reaches an *impasse*. Nevertheless, if it can be assumed that participants in the land market base their valuation of land on present value methods, a single reduced form equation may be derived to determine the equilibrium price of land for the entire market. Such an expression is consistent with the theory of asset pricing since it recognises the independence of transactions in the process of price determination and leads to specifications that may be estimated with published data. Moreover, this reduced form representation allows a number of hypotheses to be tested empirically, most importantly, those relating to the relationship between returns and asset prices and the formation of expectations. This last issue was explored in Chapter III where it was found that adaptive expectations were congruent with the data, although the special case of naive expectations may be acceptable as a first approximation. The version of rational expectations employed was refuted by the data. Using the adaptive models, the required rate of discount on land ownership was estimated to be around 3%, evidencing the widely held belief that discount rates on agricultural land are generally low. The possibility of disequilibrium pricing was also investigated, yet there was no statistical support for this notion, suggesting that disequilibrium is not a permanent feature of the land market. Clearly, the use of aggregate annual data clouds the equilibrium issue, but the evidence points to an efficient market for land in England and Wales. Whilst disequilibrium will necessarily occur at a more disaggregated level, it does not appear to be reflected in any permanent way in the average price of farmland. Finally, the empirical analysis in Chapter III suggests that the opportunity cost of capital, as defined by the Agricultural Mortgage Corporation loan rate, does not have a systematic effect on real land prices. Whilst this appears counter-intuitive, it may simply reflect a common belief among market commentators, such as those writing in the *Farmland Market*, that land prices are sticky with respect to the level of interest rates over much of the range in which interest rates have fluctuated in the post-war era. The argument proposed to account for this behaviour is that borrowed funds are generally only used to finance land purchased for amalgamation. Since neighbouring land may only come on to the market once in an individual's lifetime, the ruling rate of interest may be of limited importance, particularly so since mortgage rates are variable and the repayment period extends for some 25 years. This reasoning also suggests that the implicit use of a constant real rate of discount in the present value equations may not be as restrictive as might be thought.

The evaluation of previous land price modelling, namely that by Bruce Traill, formed the heart of Chapter V. The empirical model developed by Traill exhibits a number of disquieting methodological features such as theoretical mis-specification, the use of net farm income as a measure of the returns to land and the inclusion of variables in nominal (not real) price terms. The mis-specification arose primarily from the use of transactions as a determinant of price, which as was shown in Chapter III is independent of price. In turn, this use of transactions arose from the demand orientated nature of the study, and a mis-understanding of the concepts of stock and flow for a durable asset. In essence, the two concepts were confused in the empirical specification of the model and as a result the negative correlation observed between the number of transactions and nominal land price was used as 'evidence' for a demand curve. However, given that the number of transactions has been falling due to the effect of institutional factors on the size of the tenanted sector, and that nominal land prices have risen due to the effect of inflation, there are strong *a priori* grounds for believing the observed correlation is spurious. Moreover, research by another author, Wollmer (1988) has shown that the correlation is spurious, as implied by the theoretical model of price determination.

Using an updated sample with variables measured at constant prices the model breaks down, exhibiting structural change in the parameters, unstable dynamic behaviour, and an insignificant coefficient on the farm income variable. The model exemplifies the dangers of spurious regression that may arise through theoretical mis-specification and the use of integrated variables. The examination of the model clearly signals that greater attention needs to be paid to both the theoretical underpinnings and statistical content of empirical models.

Building on the time series analysis of Chapter VI the investigation turned to an examination of the opportunities that cointegration has to offer. Using two techniques developed in the econometric literature to test for cointegration, it was demonstrated that once account is taken of the demand for farmland as an inflation-hedge, the long run evolution of land prices is primarily determined by agricultural earning potential as measured by agricultural rents. This result has a number of interesting implications.

First, it acknowledges the investment dimension in land purchase, hitherto ignored in empirical models of land prices. Farmland is thus not solely purchased for its income bearing potential but as a secure form of investment in inflationary periods. The most likely explanation for the movement of funds in to land relates to its *relative* profitability coupled to the perceptions of investors in inflationary periods. Whilst the real annual yield on farmland (real rent) is typically lower than the return on alternative investments, land becomes more attractive in inflationary periods since this is typically when the prospects for investment opportunities elsewhere in the economy are weakest. Moreover, such transfers may initiate a prophetic cycle, in that, if land is perceived to be a good hedge against inflation, investment demand for it rises, with the result that land prices actually do rise. Intuition and anecdotal evidence suggest it is the capital growth rather than annual return that motivates inflation-based acquisitions. In addition, the modest size of the land market implies that even marginal shifts of investment portfolios can have a discernible effect on land prices. Second, because cointegration has been found between rents, inflation and land prices, the effect of all other potentially important influences, such as interest rates, capital taxes and non-pecuniary effects must be confined to the short run. Whilst this result is subject to the usual caveats concerning statistical inference it does suggest that the land price model may only be improved by the addition of explanatory variables which are I(0) in linear combination with one another or are I(0) processes themselves.

Finally, the cointegrating vector that has been identified is unique and supports the theoretical prediction of unit elasticity between returns and land prices. The discount rate implied by the long run equilibrium relationship is estimated at 3.6% which is in accordance with earlier estimates and *a priori* expectations. When substituted into an error correction model the response of land prices to rents and inflation is such that land prices tend to adjust immediately to changes in rents whereas land prices tend to over-react to changes in inflation in the short run, the period to adjustment to the long run equilibrium taking some three or four years.

IX.(ii) Limitations

In the introduction to this study a number of questions were posed that subsequent Chapters have sought to answer. Inevitably, many of the explanations given are in some way or another partial, or warrant further study. Consequently, there are some limitations and potential weaknesses of the present analysis that require a retrospective evaluation. The first of these concerns the empirical measure of returns to land.

Rents represent a bridge between the landowner and the cultivator. In a competitive economy, rents may be expected to accurately reflect market forces, yet the highly institutionalised nature of the rental market in England and Wales, may stifle rents in practice. The fact that rents and land prices do not cointegrate may even be evidence of this view. In addition, the use of rent as a return to land is frequently criticised owing to the fact that a significant majority of farmers are owner-occupiers and thus do not actually negotiate a rental payment. In this light, the use of rent as the return to landownership in modern times may appear questionable. Whilst it is argued here that such objections are fallacious, it is accepted that the use of rents does limit the analysis in a policy context since the level of rent is not at the direct control of policy-makers. In order to analyse the effect of variables over which policy-makers have direct control, such as support prices and quotas for example a rent model is required. Since a model of rent determination has not been developed here, the usefulness of the land price model in a policy context is limited, although future research would correct this deficiency.

In defence of the use of rents *per se* the following points may be noted. If we are prepared to assume that tenanted land is farmed in a similar fashion to owner-occupied land then the objection to the use of rents on the grounds that most farmers do not actually pay a rent becomes a question of sampling reliability. However, as detailed in the Data Appendix the coverage of farms in the Rent Survey is sufficiently large not to warrant criticism. If it is believed that tenanted land is farmed differently to owner-occupied land, then clearly rents will not reflect profitability on the majority of farms, although there seems little reason to believe that this is so. Furthermore, no matter how intimate the relationship between landowner and farmer may be, the functions that each performs are conceptually distinct. Whilst the owner-occupier supplants the landowner, he does not remove the functions that the landowner performs, and thus the reward he receives. Hence, part of the total return accruing to the owner-occupier must represent a return to land, no matter how invisible it may be to an outsider.

Objection to the use of rent on the grounds that legislative controls may impede rents seems more tenable, since one may argue that the volatility of the land price series merely reflects the volatility of the return to farming; a volatility that is 'ironed out' in the rent series by the institutional mechanisms that constrain the negotiation of market rents in practice. The solution to this problem is an empirical one and to the extent that the discrepancy between the land price and rent series is accounted for by a third variable - inflation - the empirical results suggest that rents do reflect underlying market forces adequately. This issue may nevertheless be investigated using a rent model. If, as it has been assumed here, that rents reflect the underlying or 'long-run' profitability of farming, then given sufficient data on the factors that determine this profitability, such as technological change and the prices of farm inputs and outputs, it should be possible to test this assumption using cointegration. If rents reflect the long term changes in these factors then rents and these other determinants will cointegrate. If this occurs, then in the long run rents and the determinants of farming profitability are tied together, despite short run divergences, caused by weather, disease and so forth. This issue will be discussed further below since it has important policy implications. The validity of the use of rents as a measure of farming profitability is nevertheless supported empirically.

Even if rents can be shown to embody the determinants of farming prosperity, a number of other potentially important determinants of land prices have been omitted, namely the non-pecuniary demand for farmland, speculation and institutional factors, such as taxation and the effect of roll-over relief in the market. These factors have been omitted since they are all particularly difficult to model empirically, though for different reasons. Whereas it is the complexity of tax law that precludes realistic measurement, it is the psychological dimension that troubles the modelling of non-pecuniary motives and also speculation. The presence of cointegration among the variables identified however seems to suggest that such factors have only a short run effect, at least over the post-war period. The speculative boom in the 1970s is a clear example however that such short run influences may have a major, albeit transient impact on the price of land. Credible models of speculative behaviour have eluded financial economists for some time, although recent breakthroughs in this area undertaken by Bulow and Klemperer (1991) throw a new light on this matter and may allow such effects to be incorporated into an empirical model of land prices.

The discussion in Chapter II suggested that institutional factors, most notably taxation and tenurial law, play an important role in the land market. Whilst such factors have been a significant driving force in the shift to owner-occupation the empirical analysis suggests that they have not been so influential on the price of land, at least during the post-war period. However, the inconclusive evidence concerning cointegration using the 120 year sample may well be partially explained by the omission of these factors which have changed dramatically over the larger sample period. This deficiency is acknowledged although there seems little that one may do to overcome it in a time series framework, given the problems that one would encounter in actually measuring such factors. However, research currently in train at Cambridge University seeks to establish the effect of these factors in farmland purchase using questionaire data, although the results of this exercise have not yet been published.

The influence of non-agricultural demand for farmland, such as residence and amenity, has also been omitted from the empirical analysis due to the unavailability of the necessary data. Whilst it is fair to say that this influence has exerted a non-trivial effect at certain times (notably at the end of the 1980s) and in certain localities (such as the Home Counties), it is in general swamped by the demand for land by commercial agriculturalists. Here, this influence has been 'artificially reduced' by the exclusion of land sold below 20 hectares from the land price series used. Again the omission is acknowledged and points to the need for further analysis which will be discussed in the following section.

