Market Efficiency and the Role of Information: An Experimental Analysis.

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

The purpose of this research is to gain additional insight concerning the highly efficient market outcomes generated under the rules of trade of the double auction, in which traders have the dual role of both buyer and seller and can simultaneously call out offers to buy and sell. It is conjectured that the experimental literature's robust results detailing the efficiency of the double auction institution may be a product of the constant and known duration of trade incorporated in previous experimental designs. In one of the few relevant theoretical discussions Friedman (1984, p.71) suggests that the predetermined, known time at which trade will cease is one of a number of institutional features of experimental double auction markets that enhance the efficiency of observed market outcomes. Known trading duration may well be a key variable in the determination of the price formation process and the convergence to competitive equilibrium in the double auction institution. This study extends previous work by conducting a series of experiments designed to determine the importance of trading duration on the convergence tendencies of experimental asset markets governed by the rules of the double auction institution. The issue is of substantive theoretical and practical interest.

The results of this study offer a number of conclusions. Aggregated across the eighteen experimental asset markets studied, transaction prices tend to exhibit convergence to competitive outcomes. Importantly, the effect of known period duration on observed market behaviour is significant. Experimental asset markets that incorporate uncertain trading durations display more aggressive trading strategies. This is evidenced by an increase in the rate of trade relative to markets where the duration of trade varies but is known. The markets with uncertain trading durations also exhibit reduced levels of market efficiency relative to the other markets studied. The implication is clear, any future refinement of either theoretical models or institutions of exchange must explicitly recognise the effect of uncertain trading duration on market behaviour in double auctions.

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List of Abbreviations

%GAIN	Percentage of gains from exchange exhausted
AC	Aggregate certainty
AU	Aggregate uncertainty
CAPM	Capital asset pricing model
CK	Constant and known period duration
CKIM	Markets with constant, known period duration, imperfect information and including an information auction
CKIN	Markets with constant, known period duration, imperfect information and no information auction
CKPM	Markets with constant, known period duration, perfect information and including an information auction
CKPN	Markets with constant, known period duration, perfect information and no information auction
CONPERIOD	Pilot market with constant period duration
DA	Double auction
EMH	Efficient markets hypothesis
Emu	Experimental monetary unit
EUH	Expected utility hypothesis
EV	Expected value
FRE	Fully revealing rational expectations equilibrium
I	Market with imperfect information structure
Inf	Informed traders
M	Markets with an information auction
MM	Maximin equilibrium
N	Markets with no information auction
NEE	Naive expectations equilibrium
NOIRE	Noisy rational expectations equilibrium
NORM%GAIN	Normalised percentage of gains from exchange exhausted
NORMVOL	Normalised volume of trade
NRE	Nonrevealing rational expectations equilibrium
ORE	Ordinary rational expectations equilibrium
P	Market with perfect information structure
PF	Perfect foresight
PI	Private information equilibrium
PRE	Partially revealing rational expectations equilibrium
RANPERIOD	Pilot market with random period duration
REE	Rational expectations equilibrium
RMSD	Root mean squared deviation of transaction prices across an entire trading period

RMSD45	Root mean squared deviation of transaction prices for the first 45 seconds of trade
RMSD60	Root mean squared deviation of transaction prices for the first 60 seconds of trade
RMSD90	Root mean squared deviation of transaction prices for the first 90 seconds of trade
SCT	Subjective cost of transacting
TRE	Telepathic rational expectations equilibrium
UInf	Uninformed traders
URE	Uninformed rational expectations equilibrium
V/D ratio	Volume of trade per period divided by period duration (equivalent to NORMVOL)
VK	Variable and known period duration
VKIM	Markets with variable, known period duration, imperfect information and including an information auction
VKIN	Markets with variable, known period duration, imperfect information and no information auction
VKPM	Markets with variable, known period duration, perfect information and including an information auction
VKPN	Markets with variable, known period duration, perfect information and no information auction
VOL	Volume of trade over an entire trading period
VOL45	Volume of trade over the first 45 seconds of a trading period
VOL60	Volume of trade over the first 60 seconds of a trading period
VOL90	Volume of trade over the first 90 seconds of a trading period
VU	Variable and unknown period duration
VUIM	Markets with variable, unknown period duration, imperfect information and including an information auction
VUIN	Markets with variable, unknown period duration, imperfect information and no information auction
VUPM	Markets with variable, unknown period duration, perfect information and including an information auction
VUPN	Markets with variable, unknown period duration, perfect information and no information auction
WSR	Wilcoxon signed ranks test for matched pairs
ZI-C	Zero intelligence traders constrained
ZI-U	Zero intelligence traders unconstrained

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Chapter One

1 INTRODUCTION

'At the heart of economics is a scientific mystery: How is it that the pricing system accomplishes the world's work without anyone being in charge?'

Smith (1982a, p.283)

'The mystery remains unresolved to this day, despite the central importance of the issues it raises .....'