Finally, it is important to underscore the limitations of the statistical techniques employed, given that so many of the conclusions that have been reached rely on statistical inference. As discussed in Chapter VII, unit root testing and cointegration are vulnerable to a number of criticisms and should be treated with the same degree of caution as with any statistical procedure. At best, cointegration serves as a test of model adequacy and thus the statistical results should be interpreted as providing evidence rather than answers.

IX(iii) Avenues of future Research

As with any investigative exercise, the initial research throws up many new and interesting issues that require further attention. Here, there are four main areas on which future research could focus.

(i) It has been implicitly assumed in this investigation that cash rents provide a reliable measure of the returns to land ownership. As such rents embody a number of influences that determine the demand for and supply of farmland. Consequently, a logical extension of this work would be to model rent determination itself. Coupled with the land price model developed here there would be a number of interesting policy implications of such a study. These derive from the fact that since rents are not directly under State control the influence of price reform cannot be directly quantified. Using a model of rent determination the effects of product price changes could be traced through to land prices and estimates derived for the effect on farm wealth and debt. This would represent a major study in itself and has not been attempted here for that reason, although it is clearly an avenue of research that may merit further attention, particularly in light of its pertinent policy implications.

(ii) The effect of non-agricultural demand has been excluded to all intents and purposes by the exclusion of smallholdings from the empirical series. In Chapter II attention was paid to the emergence of a two-tier land market. Whilst the effect of non-agricultural demand reflects the buoyancy of the general economy more than any other factor, and as such has only been of minor importance recently, there are some interesting theoretical and empirical implications of a resurgence in non-agricultural demand, particularly if this coincides with low agricultural demand for land. Development of a theoretical model that includes both these sectors is currently underway although an empirical model is likely to encounter limitations in the data that is currently available.

(iii) The use of cointegration and error correction models using the vector autoregressive representation also warrants further analysis. As mentioned in Chapter VII hypothesis testing was restricted due to the software currently available, although the recent introduction of software capable of dealing with these techniques will allow the investigation to proceed much further, particularly with respect to the nature of short run influences of such factors as interest rates, non-agricultural demand and possibly speculation. Whilst the presence of cointegration implies that the long run influences on land price has been identified, as alluded to above it does not deny a host of other influences contributing to price changes in the short run. One important candidate for further investigation is the interest rate which has been relegated in the previous Chapters simply because our main concern has been with the long run. Further analysis is required to investigate this short run influence, particularly so since the preliminary investigation in Chapter III hinted at a discernible influence.

(iv) Like many agricultural markets, empirical measurement of underlying relationships is often thwarted by the presence of outlying observations. The analysis of outliers has surprisingly been neglected in the agricultural economics literature, despite the development of techniques that facilitate their analysis. The outliers here represent speculative influences that resulted from the macro-economic shocks of the early 1970s. Time series analysis of this phenomenon will uncover the dynamic response and may be complementary to the development and application of models of speculative behaviour. The forecasting models developed in Chapter VIII play a crucial role in this examination and may be used subsequently in transfer function models where elements of both structural economic models and forecasting models are exploited in a hybrid model.

This outline of potential research topics is by no means definitive, but it does indicate those areas in which future research may be most fruitful and above all, that much research still remains. Only when armed with a richer understanding of the way in which the land market operates and the means with which it can be modelled, can economists provide insight into the likely consequences of agricultural policy, on the owners and cultivators of farmland. However, policy issues have not been the principal rationale for this present study, and as a result the contribution of this thesis to the policy debate is accordingly modest. Motivating this research is the unstructured and statistically spurious models of land prices that have been developed in the past. The questions posed in the introduction implied the need to develop models that are both theoretically and statistically valid and the models developed here attempt to achieve that dual aim. They are logically deduced and statistically congruent and as such are distinct from their predecessors. The theoretical framework and econometrics techniques applied here are necessary precursors to policy analysis and represent important steps that signal the direction which future land market research may follow.

Data Appendix

A.(i) Agricultural Land Price series in England and Wales

(a) MAFF Series

Since the Finance Act of 1931 it has been a statutory obligation of the purchaser to inform the Inland Revenue of a transaction in land or property. This information (contained in 'particulars delivered' or PD forms) is analysed by the Inland Revenue, where it undergoes a screening process to remove certain categories of sales (see below) and to uphold the confidentiality of transactions.[1] These filtered data are subsequently passed onto the Ministry of Agriculture, Fisheries and Food who then publish annual (and quarterly at present) summary reports.

The resulting series are based on all sales of agricultural land (bare land and land with buildings) of five hectares (four hectares/10 acres prior to October 1978) and above. Specifically, it *includes*,

(a) sales of agricultural land with some potential for development;
(b) any sales of land that may be regarded as being sold at prices below that ruling in the open market, *e.g.* between family members;
(c) sales where the vendor retains rights over the land such as rights to fish and hunt;
(d) sales of agricultural land in which the value of the farm dwelling represents a substantial part of the total *i.e.* small holdings;

but it *excludes*:

(e) sales of farmland designated for alternative use, such as development and gravel workings;
(f) gifts and inheritances of land;
(g) transactions costs (legal fees and Stamp Duty); and
(h) areas of woodland sold as a complete entity for commercial exploitation.

A land price series based on the conditions outlined above was first published in aggregate form dating from 1945 in annual ADAS Technical Reports commencing in 1969.[2] The basic aggregates of area sold, total value and land price have

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[1] The confidentiality clause is invoked where there are fewer than five transactions in any particular category, and entails that data in many regional classifications are not presented. The' confidential data' is however incorporated into the aggregates where it can be assured that details of individual sales cannot be identified or derived.

subsequently been embelished at sporadic intervals to include dissaggregations by region, tenure, size of holding, land quality, type of vendor/purchaser. Detailed information as to the timing and precise nature of these revisions may be found in Lund and Slater (1979) although the following points are worthy of note. In response to the persistence of the premium payable on land sold with vacant possession, which had emerged during the 1930s, land sales were classified by tenure, in 1969. In 1972 information from the statutory returns was presented quarterly and as of 1976 the categories of spatial aggregation were switched from the 21 valuation office regions to the eight MAFF administrative regions (although there exists one year in which both were calculated). As of 1989 information on land sales in the England and Wales aggregate ceased to be published, however, for the purposes of this study this type of information was aggregated from the figures published for the two individual countries in order to maintain a relatively long and consistent series for the England and Wales aggregate.

Due to the statutory nature of the PD returns the MAFF series provides an authoritative summary of land market trends, yet the comprehensive nature of the information is achieved at the price of punctualilty; such that there is an approximate delay of 6 months before statistics are published.[3] Moreoever, details of any one particular transaction are included in the year that the PD form is lodged with the Inland Revenue, and not the time of actual sale. Consequently, information pertaining to a sale agreed in December, may be registered with the Inland Revenue in the following September: Lund and Slater (1979) suggest that the lag between the time of sale reporting to the Inland Revenue is around nine months on average. This implies that sales reported to the Inland Revenue

2 The ADAS Technical Reports were superceded in 1978 by an ADAS booklet series, {SLP21, SLP22, Booklets 2320(79), 2320(80), 2320(81), 2320(82), 2320(83), 2320(84) and 2320(85)} which continued until 1986. Land price data were then published annually by MAFF until 1989, {73/97, 73/88} whereafter land prices in England and in Wales were published in separate publications by MAFF {in, Stats 56/89, Stats 51/90 and Stats 61/91} and the Welsh Office {no reference numbers given) respectively.

3 More punctual indicators of land prices are available (such as the ADAS/AMC series and the CLA series) and are based on sample data. The short historical duration of these, and other more recent series, (such as that constructed by Strutt and Parker) and to a lesser degree their partial coverage preclude their use in the statistical analyses of this study and will not be discussed further. See Lund and Slater (1979) for details.

in the administraive year ending on the 30 September in year *t* more accurately reflects the sales that took place in the calendar year *t*-1, (increasing the overall delay to around 15 months). This heuristic convention has been used in this study : all data presented is in a calendar year basis, having adjusted for the lag in reporting actual sales. This basic data has been amended for the purposes of statistical analysis and a brief explanation of the series follows.

(b) The Construction and Definitions of The Land Price Series

Table A.1 presents a summary of all the average land price series for the England and Wales aggregate in nominal terms that have been derived from the statutory returns. Each price series, is an 'unweighted' average, in that no account is taken of the composition of the sales included, and so the price is calculated by simply dividing the total value of land sold by the area of the land traded. All the series are expressed in £ per hectare and are calculated on a calendar year basis. Referring to Table A1, we may define:

'nom P'; the nominal average price of all sales of farmland of 5 hectares and above sold in England and wales (subject to the excluded categories outlined above) during calendar year t.

'nom VP'; the nominal average price of all land sold with vacant possession of 5 hectares and above in England and wales (subject to the excluded categories outlined above) during calendar year t.

'nom WP'; the nominal average price of all land sold without possession (*i.e.* tenanted land) of 5 hectares and above in England and wales (subject to the excluded categories outlined above) during calendar year t.

Table A.1 also includes the variables 'nom P20', 'nom VP20' and 'nom WP20' which differ from those defined above in that sales of land below 20 hectares have been excluded. These adjusted series incorporate a crude attempt to exclude small-holdings that may be purchased primarily for their amenity or recreational value and not their agricultural value. Note that because land sales by size were not recorded prior to 1964 for the England and Wales all sales aggregate measure the 'nom P' and 'nom P20' series are identical for earlier years, although the recreational demand for smallholdings in the earlier period covered by the data was probably small in any case.

The nominal land price information of Table A.1 and A.2 have been calculated from the size disaggregations for the all sales, vacant possession and without possession farmland displayed in Tables A.2, A.3 and A.4 respectively. Changes to the size classifications in 1969 and 1978 require that some care should be exercised when viewing the data. These tables also provide the figures for the England and Wales aggregate on the number of sales concluded, and the area of land involved. It should be noted that figures in bold type represent years in which the confidentiality clause prohibits declaration of the actual totals, with the result that the bold figures will represent a proxy based solely on sales in England for example, although the reader is directed to the appropriate footnotes for the precise reason and nature of the change.

In the empirical Chapters, the MAFF series expressed in current prices are not used due to the trending effect that inflation has on these series. In the empirics, all variables are expressed at constant (1990) prices and have been deflated by the Gross Domestic Product price index, (see later). All series expressed at constant prices have the 'nom' prefix deleted from their names, so that *P*, *P20*, *VP*, *VP20 WP*, *WP20* are the deflated counterparts of *nom P*, *nom P20*, *nomVP*, nom *VP20*, *nomWP* and *nomWP20*.

Table A.1 : The Land Price Series in Nominal Terms Derived From MAFF Data

Calendar Year	nom P	nom P20	nom VP	nom VP20	nom WP	nom WP20
1944	90	90				
1945	95	95				
1946	103	103				
1947	100	100				
1948	126	126				
1949	139	139				
1950	141	141				
1951	153	153				
1952	142	142				
1953	155	155				
1954	134	134				
1955	138	138				
1956	141	141				
1957	146	146				
1958	162	162				
1959	195	195				
1960	235	235				
1961	247	247				
1962	272	272				
1963	309	309				
1964	403	403				
1965	413	384				
1966	430	405				
1967	452	431				
1968	492	480				
1969	494	468	516	511	371	336
1970	474	446	489	456	348	340
1971	544	514	578	546	395	381
1972	1092	1058	1134	1094	983	990
1973	1480	1436	1540	1491	1274	1274
1974	1213	1132	1257	1165	919	908
1975	1081	997	1168	1076	783	765
1976	1291	1194	1410	1300	958	944
1977	1802	1707	1888	1783	1442	1447
1978	2316	2196	2473	2357	1584	1577
1979	3039	2862	3126	2942	2310	2311
1980	3162	2990	3304	3143	2212	2199
1981	3098	2921	3213	3030	2324	2329
1982	3321	3090	3428	3224	2379	2385
1983	3496	3266	3617	3386	2392	2371
1984	3586	3321	3664	3386	2735	2757
1985	3499	3220	3610	3336	2116	2094
1986	3200	2955	3270	3029	2044	2040
1987	3141	2855	3200	2913	2304	2300
1988	4063	3760	4161	3849	3061	3078
1989	4511	4264	4676	4444	2135	2130

Table A.2 : All Sales of Agricultural Land by Size in England and Wales 1965-1989

Calendar	4-19 Ha	4-19 Ha	4-19 Ha	20-39 Ha	20-39 Ha	20-39 Ha				40-119 ha	40-119 ha	40-119 ha	> 120 Ha	> 120 Ha	> 120 Ha	ALL SIZES	ALL SIZES	ALL SIZES	> 20 Ha.	> 20 Ha.	> 20 Ha.
Year	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.				No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.
1965	3619	34943	550	1350	39156	438				1157	76730	410	239	57250	313	6365	208079	412	2746	173136	384
1966	3780	36805	542	1440	41626	440				1260	82681	403	215	44651	376	6695	205763	429	2915	168958	405
1967	3483	34986	554	1343	38535	451				1205	80525	423	226	46468	429	6257	200514	453	2774	165528	431
1968	3525	34602	601	1281	36902	507				1102	75122	487	212	47368	448	6120	193994	502	2595	159392	480
	4-19 Ha	4-19 Ha	4-19 Ha	20-39 Ha	20-39 Ha	20-39 Ha	40-59 Ha	40-59 Ha	40-59 Ha	60-119 Ha	60-119 Ha	60-119 Ha	> 120 Ha	> 120 Ha	> 120 Ha	ALL SIZES	ALL SIZES	ALL SIZES			
	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.			
1969	3337	32442	606	1224	35710	501	473	23245	477	531	44366	476	168	36001	510	5733	171764	494	2396	139322	468
1970	3772	37032	603	1359	39471	492	606	29614	452	609	50546	450	246	53049	405	6592	209711	474	2820	172679	446
1971	3501	34735	689	1265	36505	561	602	29331	554	600	49662	499	249	53743	472	6217	203978	544	2716	169243	514
1972	2964	29195	1275	1026	29743	1035	458	22359	951	548	46003	1008	259	59342	1149	5262	187639	1092	2298	158444	1058
1973	2620	25778	1703	880	24958	1517	423	20699	1379	389	32172	1455	219	52510	1406	4531	156116	1480	1911	130338	1436
1974	2533	24568	1468	716	20252	1231	301	14505	1238	249	20623	1122	92	20194	971	3908	101763	1213	1375	77195	1132
1975	3646	35116	1457	1083	30496	1176	494	24132	1100	474	38994	968	257	62784	888	5954	191522	1081	2308	156406	997
1976	4031	38856	1739	1110	31226	1434	529	25731	1295	573	47553	1215	304	74583	1044	6547	217949	1291	2516	179093	1194
1977	4018	37879	2211	1169	33183	1865	514	25019	1721	503	42734	1659	270	62608	1653	6484	201423	1802	2466	163544	1707
	5-9.9 Ha	5-9.9 Ha	5-9.9 Ha	10-19.9 Ha	10-19.9 Ha	10-19.9 Ha	20-49.9 Ha	20-49.9 Ha	20-49.9 Ha	50-99.9 Ha	50-99.9 Ha	50-99.9 Ha	> 100	> 100	> 100	ALL SIZES	ALL SIZES	ALL SIZES			
	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.			
1978	1779	12849	3067	1388	19755	2670	1304	41005	2358	520	35990	2368	295	61795	1988	5286	171394	2316	2119	138790	2196
1979	2225	15861	3906	1672	23491	3560	1299	41218	3202	553	38221	3021	273	67618	2565	6022	186409	3039	2125	147057	2862
1980	1924	13808	3905	1431	20340	3600	1154	35963	3252	438	30169	3093	231	45357	2713	5178	145637	3162	1823	111489	2990
1981	2094	14888	4006	1599	22643	3563	1323	41390	3184	542	36763	2964	293	57306	2703	5851	172990	3098	2158	135459	2921
1982	2269	16390	4286	1786	25294	3794	**1359**	**42933**	3493	**504**	**34956**	3226	**230**	**42453**	2725	6325	162026	3321	2270	120342	3090
1983	2191	15776	4525	1469	20756	4185	1287	40485	3815	531	36195	3379	239	55824	2795	5717	169036	3496	2057	132504	3266
1984	1969	14153	4511	1429	20162	4308	1054	33157	3908	414	28622	3449	194	42856	2782	5060	138950	3586	1662	104635	3321
1985	2120	15277	4618	1471	20691	4062	1169	36429	3737	400	27793	3195	205	38792	2753	5365	138982	3499	1774	103014	3220
1986	1710	12220	4374	1260	17799	3746	1014	31479	3376	388	27270	2999	202	39631	2590	4575	128399	3200	1605	98380	2955
1987	1462	10482	4746	1191	17011	4142	1002	31323	3409	414	28917	3272	241	57909	2347	4310	145642	3141	1657	118149	2855
1988	1541	11132	5577	1262	17886	5136	1082	34589	4677	420	29459	3767	259	55260	3183	4564	148326	4063	1761	119308	3760
1989	1253	9074	5846	1017	14430	5301	835	26166	4787	345	24390	4247	205	44543	3965	3655	118603	4511	1385	95099	4264

Notes

Figures in bold type represent vacant possession information only due to the confidentiality clause binding on without possession sales in England and Wales.

The number of transactions and area sold figures for 1970 relate to the 12 months ending 30 June 1970, and not to the calendar year.

Sources

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Welsh Office, "Agricultural Land Prices in Wales" Statistics, Prepared by the GSS. Annually (with quarterly updates) from 1989.

Table A.3 : Sales of Vacant Possession Land by Size in England and Wales 1969-1989

Calendar	4-19 Ha	4-19 Ha	4-19 Ha	20-39 Ha	20-39 Ha	20-39 Ha	40-59 Ha	40-59 Ha	40-59 Ha	60-119 Ha	60-119 Ha	60-119 Ha	> 120 Ha	> 120 Ha	> 120 Ha	ALL SIZES	ALL SIZES	ALL SIZES	> 20 Ha.	> 20 Ha.	> 20 Ha.
Year	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.
1969	2116	20665	624	780	22940	517	317	15541	482	317	26140	492	91	20287	550	3621	105573	533	1505	84908	511
1970	2568	25071	628	918	26592	497	394	21165	455	371	30819	469	124	23116	393	4375	126763	490	1807	101692	456
1971	2352	23364	712	846	24291	575	403	19607	581	352	29017	502	137	24578	541	4090	120857	578	1738	97493	546
1972	1882	18612	1315	677	19715	1095	275	13463	993	317	26356	1053	118	23819	1196	3269	101965	1134	1387	83353	1094
1973	2025	19866	1749	661	18788	1579	315	15435	1460	277	22555	1542	119	24503	1396	3397	101147	1542	1372	81281	1491
1974	2082	20182	1512	552	15730	1260	251	12021	1280	181	14825	1149	61	11839	941	3127	74597	1259	1045	54415	1165
1975	3041	28938	1504	852	23981	1230	379	18514	1171	346	28542	1028	155	33215	954	4773	133190	1169	1732	104252	1076
1976	3315	31700	1800	888	24839	1514	406	19616	1351	312	**26010**	1330	**146**	**35023**	1101	5140	144041	1410	1825	112341	1300
1977	3818	35814	2260	1064	30195	1928	443	21521	1808	429	35639	1763	175	39730	1676	5929	162899	1888	2111	127085	1783
	5-9.9 Ha	5-9.9 Ha	5-9.9 Ha	10-19.9 Ha	10-19.9 Ha	10-19.9 Ha	20-49.9 Ha	20-49.9 Ha	20-49.9 Ha	50-99.9 Ha	50-99.9 Ha	50-99.9 Ha	> 100	> 100	> 100	ALL SIZES	ALL SIZES	ALL SIZES			
	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.			
1978	1721	12438	3102	1303	18476	2743	1184	36996	2451	440	30219	2555	216	43016	2135	4864	141145	2473	1840	110231	2357
1979	2158	15362	3950	1611	22631	3612	1228	38923	3266	**400**	**27432**	3179	**219**	**54383**	2577	5711	166421	3126	1942	128428	2942
1980	1880	13491	3943	1390	19741	3631	1083	33615	3337	**333**	**22807**	3249	**164**	**30151**	2862	4924	126655	3304	1654	93423	3143
1981	2036	14462	4051	1544	21838	3617	1241	38792	3261	496	33450	3087	230	42084	2773	5547	150626	3213	1967	114326	3030
1982	2219	16013	4331	1732	24548	3841	1359	42933	3570	504	34956	3329	230	42453	2787	6044	160901	3428	2093	120340	3224
1983	2144	15433	4566	1430	20206	4226	1230	38652	3887	482	32807	3507	195	45344	2872	5481	152443	3617	1907	116804	3386
1984	1917	13799	4555	1385	19535	4371	1003	31348	3981	381	26259	3548	164	36269	2755	4850	127209	3664	1548	93875	3386
1985	2084	14988	4656	1437	20184	4102	1116	34623	3805	363	25121	3311	173	33686	2870	5172	128601	3610	1651	93429	3336
1986	1683	12025	4414	1034	14600	**3885**	816	25513	3597	369	25896	3035	163	31942	2817	4454	120995	3270	1737	94370	3029
1987	**1214**	**8680**	**4928**	973	13841	4332	972	30329	3453	393	27388	3350	208	49069	2338	3760	129306	3200	1573	106785	2913
1988	1530	11053	5560	1055	17714	5164	**886**	**28361**	4926	339	23743	3963	219	43563	3206	4461	135283	4161	1876	106516	3849
1989	1237	8956	5889	1003	14240	5344	816	25567	4851	327	23107	4381	184	39011	4214	3567	110880	4676	1327	87684	4444

Notes

Figures in bold type represent information pertaining to England only, due to the confidentiality clause binding on without possession sales in England and Wales.