Friedman (1993, p.4)

1.1 Introduction

In the theoretical world of microeconomics the price at which a particular commodity is exchanged is determined by the intersection of the supply and demand schedules for that particular commodity. The equilibrium price is the market-clearing price at which there exists no excess supply or demand for the commodity. The market arrives at the equilibrium price through the actions of a Walrasian auctioneer that co-ordinates the exchange process. In the market places of the real world, however, there exists no overseeing auctioneer or intermediate market maker to guarantee that the price is set at the market-clearing price. The objective of this research is to shed light on the price formation process at play in the world's market places.

Auctions (or markets) are of obvious practical and theoretical importance. The volume of trade on the world's markets is phenomenal, whilst auction theory offers an interpretation of the price formation process in the absence of a co-ordinating body or individual. The rules of exchange differ from market to market. For example, many antique auctions follow the rules of English auctions in which buyers submit progressively higher and higher bids, with the winner being the individual submitting the highest bid. In contrast the Dutch auction, which originated in the Dutch tulip markets, incorporates a price clock that ticks down until a buyer stops the clock at the price they are willing to pay. The institutional rules of exchange that govern a particular auction will have implications for both the price formation process and level of gains from trade exhausted. It is not the intention here, however, to undertake a comparative analysis of the impact of disparate institutional rules on the characteristics of observed market performance. Indeed, much experimental and theoretical work has already been carried out in this area (see Kagel, 1995, for a review). Instead the intention here is to focus on one particular institution of exchange and investigate the impact on the observed price and allocation behaviour of uncertainty concerning the end of trade. The institution under consideration is the two-sided double auction (DA) in which buyers and sellers can simultaneously call out offers to buy and sell. The trade of securities on many of the world's financial markets is governed by one form or another of the double auction and it is for this reason that the DA is the chosen institution.

This chapter is intended as an introduction to the research agenda at the heart of this thesis and discusses the issues of interest that motivated this research. Also, introduced are the proposed research agenda and the research method adopted. The structure of the chapter is as follows. The subsequent section discusses the role of the financial markets that is central to the functioning of economic systems. Section 1.3 offers a brief historical development of the experimental method utilised in this research programme. Sections 1.4 and 1.5 discuss the motivation for the current research and the proposed research agenda, respectively. The rapid development of on-line electronic networks has provided a new channel for trade that is growing rapidly. Section 1.6 discusses how these recent developments are changing the way that markets are conducted, highlighting the practical importance of this research. The concluding section introduces the structure of the thesis on a chapter by chapter basis.

1.2 Role of Financial Markets

Markets, as institutions of exchange, are central to the functioning of economic systems, in which individuals' activities require co-ordinating to ensure that scarce resources are put to best use. The co-ordination of activities is hampered by the existence of uncertainty concerning the opportunities available to society and by the dissemination of information concerning these activities across society as a whole. It is the pricing system that provides the means of guiding resource allocation and economic activity. In the highly developed economies of the world today, it is the financial asset markets that constitute the highest level at which this co-ordination takes place. The efficiency with which the world's financial markets allocate scarce capital among competing investment opportunities and promote the generation of economic wealth via gains from exchange is of paramount importance. Such is the importance of this issue that the question of just how efficient the financial markets are has been the focus of a long standing academic debate and has dominated the finance literature for a number of decades.

Whilst there does not appear to be a general consensus on the issue of market efficiency it is clear that the institutional rules governing trade play a key role in the price formation process and consequently overall efficiency. The market institution specifies the rules that govern the economic interaction of individuals, thus determining not only the nature and timing of messages and decisions, but how these map into monetary outcomes. The trading rules of the market institution clearly have behavioural implications. The double auction (DA) is a trading institution used the world over, from the London Stock Exchange to the New York Stock Exchange. Briefly, the rules of the DA allow buyers and sellers to simultaneously call out offers to buy (bids) and offers to sell (asks) at any point in the trading process. A transaction occurs when the outstanding bid is equal to the outstanding ask, after which the bidding process begins again. Thus the market is two-sided and continuous. This is in contrast to, for example, single-sided markets such as the posted-offer market as adopted in retail markets where the seller offers a single price on a take-it-or-leave-it basis. It is also in contrast to discrete markets such as the call market in which bids and asks are accumulated and all transactions take place simultaneously at a single market clearing price.

Given the influence of trading rules on market behaviour it is vitally important to be able to compare market performance (both price and allocation) under various institutional designs in order to determine their relative efficiencies. Unfortunately this is not strictly achievable by comparison of outcomes in naturally occurring markets due to the disparate environments in which they operate. It is not possible to ensure that relative performances are evaluated on a level playing field, because of a lack of control over the naturally occurring environment in which the institutions exist. However, this strict control is possible with the adoption of a different methodological approach. Experimental methods provide the ability to strictly control relevant variables, as determined by either theory (numbers of buyers and sellers, information structures) or intuition. It is to a brief introduction of the adoption of experimental methods in economics that the discussion now turns.