The number of transactions and area sold figures for 1970 relate to the 12 months ending 30 June 1970, and not to the calendar year.

Sources

A.D.A.S. "Agricultural Land Prices in England and Wales" Technical Reports, 20-20/9. Annually from 1969 to 1977.

A.D.A.S. "Agricultural Land Prices in England and Wales" Booklet Series, MAFF. Annually from 1978 to 1986.

M.A.F.F. "Agricultural Land Prices in England and Wales" MAFF Statistics, Prepared by the GSS. Annually from 1987 to 1988.

M.A.F.F. "Agricultural Land Prices in England" MAFF Statistics, Prepared by the GSS. Annually (with quarterly updates) from 1989.

Welsh Office, "Agricultural Land Prices in Wales" Statistics, Prepared by the GSS. Annually (with quarterly updates) from 1989.

Table A.4 : Sales of Without Possession Land by Size in England and Wales 1969-1989

Calendar	4-19 Ha	4-19 Ha	4-19 Ha	20-39 Ha	20-39 Ha	20-39 Ha	40-59 Ha	40-59 Ha	40-59 Ha	60-119 Ha	60-119 Ha	60-119 Ha	> 120 Ha	> 120 Ha	> 120 Ha	ALL SIZES	ALL SIZES	ALL SIZES	> 20 Ha.	> 20 Ha.	> 20 Ha.
Year	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.
1969	101	1039	381	29	840	371	23	1129	301	28	2266	334	14	3951	341	195	9218	341	94	8179	336
1970	211	2181	418	106	3157	353	60	2968	311	66	5404	341	26	7380	346	469	21091	348	258	18910	340
1971	211	2163	487	86	2497	388	54	2717	363	52	3721	346	21	5364	418	424	16462	395	213	14299	381
1972	146	1480	887	85	2526	672	45	2202	623	60	5185	855	43	11448	1193	379	22841	983	233	21361	990
1973	165	1678	1292	56	1586	2162	42	2045	857	41	3390	996	35	11758	1483	349	21260	1275	184	19582	1274
1974	119	1190	1006	53	1507	951	22	1133	850	24	2045	862	11	2980	934	243	10900	919	124	9710	908
1975	172	1852	1058	79	2302	916	56	2716	779	67	5564	662	51	16335	777	430	29829	783	258	27977	765
1976	255	2586	1175	116	3316	940	69	3455	970	122	10093	888	95	24390	964	657	43840	958	402	41254	944
1977	200	2065	1352	105	2988	1226	71	3499	1183	84	7095	1138	95	22878	1611	555	38524	1442	355	36459	1447
	5-9.9 Ha	5-9.9 Ha	5-9.9 Ha	10-19.9 Ha	10-19.9 Ha	10-19.9 Ha	20-49.9 Ha	20-49.9 Ha	20-49.9 Ha	50-99.9 Ha	50-99.9 Ha	50-99.9 Ha	> 100	> 100	> 100	ALL SIZES	ALL SIZES	ALL SIZES			
	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.	No.s Sales	Area Traded	£/ha.			
1978	58	410	1993	85	1279	1617	120	4009	1500	80	5771	1390	79	18778	1651	422	30248	1584	279	28559	1577
1979	67	449	2530	61	861	2181	71	2295	2113	63	4611	1956	41	11023	2504	311	19987	2310	183	18677	2311
1980	44	318	2294	41	599	2570	71	2349	2034	45	3166	1977	43	11171	2299	254	18982	2212	169	18065	2199
1981	58	426	2495	55	805	2095	82	2598	2037	46	3313	1728	63	15221	2510	304	22364	2324	191	21133	2329
1982	50	377	2371	54	746	2255	68	2269	2149	*	*	2234	*	*	2487	281	18215	2379	177	17092	2385
1983	46	337	2733	36	507	2809	57	1833	2305	48	3318	2179	44	10480	2462	236	16593	2392	154	15749	2371
1984	52	354	2767	44	627	2343	51	1810	2643	33	2362	2354	30	6587	2933	210	11741	2735	114	10760	2757
1985	36	265	2511	34	477	2346	54	1786	2410	37	2672	2103	32	5106	1978	193	10307	2116	123	9565	2094
1986	27	195	1948	18	273	2208	33	1051	2183	19	1375	2324	18	4306	1958	120	7404	2044	75	6936	2040
1987	14	104	2034	13	209	2632	30	995	2047	21	1529	1887	33	8840	2400	111	11677	2304	84	11364	2300
1988	11	79	2409	11	172	2157	31	1069	2725	16	1231	2369	30	10240	3199	99	12791	3061	77	12540	3078
1989	16	119	2620	14	190	2018	19	599	2057	18	1283	1838	21	5531	2206	88	7722	2135	58	7413	2130

Notes

Figures in bold type represent vacant possession information only due to the confidentiality clause binding on without possession sales in England and Wales.

The number of transactions and area sold figures for 1970 relate to the 12 months ending 30 June 1970, and not to the calendar year.

An asterisk denotes there is no meaningful alternative proxy for that datum due to confidentiality binding in both England and Wales.

No tenanted sales were recorded for Wales in 1986 (except for the totals) due to the confidentiality provisions. Consequently, only English farms have been taken out of the >20 hectare series.

Sources

A.D.A.S. "Agricultural Land Prices in England and Wales" Technical Reports, 20-20/9. Annually from 1969 to 1977.

A.D.A.S. "Agricultural Land Prices in England and Wales" Booklet Series, MAFF. Annually from 1978 to 1986.

M.A.F.F. "Agricultural Land Prices in England and Wales" MAFF Statistics, Prepared by the GSS. Annually from 1987 to 1988.

M.A.F.F. "Agricultural Land Prices in England" MAFF Statistics, Prepared by the GSS. Annually (with quarterly updates) from 1989.

Welsh Office, "Agricultural Land Prices in Wales" Statistics, Prepared by the GSS. Annually (with quarterly updates) from 1989.

(c) Other Land Price Series

By far the longest time series of land prices in England and Wales is that prepared (until recently) by the Institute of Agricultural Economics at Oxford University. This series is currently published in *The Farmland Market* but originated in Britton (1949), where an annual series was calculated for the period 1918-38.[4] Ward (1958) backdated the series so that at present a continuous series from 1857 is available. A number of factors militate against its extensive use in this study, and these are now briefly discussed although for a more detailed description of its construction see Lund and Slater (1979) in addition to the articles cited above. The series is an annual weighted average of a sample of 'farms' sold at auction of between five and 300 acres in size and thus excludes all sales of land by private treaty and all sales of land not deemed to be 'farms', *i.e.* smallholdings of less than five acres, bare land, land with outline planning permission, enterprises of a specialist nature, such as hop farms and market gardens, and estates of more than one farm. In 1950 sales of land over 300 acres were included in the calculation of the series. Prior to 1970 the weighting scheme was by size of farm but switched thereafter to a weighting by region to overcome the criticism that the series primarily reflected sales in the south and centre of England. Another change in 1970 increased the 5 acre floor on eligability to 25 acres to reduce the value of farmhouses in the aggregate farmland price.

Although Britton (1949) calculated annual averages over the 1918-39 period, in Ward's (1958) study a five year rolling average was used so that the datum for 1859 represents the average of the annual prices recorded for the five years 1857 to 1861 inclusive. Ward (1958) used this rolling average to overcome annual price fluctuations that occurred due to the small sample used and hence make the detection of broad trends more identifiable for his descriptive analysis. Since 1938 the Oxford Institute series has been calculated for vacant possession sales and tenanated sales only and due to the changes in methodology incorporated in 1970 results in a discrete downward shift in the series at that date.[5]

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4 Since 1989 compilation of the series is performed by staff at Savills land agents. The series is now known as the 'Oxford Institute/Savills' series.

5 The Oxford Institute series exhibits a 22% drop in vacant possession land prices between 1969 and 1970, compared to a 6% fall in the MAFF statutory series (for England and Wales) over the same period.

The size of sample used to calculate the series that comprise the Oxford Institute Series has in the past led to some criticism. In Ward's (1958) study, 25,355 sales were used over the century which the series spans, and hence the average number of farms used in the derivation in land prices for any one year is 253, although the variance is considerable:the range being bounded by 15 sales in 1864 up to 1217 in 1918. The average number of farm used in Britton's (1949) paper was a little higher at 289, representing some 15,000 acres and in no year was the sample size allowed to fall below 150.

Table A5 presents, in nominal (current price) terms the series produced by Ward, Britton and the Oxford Institute continuation of the auction price series. In the final column of Table A5 a hybrid time series has been constructed so to obtain a long historical series of land prices in England and Wales. In it Ward's (1958) 'all farms' series has been spliced with Britton's (1949) and the Oxford Institute/Savills 'vacant possession' series. Whilst each series is derived from samples of auction sales only, the caveats highlighted above regarding the reliability of the series should be bourne in mind. Note however that the premium for vacant possession land was of minor significance before the second world war and hence the switch from sales of all farms to vacant possession does not give rise to concern - the sampling bias being probably far more distortionary anyway.[6]

In the empirical analysis a constant (1990) price version of the hybrid series is used. As with all the other series the deflator used is the Gross Domestic Product price index. The constant price hybrid series is called, *PX*.

6 In 1938 Britton's (1949) observation of all farms price is £68 per hectare compared to the price of £65 recorded for vacant possession farms by the Oxford Instite/Savills series.

Table A.5: The Oxford Institute/Savills and Related Land Price Series (Nominal Terms) 1859-1990

		Ward (1958)		Britton (1949)		Oxford Institute Series		Spliced
	£ per acre	£ per acre	£ per acre	£ per acre	£ per ha.	£ per ha.	£ per ha.	£ per ha.
	All Farms	V.P.	W.P.	All Farms	All Farms	V.P.	W.P.	All/V.P.
1859	39							96
1860	40							99
1861	39							96
1862	39							96
1863	38							94
1864	37							91
1865	38							94
1866	39							96
1867	41							101
1868	41							101
1869	44							109
1870	44							109
1871	48							119
1872	49							121
1873	52							128
1874	53							131
1875	54							133
1876	52							128
1877	51							126
1878	49							121
1879	45							111
1880	43							106
1881	38							94
1882	38							94
1883	35							86
1884	33							82
1885	31							77
1886	31							77
1887	27							67
1888	26							64
1889	27							67
1890	25							62
1891	24							59
1892	21							52
1893	20							49
1894	19							47
1895	19							47
1896	19							47
1897	20							49
1898	20							49
1899	20							49
1900	20							49
1901	20							49
1902	20							49
1903	20							49
1904	20							49
1905	21							52
1906	20							49
1907	21							52
1908	21							52

1909	22							54
1910	22							54
1911	24							59
1912	24							59
1913	23							57
1914	23							57
1915	23							57
1916	24							59
1917	25							62
1918	27			29.6	73			73
1919	28			30.2	75			75
1920	28			35.1	87			87
1921	29			28.6	71			71
1922	29			28.7	71			71
1923	28			30.3	75			75
1924	28			30.6	76			76
1925	28			30.9	76			76
1926	27			28.9	71			71
1927	25			27.6	68			68
1928	24			27.4	68			68
1929	23			21.3	53			53
1930	21			22.4	55			55
1931	20			23.6	58			58
1932	22			22.8	56			56
1933	22			24.8	61			61
1934	23			27.1	67			67
1935	24			24.7	61			61
1936	25			27.3	67			67
1937	24			27.3	67			67
1938	25			27.6	68	65	47	65
1939		29	21	25.8	64	62	47	62
1940		31	22			77	47	77
1941		36	24			91	67	91
1942		40	26			91	62	91
1943		42	28			116	67	116
1944		47	28			111	72	111
1945		53	30			111	72	111
1946		60	33			146	77	146
1947		66	35			173	84	173
1948		73	38			195	106	195
1949		79	40			188	94	188
1950		80	40			198	96	198
1951		79	39			217	109	217
1952		78	39			188	94	188
1953		78	42			180	86	180
1954		76	43			185	101	185
1955		76	43			198	128	198
1956		77	45			193	114	193
1957		78	48			180	94	180
1958		78	45			210	121	210
1959						250	168	250
1960						304	131	304
1961						306	180	306
1962						331	188	331
1963						415	287	415

1964						529	319	529
1965						581	368	581
1966						598	353	598
1967						638	n.a	638
1968						692	n.a	692
1969						739	n.a	739
1970						605	n.a	605
1971						647	544	647
1972						1473	1317	1473
1973						1871	1240	1871
1974						1572	n.a.	1572
1975						1332	n.a.	1332
1976						1814	951	1814
1977						2449	1208	2449
1978						3279	2039	3279
1979						4371	2723	4371
1980						4265	n.a.	4265
1981						4272	n.a.	4272
1982						4557	n.a.	4557
1983						5145	n.a.	5145
1984						4888	n.a.	4888
1985						4781	n.a.	4781
1986						4193	n.a.	4193
1987						4944	n.a.	4944
1988						6716	n.a.	6716
1989						6558	n.a.	6558
1990						6346	n.a.	6346

Sources: Ward (1958), Britton (1949) The Farmland Market (1991)

Notes to Table A.5

In 1970 major changes to the construction of the Oxford Institute series took place, resulting in a discrete downward shift in the series. See Maunder (1973) 'The Search for a More Accurate Average Price for Land' *The Farmland Market* no.3.

Entries denoted "n.a." mean that insufficient sales were recorded in that year to present an average price without breaching the confidentiality of sales.

In summary, whilst the Oxford Institute series has the definite advantage of longevity it suffers from a number of drawbacks relating to the relatively small nature of the sample: specifically, the biased composition of sales (by region and type of sale) and the actual number of sales used in some years. Writing prior to the 1970 changes in methodology, Harvey (1974) goes as far as suggesting that due to the non-random nature and size of the sample the Oxford Institute series may not even present an accurate reflection of the auction market for farmland let alone the market as a whole (p.15), and dismisses the series as unreliable, despite concluding,

> ". . . as far as trends and turning points are concerned, there is little to choose between the Ministry and Oxford price series . . . " (p.17)

(d) A Brief Comparison of the Oxford Institute/Savills and MAFF series

Let us now breifly assess the effects of these drawbacks by comparing the similarity of the Oxford Institute and MAFF series over the period for which statistics on both series are available.[7] Visual inspection of Figure A.1 suggests that despite the criticisms directed at the Oxford Institute series there is a very good correspondence between the two series expressed in real terms. Whilst the Institute series is persistently higher, trends and turning points are common to both series.[8] Furthermore, using a logarithmic scale Figure A.2 suggests that *proportional* changes in the two series are also similar. We may pursue this further by regressing the MAFF series on the Oxford Institute series, over the period for which both series are available, 1945 - 89. Using MAFF's average land price series P_t , and PX_t yields the equation,

$$P_t = \underset{(2.54)}{240.33} + \underset{(33.60)}{0.644} PX_t \qquad R^2 = 0.96$$

(t - ratios in parenthesis).

Calculating the elasticity at the mean values yields a coefficient of 0.92 implying that a 1% change in the Oxford Instiutre series is matched by a 0.92% change in the MAFF series.

7 The MAFF series used here is that denoted by the land price series 'P20' on page A4.

8 Due to the fact that the Oxford Instiute series is based on information pertaining to the actual date of sale, the similarity between the two series suggests that the MAFF series reflects more accurately the market nine months previously - the series being adjusted on that basis here.

Figure A.1: The Oxford Institute /Savills, (PX_t) and MAFF Land Price Series for England and Wales at 1989 prices, (P_t) (GDP Deflator)

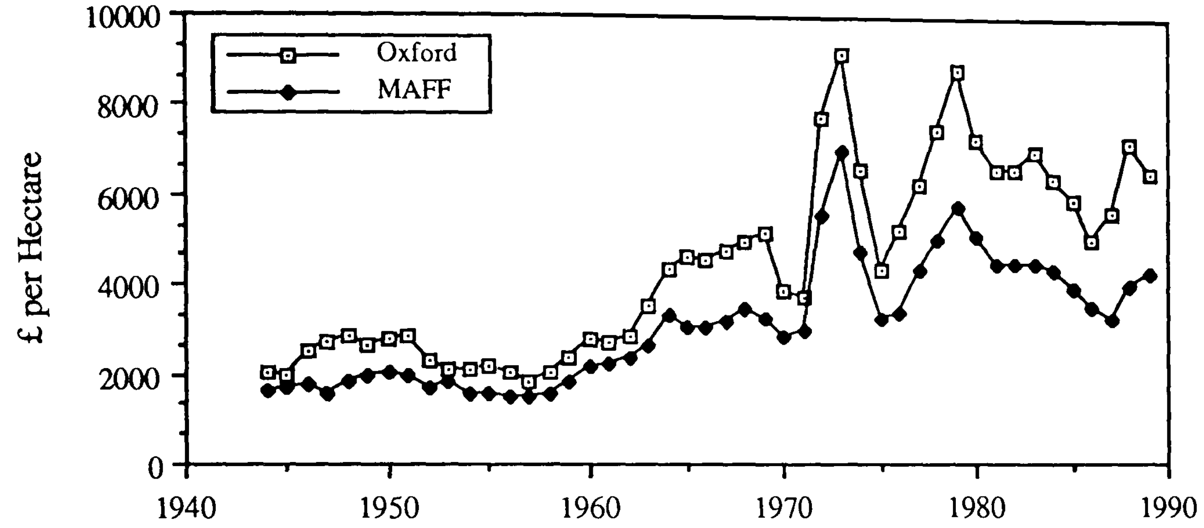
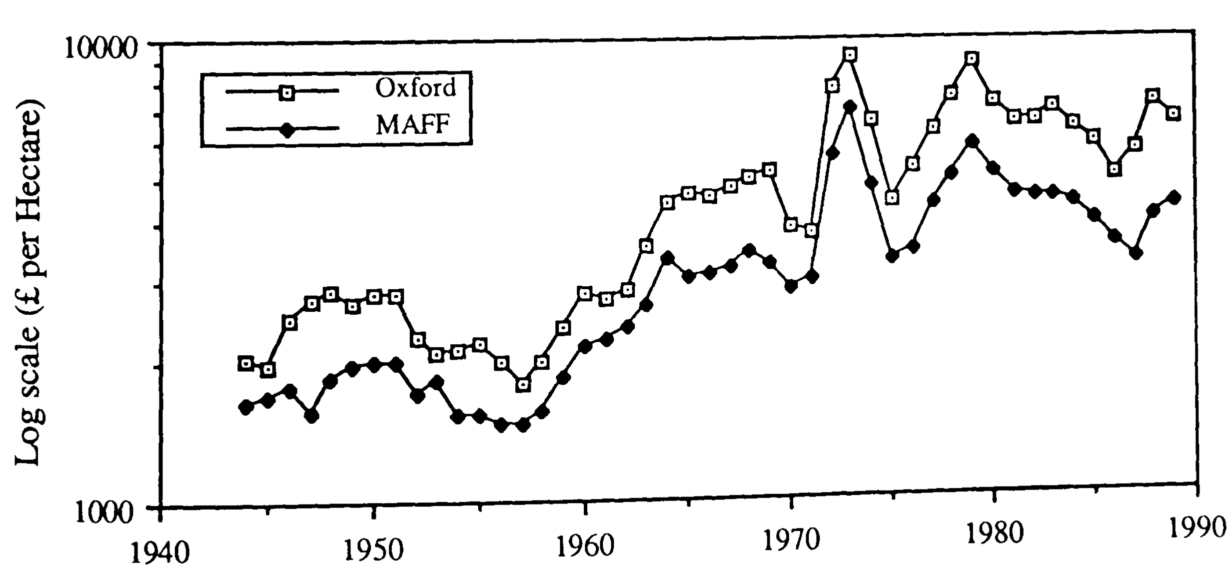


Figure A2: The Oxford Institute/Savills, (PX_t) and MAFF Land Price Series for England and Wales at 1989 prices (P_t) using a log scale (GDP Deflator)



Clearly, where the elasticity is unity both series change in identical proportions, implying that both series reflect movements in the land market equally well. Transformation of the two series into logarithms allows us to test statistically the unit elasticity hypothesis. Regressing the log of the MAFF series on the log of the Oxford series yields,

$$\log P_t = \underset{(2.66)}{0.557} + \underset{(35.43)}{0.892} \log PX_t \qquad R^2 = 0.97$$

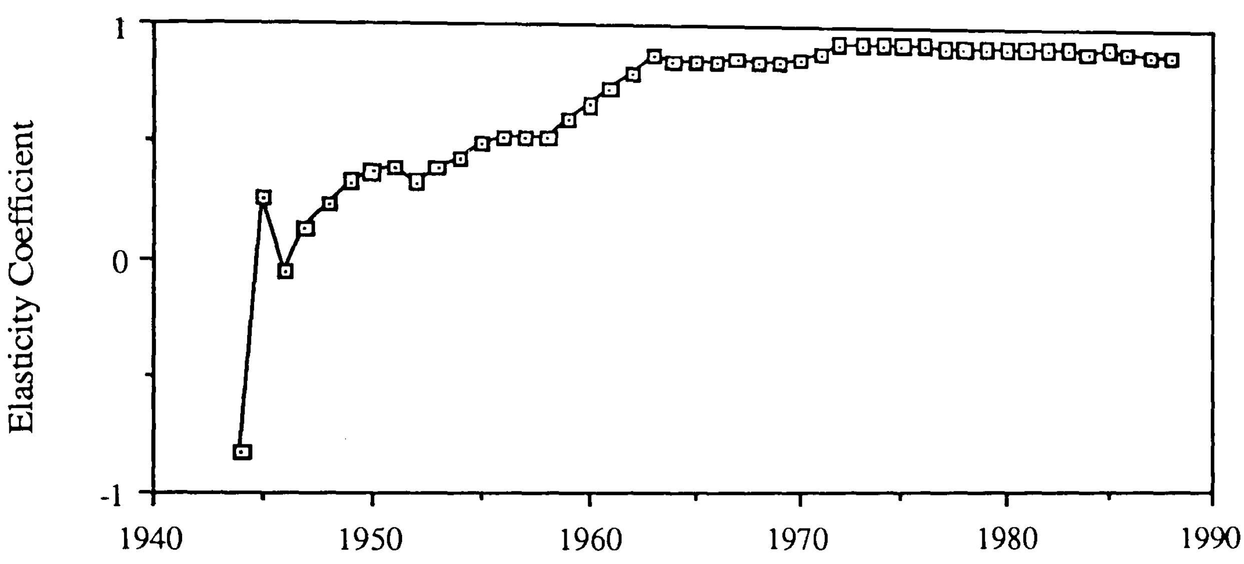
(t - ratios in parenthesis)

where the coefficient 0.892 is an estimate of the elasticity between the Oxford and MAFF series. Under the null hypothesis of unit elasticity we obtain a t ratio of - 4.29, which leads us to reject the null at the 1% significance level. This result suggests that the Oxford Institute series is more responsive than the statutory series in that the proportionate change in the Oxford series is greater than portrayed in the MAFF series in any time period. This result is interesting because it is actually what one may expect *a priori* : not only do auction sales tend to respond more vigorously to speculative expectations but they exclude sales by private treaty - some of which occur at prices generally perceived to be below that ruling in the market, such as sales between relatives.

The results from estimation of the elasticity coefficent by recursive methods is depicted in Figure A.3. This time series plot of recursive elasticities suggests that after allowance is made for the small sample size initially, the relationship between the two land price series has remained stable, a result confirmed by a Chow test for parameter constancy. This has important implications for it indicates that despite the non-random nature of the Oxford Instiute sample of land sales it appears to be behaving in much the same way as the Ministry's statutory series.

To summarise this comparison it can be stated that the Oxford Institute series is persistently higher and is more volatile than the Ministry's statutory series during the sample period. Because there is evidence to suggest that the relationship between the two series has remained stable over time the non-random nature of the Oxford Institute sample is only important in respect to the absolute level of average land prices and does not imply that auction sales respond in a qualitatively different way to land sales in general. Consequently, there appear to be no empirical grounds for dismissing the Oxford Institute series on the basis of the reliability of the sample with the implication that the choice of the most appropriate series rests solely on which series most accurately reflects the 'true' absolute pricelevel of land sold in England and Wales and the purpose to which the series is to be put.

Figure A.3 : Recursive Estimation of the Elasticity Coefficient Between The Oxford Institute (PX_t) and MAFF Land Price Series (P_t)



Whilst the statutory series has traditionally been perceived as more representative of the absolute level of farmland prices, clearly, a case could be argued to the contrary. Recalling that the MAFF series includes sales by private treaty, some of which may bear little relation to market forces, the series may well incorporate a significant downward bias. In the final analysis neither series may be ideal, yet both are as good as each other in depicting the state of the market for agricultural land.

A.(ii) Agricultural Rent series in England and Wales

(a) Official Rent Series

The regular collection of comprehensive information on farm rents began in 1960 with the first of the annual Rent Enquiries undertaken by MAFF (Economics Division) and the Agricultural Land Service[9] (ALS). Initially, summary information from each annual enquiry was published by MAFF starting in 1961. However, in 1969 a separate report of a detailed breakdown of the results was published and has continued in various guises ever since.[10] Prior to 1972, information on rents was recorded on an estate basis but thereafter on a farm basis, which enabled a more informative breakdown of basic data provided. The annual Rent Enquiry bases its figures on information provided voluntarily by respondents, covering an area of one million hectares, which represents about 25% of the total tenanted area in England and Wales which itself is about one-third of the total agricultural area. Whilst the coverage in terms of area has declined from 1.4 million hectares in 1959 to 900,000 hectares in 1989 the proportion of the area tenanted has remained constant at around 25% due to a decline in the area of tenanted farms over the period. Due to the unequal coverage of farms in the sample, average rent figures are derived on a weighted basis according to the tenanted area in each county and area size group indicated by the June census.

The Rent Enquiry's primary aim has been to establish the average rent of all farms in the sample and also its annual rate of change. However, because of the historical precedent of tri-annual rent changes (which has subsequently entered into tenure Law) only one-third of farms sampled in any year will have had a rent change in that year.

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9 In 1974 the ALS was replaced by the Agricultural Development and Advisory Service (ADAS).

10 The summary information of Rent Enquiry results continued to be published in MAFF's journal *Agriculture* until 1968. In 1969 this was superceded by detailed analyses of the rent data in a series of annual Technical reports {19, 19/1, 19/2, 19/3, 19/4} published by the ALS. From 1974 the technical reports were produced by ADAS and continued until 1977 {as Technical Reports 19/5, 19/6, 19/7 and 19/8}. From 1978 to 1986 ADAS continued to publish the farm enquiry results in a booklet series {SFR21, SFR22, Booklets B2319(79), 2319(80), 2319(81), 2319(82), 2319(83), 2319(84), 2319(85)} until 1986. In 1987 MAFF took over the publication of the annual Rent Enquiry for England and Wales however in 1989 this became the responsibility of MAFF for the English statistics and the Welsh Office for Welsh Statistics. This format continues to the present, with the result that England and Wales combined statistics have not been published since the 1987 Enquiry published in 1988. These have been derived to keep a long historical time series, as described in the text.

Consequently, two raw rents series exist; average rents for all farms in the sample and average rents on the subset of farms which have had a rent increase in the last twelve months. This allows a distinction to be made between the rate of change of rent levels over the entire sample and that pertaining to the subset that has actually undergone a rent change in the last year.

Due to fact that the composition of the sample is not constant over time, each respondent is asked for the level of rent at October in year t and also for the rent prevailing in October t-1. Consequently, the average rent recorded for, say 1990, will represent the arithmetic mean of average rent in the 1990 sample and the average rent recorded for October t-1 in the 1991 sample. It should be noted however that due to the large sample size the difference between the two estimates is negligible. Rents are then put on a calendarised basis using a simple weighting scheme so that rent for the calendar year 1990 is derived by taking 0.74 of the rent recorded for October 1989 and 0.26 of the rent recorded for October 1990. This interpolation procedure is based on information on term dates collected in the 1975 Rent Enquiry and on the assumption that rents are normally paid half yearly in arrears.

Although changes to the questionaire have taken place over the years, rents are recorded by county, region and country, across size group and land quality, however due to the changes in the local authority boundaries in 1972, use of dissagregated data is not possible in time series analysis.

In 1987 the structure of the Enquiry was altered slighlty to improve the quality of inference. Specifically, the category, 'farms with a rent change' was replaced by 'farm due a rent review' thus account is taken of farms where a reivew has taken place but which did not result in a change in the level of rent. Consequently, inferences based on the information from this subgroup now more accurately reflect the state of the rental market (particularly in recession) existing at a particular time; previously rental growth being exaggerated in periods of recession.

In 1989 England and Wales aggregate statistics were no longer published, so that MAFF produced the English results and all counties therein and the Welsh Office published rents for Wales and the Welsh counties. As the terms of reference for this study is England and Wales combined, recent statistics for rents have been combined from these two separate sources according to a weighting scheme estimated by OLS as,

$$R_{EW_t} = 0.87R_{E_t} + 0.13R_{w_t}.$$

where R_{EW_t} is the average rent at mid-October in year t for England and Wales combined; R_{E_t} is the average rent at mid-October in England in year t and R_{w_t} the average rent at mid-October in Wales in year t.

As alluded to above however this average rent series does not convey the most pertinent information regarding the state of the rental market as it includes farms for which rent has not increased. Consequently, another series is constructed using only those farms for which there has been a rent review in the last year (or rent increase prior to 1987). For this series a similar weighting scheme to that shown above is applied to obtain a calendar year based series however, estimates of rents for the England and Wales aggregate from English and Welsh averages are based on a weighting scheme obtained by OLS of the following form,

$$R_{EW_t} = 0.87R_{E_t} + 0.13R_{w_t}$$

A summary of the nominal cash rent series for the England and Wales aggregate derived from the annual Rent Enquiry is contained in Table A.6. The series in that table are defined as follows:

R_{1_t} : Nominal average cash rents for tenanted farms in England and Wales at mid-October of year t, (£/ha.). Each figure is the mean of the two sample observations for rents in that year. From 1987 figures are estimated from English and Welsh averages according to the weighting,
$R_{1_t} = 0.87R_{E_t} + 0.13R_{w_t}$.

R_{2_t} : Calendarised version of R_{1_t} using the weighting scheme,
$R_{2_t} = 0.74R_{1_{t-1}} + 0.26R_{1_t}$.

R_{3_t} :Nominal average cash rents for tenanted farms in England and Wales at mid-October of year t, that have had a rent increase in the last year (£/ha.). Each figure is the mean of the two sample observations for rents in that year. From 1987 figures are estimated from English and Welsh averages according to the weighting, $R_{1_t} = 0.91R_{E_t} + 0.10R_{w_t}$.

R_{4_t} : Calendarised version of R_{3_t} using the weighting scheme,
$R_{4_t} = 0.74R_{3_{t-1}} + 0.26R_{3_t}$.

Table A.6 : Nominal Average Rents in England and Wales 1960-1989

	A	B	C	D	E
1	Year	R1	R2	R3	R4
2	1960	6.18	n.a.	n.a.	n.a
3	1961	6.92	6.37	n.a.	n.a
4	1962	7.72	7.13	n.a.	n.a
5	1963	8.52	7.93	n.a.	n.a
6	1964	8.96	8.63	9.51	n.a.
7	1965	9.20	9.02	10.75	9.83
8	1966	10.07	9.43	11.74	11.01
9	1967	10.25	10.12	12.23	11.87
10	1968	11.00	10.45	12.97	12.42
11	1969	11.96	11.25	14.21	13.29
12	1970	13.20	12.28	15.10	14.44
13	1971	14.31	13.48	15.79	15.28
14	1972	15.22	14.54	17.22	16.16
15	1973	16.19	15.47	19.05	17.70
16	1974	18.31	16.74	20.31	19.38
17	1975	22.29	19.34	24.56	21.42
18	1976	28.32	23.86	30.71	26.16
19	1977	34.00	29.80	37.85	32.57
20	1978	41.49	35.95	46.55	40.11
21	1979	47.79	43.13	54.32	48.57
22	1980	53.37	49.24	60.10	55.82
23	1981	61.01	55.36	68.16	62.20
24	1982	68.67	63.00	77.05	70.47
25	1983	75.96	70.56	86.23	79.44
26	1984	84.88	78.28	91.10	87.50
27	1985	89.35	86.04	93.49	91.72
28	1986	90.98	89.78	93.56	93.51
29	1987	91.60	91.14	96.89	94.43
30	1988	92.12	91.73	96.89	96.89
31	1989	93.89	92.58	97.47	96.78
32	1990	96.26	94.51	102.43	98.76

(b) Other Post War Cash Rent Series

Since the Second World War there have been a number of studies undertaken which furnish estimates of cash rents. The Central Landowners Association (later the Country Landowners Association) in collaboration with the Ministry of Agriculture conducted an investigation into landowner expenses and rents along similar lines to the ALS Rent Enquiry for the years 1947, 1950 and 1951 from a sample of around 300 estates covering some 700,000 hectares. Denman and Stewart (1959) also report average rents from a sample of landowners for the years 1945 - 1958. Both of these sources have limited appeal for the purposes of time series analysis although a longer cash rent series can be derived from the annual Farm Management Survey results. The FMS rent figures cover both owner-occupied and tenanted farms; the rent for owner-occupied farms being imputed on the basis of rents paid for tenated farms in the locality. However, the sample is small, covering only some 0.02% of the total agricultural area in England and Wales and is thus not ideal for statistical purposes. A more reliable source of rents has been derived by Harvey (1974) using information from the ALS Enquiries and a similar survey of agricultural landowners in Scotland. Although the correspondence between the FMS series and this derived series is very close (see Harvey (1974, p.208) the latter series is that chosen by Harvey (1974) in his empirical analysis for the year 1946 to 1959 due to the fact that its coverage is larger. The series measures rents prevailing at October in each year and will be spliced with the R_{1_t} series to give a time series on average rents on tenanted farms from 1946 to 1990. This spliced series, R_{5_t} is presented in Table A.7, with a calendarised version, R_{6_t} derived using the same weighting scheme as used for the other calendar year series R_{2_t} and R_{4_t}.

In order to extend the series of farms with a change in rent (R_{3_t} and R_{4_t}) back to the end of the Second World War, a series has been estimated from the relationship between the average rent on all farms and the subset of farms with a rent change in the previous year from the period in which both series are available, namely 1964 - 90. Over that period OLS estimates a relationship of the form, $R_{3_t} = 1.06R_{1_t}$. Using this relationship an estimate of rent on farms with a rent change may be produced for the years 1946 to 1963, which is appended to the series R_{3_t}. Whilst this expedient is not wholly satisfactory, it is widely accepted that rents changed very slowly during most of the 1946-63 period because the rent arbitration legislation in operation at this time (and discussed in Chapter II) deterred landowners from negotiating market rents on land with a sitting tenant. In 1958 a change in the legislation rectified this retardation of rents although the response was distributed over a number of years due to the tri-annual review procedure. Consequently, we do not expect that the use of estimates over this period to adversely bias the accuracy of the series in a significant way. The resulting series denoted, R_{7_t} is presented in Table A.7, with a calendarised version of it R_{8_t} being calculated using the same weighting scheme as the other calendar year based series.

In the emprical analysis the rent series are deflated by the Gross Domestic Product price index. There are two constant price series for farm rents that are used in the emprical analysis over the post World War II period. These are R_t and RN_t which correspond to the nominal rent series R_{6t} and R_{8t} respectively.These two series are defined as follows,

R_t :Average rent paid on tenanted land in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1946 to 1990.

RN_t :Average rent paid on tenanted farms that have undergone a rent increase in the past year in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1946 to 1990.

Table A.7 : Nominal Cash Rent Series 1946 - 1990

	A	B	C	D	E
1	Year	R5	R6	R7	R8
2	1946	3.52	-	3.73	-
3	1947	3.59	3.54	3.80	3.75
4	1948	3.74	3.63	3.96	3.85
5	1949	3.88	3.77	4.11	4.00
6	1950	4.02	3.92	4.26	4.15
7	1951	4.21	4.07	4.47	4.31
8	1952	4.39	4.26	4.65	4.51
9	1953	4.56	4.43	4.83	4.70
10	1954	4.72	4.60	5.00	4.88
11	1955	4.85	4.76	5.15	5.04
12	1956	5.03	4.90	5.33	5.20
13	1957	5.24	5.09	5.56	5.39
14	1958	5.50	5.31	5.83	5.63
15	1959	5.85	5.59	6.20	5.93
16	1960	5.81	5.84	6.16	6.19
17	1961	6.55	6.00	6.94	6.36
18	1962	7.12	6.70	7.55	7.10
19	1963	7.73	7.28	8.19	7.72
20	1964	8.15	7.84	9.51	8.54
21	1965	8.77	8.31	10.75	9.83
22	1966	9.46	8.95	11.74	11.01
23	1967	10.25	9.67	12.23	11.87
24	1968	11.00	10.45	12.97	12.42
25	1969	11.96	11.25	14.21	13.29
26	1970	13.20	12.28	15.10	14.44
27	1971	14.31	13.48	15.79	15.28
28	1972	15.22	14.54	17.22	16.16
29	1973	16.19	15.47	19.05	17.70
30	1974	18.31	16.74	20.31	19.38
31	1975	22.32	19.35	24.56	21.42
32	1976	26.93	23.52	30.71	26.16
33	1977	32.18	28.30	37.85	32.57
34	1978	38.22	33.75	46.55	40.11
35	1979	45.39	40.08	54.32	48.57
36	1980	53.37	47.47	60.10	55.82
37	1981	61.01	55.36	68.16	62.20
38	1982	68.67	63.00	77.05	70.47
39	1983	75.96	70.56	86.23	79.44
40	1984	84.88	78.28	91.10	87.50
41	1985	89.35	86.04	93.49	91.72
42	1986	90.98	89.78	93.56	93.51
43	1987	91.60	91.14	96.89	94.43
44	1988	92.12	91.74	96.54	96.80
45	1988	93.89	92.58	97.47	96.78
46	1988	96.26	94.51	102.43	98.76

(c) Historical Rent Series

Whilst a single long and continuous rent source does not exist as it does for land price, an index of rents has been derived by Rhee and published in the Central Landowners Association (1949). The index is based on a large number of different surveys most of which were conducted by private researchers. The area of land included in each survey is generally very small indeed, often reflecting market conditions in a paritcular county or Family Estate. Exceptions to this are notable, including the work of R.J. Thompson (1907) spanning 1872-33 and the Royal Commission on Agriculture (1896) spanning 1872-1892. A detailed review of the construction of this index made be found in Central Landowners Association (1949) however a few points deserve mention here as the index will be converted into £/ha terms and used in statistical analysis later. Rhee stresses a number of caveats to be borne in mind when interpreting the index, namely that it includes gardens over 1 acre in size and that it is a measure of gross rent payable under a lease and not the cash rent paid after the deduction of abatements and temporary remissions. Furthermore, in addition to tenanted land the rent assessment in each year includes a notional allowance for owner-occupied land. Consequently, the index measures gross income accruing to landowners, and not the net pecuniary benfits of ownership. Although this is consistent with more recent rent series the dramatic changes in taxation over this period play an important distortionary role, not present to such the same degree in later years.[11] Given that this index is the only measure of rents avaliable prior to the more comprehensive and consistent series discussed earlier, the usefulness of this series to this study remains an empirical question.

The base year in Rhee's study was 1872 in which average rent is estimated as £3.45 per hectare. From this base the index is converted into nominal monetary units over the period 1870 to 1936 and calendarised using the weighting scheme described above. This series is then appended with rents estimated from the Farm Management Survey data for the years spanning 1937 to 1945 yielding a continuous rent series of 120 observations over the 1870 to 1989 period.This Series, denoted R_{9_t} is presented in Table A.8. Using the Gross Domestic Product deflator $R_{9_t}$is revalued at constant 1990 prices and it is this series that will be used in the empirical analysis

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11 For example the standard rate of taxation over the period of Rhee's study rose from 2.5% to 50%. See page 52 of the Central Landowners Association (1949) for further details.

Table A.8 : Calendar Year Average Rents in England and Wales in Nominal Terms (1871-1990)

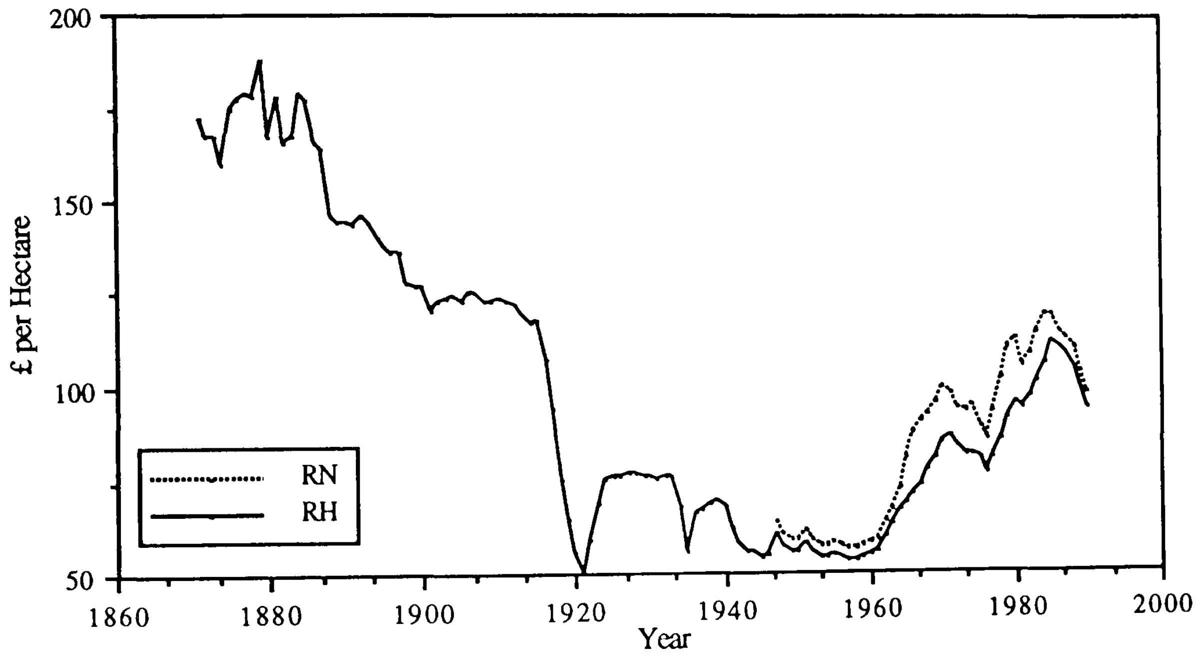
	A	B	C	D	E	F
1	Year	R9	Year	R9	Year	R9
2	1871	3.29	1911	2.56	1951	4.07
3	1872	3.38	1912	2.57	1952	4.26
4	1873	3.64	1913	2.59	1953	4.43
5	1874	3.67	1914	2.57	1954	4.60
6	1875	3.68	1915	2.60	1955	4.76
7	1876	3.69	1916	2.63	1956	4.90
8	1877	3.68	1917	2.63	1957	5.09
9	1878	3.68	1918	2.65	1958	5.31
10	1879	3.54	1919	2.71	1959	5.59
11	1880	3.28	1920	2.76	1960	5.84
12	1881	3.23	1921	2.93	1961	6.00
13	1882	3.18	1922	3.16	1962	6.70
14	1883	3.30	1923	3.08	1963	7.28
15	1884	3.29	1924	3.08	1964	7.84
16	1885	3.14	1925	3.08	1965	8.31
17	1886	2.92	1926	3.08	1966	8.95
18	1887	2.91	1927	3.07	1967	9.67
19	1888	2.76	1928	3.02	1968	10.45
20	1889	2.85	1929	2.94	1969	11.25
21	1890	2.86	1930	2.93	1970	12.28
22	1891	2.84	1931	2.90	1971	13.48
23	1892	2.80	1932	2.84	1972	14.54
24	1893	2.71	1933	2.73	1973	15.47
25	1894	2.71	1934	2.42	1974	16.74
26	1895	2.63	1935	1.97	1975	19.35
27	1896	2.61	1936	2.35	1976	23.52
28	1897	2.56	1937	2.39	1977	28.30
29	1898	2.55	1938	2.55	1978	33.75
30	1899	2.51	1939	2.66	1979	40.08
31	1900	2.47	1940	2.66	1980	47.47
32	1901	2.51	1941	2.65	1981	55.36
33	1902	2.54	1942	2.70	1982	63.00
34	1903	2.50	1943	2.77	1983	70.56
35	1904	2.51	1944	2.87	1984	78.28
36	1905	2.47	1945	2.99	1985	86.04
37	1906	2.53	1946	3.12	1986	89.78
38	1907	2.56	1947	3.54	1987	91.14
39	1908	2.56	1948	3.63	1988	91.74
40	1909	2.56	1949	3.77	1989	92.58
41	1910	2.56	1950	3.92	1990	94.51

The series is defined as follows:

RH_t :Average rent of agricultural land in England and Wales (£/ha.) expressed at constant 1990 prices for the calendar years 1871 to 1990.

The series RN_t and RH_t are plotted in Figure A.4.

Figure A.4 : Time Series of Real Rents (1990 prices) in England and Wales



A.(iii) The Price Deflator

In order to remove the effect of general price inflation from the value-based series used here, all series are deflated by an index of the implied Gross Domestic Product (GDP) deflator which is a 'Paasche' or current weighted index measured at factor cost using the expenditure method. Inflation is calculated as,

$$\frac{GDP_{tc}}{GDP_{tk}}$$

expressed as a percentage change on the previous year, where, subscripts t, c, and k represent the year, current prices and constant (base year) prices. This measure of inflation has certain advantages over other deflators in that it may be calculated consistently since 1856 and is more representative of the general price trend of all goods and services rather than a relatively small basket of consumer items as is used to construct the Retail Price Index. Table A.9 contains the percentage inflation rate obtained using the GDP deflator from 1856 to 1989 and the index used to deflate the value based series used here. See Table A.9 and the references or details of the sources used to derive the GDP deflator.

Table A.9: The Implied Gross Domestic Product Deflator and Index at 1990 prices

	1	2	3	4	5	6	7	8	9	10	11	12
1	Year	Inflation	Index	Year	Inflation	Index	Year	Inflation	Index	Year	Inflation	Index
2	1990	9.3	1	1955	3.9	12.14	1920	20.5	18.43	1885	0	61.66
3	1989	7.2	1.09	1954	1.8	12.61	1919	17.7	22.21	1884	-3.6	61.66
4	1988	6.4	1.17	1953	3.3	12.84	1918	18.7	26.14	1883	-6.7	59.44
5	1987	5.2	1.25	1952	7.6	13.26	1917	26.4	31.03	1882	2.4	55.46
6	1986	2.6	1.31	1951	9.1	14.27	1916	14.1	39.22	1881	6.1	56.79
7	1985	5.9	1.35	1950	0.2	15.57	1915	10.8	44.75	1880	-7.3	60.26
8	1984	4.8	1.43	1949	2.9	15.60	1914	0.7	49.59	1879	3.8	55.86
9	1983	5.7	1.49	1948	7.1	16.05	1913	0.8	49.93	1878	-8.8	57.98
10	1982	7.1	1.58	1947	9	17.19	1912	3	50.33	1877	0.5	52.88
11	1981	10.1	1.69	1946	3.2	18.74	1911	1.5	51.84	1876	-1.5	53.14
12	1980	18.8	1.86	1945	3	19.33	1910	0.3	52.62	1875	-0.8	52.35
13	1979	12.8	2.21	1944	6	19.91	1909	-0.4	52.78	1874	-8.3	51.93
14	1978	12.1	2.49	1943	4.5	21.11	1908	0	52.57	1873	5.6	47.62
15	1977	12.3	2.80	1942	7.2	22.06	1907	1.9	52.57	1872	7.7	50.28
16	1976	14.4	3.14	1941	9	23.65	1906	0.5	53.57	1871	5.6	54.15
17	1975	27.4	3.59	1940	8.6	25.78	1905	0.6	53.83	1870	-0.8	57.19
18	1974	16.8	4.58	1939	2.5	27.99	1904	0	54.16	1869	1.2	56.73
19	1973	7.9	5.35	1938	2.7	28.69	1903	-0.3	54.16	1868	-3.3	57.41
20	1972	10.2	5.77	1937	3.8	29.47	1902	-1.9	53.99	1867	-1.8	55.52
21	1971	11	6.36	1936	0.5	30.59	1901	-0.7	52.97	1866	1.7	54.52
22	1970	7.7	7.06	1935	1	30.74	1900	6.6	52.60	1865	-1.1	55.44
23	1969	3.6	7.60	1934	-0.9	31.05	1899	-1.5	56.07	1864	1.8	54.83
24	1968	3.2	7.87	1933	-1.3	30.77	1898	-0.6	55.23	1863	-0.5	55.82
25	1967	2.8	8.12	1932	-3.6	30.37	1897	5.8	54.90	1862	2.3	55.54
26	1966	4.1	8.35	1931	-2.4	29.27	1896	-1.9	58.08	1861	0.8	56.82
27	1965	4.1	8.69	1930	-0.4	28.57	1895	0.6	56.98	1860	4.3	57.27
28	1964	3.1	9.05	1929	-0.4	28.46	1894	-0.9	57.32	1859	-2.8	59.74
29	1963	2	9.33	1928	-1	28.34	1893	2.6	56.80	1858	0.4	58.06
30	1962	3.2	9.52	1927	-2.4	28.06	1892	-2.5	58.28	1857	-3.2	58.30
31	1961	3.3	9.82	1926	-1.5	27.39	1891	-3.1	56.82	1856	0.3	56.43
32	1960	1.8	10.15	1925	0.3	26.98	1890	0	55.06	1855		56.60
33	1959	1.7	10.33	1924	-1.4	27.06	1889	0.7	55.06			
34	1958	4.6	10.50	1923	-8	26.68	1888	4.5	55.45			
35	1957	4.1	10.99	1922	-16	24.54	1887	6	57.94			
36	1956	6.1	11.44	1921	-10.6	20.62	1886	0.4	61.42			

Sources : For 1855-1900 see Mitchell (1988), 1901-1986 see Parkin and Bade, and 1987-1990 see Economic Trends.

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