1.3 Experimental Economics: A Brief Introduction

The experimental economics literature has developed in three broad areas (Davis and Holt, 1993, p.5): market experiments, game experiments and individual choice experiments. Given that this research programme is centred upon the study of financial asset markets, it is experiments in the first of these areas that provide the topic for the following introduction. Roth (1995) provides an excellent introduction to all the facets of experiments in economics, illustrating how the discipline began with the pioneering experiments of the 1930s to become transformed into an accepted mainstream subject by the early 1990s.

The first market experiments were conducted by Chamberlin (1948) in an attempt to investigate whether markets were able to attain predicted competitive price and quantity equilibrium levels. The experimental outcomes reported deviated systematically from predicted values. Smith (1962, 1964) believed these findings were the result of the decentralised trading in Chamberlin's markets, and so implemented an alternative trading institution, the 'double auction', the rules of which require the public availability of bids, asks and transaction prices. The subsequent results provided support for the predictions of competitive price theory. The above illustrates how experimental progress occurs, with initial experiments serving to focus the investigation while subsequent experiments aim to identify potentially critical variables (Roth, 1988, p.975). These two pioneering experiments are the basis from which the experimental literature developed to investigate the impact on market behaviour of institutional rules of trade and an analysis of efficiency in financial asset markets.

The experimental economics literature has witnessed a proliferation of articles investigating various institutional rules of exchange and their comparative efficiencies (see Kagel, 1995, for a review of the research results). The overwhelming evidence concerns the rapid convergence of transaction prices to close approximations of the competitive price equilibrium and the high percentage of gains from trade exhausted when markets are governed by the trading rules of the double auction institution. Similarities between the double auction and the rules governing the trade of securities on a number of the world's stock exchanges prompted a series of experimental studies focusing on financial asset markets.

Since the beginning of the 1980s the volume of literature on the market behaviour observed in experimental financial asset markets has grown steadily. One of the earliest studies by Plott and Sunder (1982) incorporated a simple experimental design in which a market was created where traders were able to both buy and sell 'shares' with uncertain values. Some traders knew the value of the shares, whilst others did not. The competitive nature of the market meant that the price at which the shares changed hands converged to the true (fundamental) value of the shares. This result was replicated by Banks (1985), amongst others. In a later study Plott and Sunder (1988) increased the complexity of their earlier experimental design by removing the certain knowledge of some traders as to the value of the traded shares. Instead, some traders faced reduced uncertainty concerning the value of the shares, relative to other traders. The increased uncertainty resulted in a failure of prices to converge to the true value of the shares.

Duxbury (1995) surveys the results reported from numerous experimental financial asset markets. In conclusion, for the simple experimental designs of early studies, the price at which shares are traded generally converges to the true value of the shares and those traders for whom the shares represent the greatest value generally hold the shares. However, the results of later studies (see for example, Forsythe and Lundholm, 1990 and Lundholm, 1991), in which the complexity and uncertainty of the trading environment is increased, do not offer evidence in support of this conclusion. Sunder (1995) also provides a detailed survey of experimental asset markets. The major findings in the experimental asset market literature to date will be discussed in detail in Chapter Three.

The fundamental objective of laboratory experiments is the creation of an environment that can be controlled, manipulated as desired and which allows accurate measurement of all relevant variables (Wilde, 1980). A carefully designed laboratory experiment can achieve greater precision than is possible with empirical research. Thus, in the context of financial asset market experiments a major benefit provided by an experimental methodology is the ability to control relevant variables so as to maintain the *ceteris paribus* conditions specified by the theory under consideration. It is this potential that enables the investigation of static equilibrium theories, which is not conventionally possible if one or more variables fluctuate rapidly. Individuals' private information and the arrival of new information can be specified and controlled. Furthermore, the complete knowledge of all parameters by the experiment designer allows a theoretically optimal allocation to be calculated. This is problematic in field studies as one can never be sure the observed outcome is optimal. Control is the substance of experimental economics. A more detailed discussion of the experimental economics methodology will be given in Chapter Four.

The purpose of experimentation within the financial asset market literature has shifted and developed. Initial experiments were double focused, providing both a means of testing and discriminating between competing theories (which Smith, 1982a, terms nomotheoretical experiments) and documenting generalised, replicable empirical 'laws' (nomoempirical experiments). Later experiments became vehicles for the 'stress testing' of specific theories, allowing the determination of important variables and the limitations of a theory's domain. With this in mind the motivation behind the current research programme will now be introduced.

1.4 Research Motivation

Despite the wide ranging evidence documenting the rapid and relatively robust convergence tendencies of the double auction, no general consensus has emerged on why the double auction institution performs so efficiently. The lack of consensus is not surprising. The theoretical literature has failed to produce a generally accepted model of the double auction that can be subjected to stringent empirical testing. Only a few theoretical papers attempt to model the efficiency of the double auction institution (examples include Friedman, 1984, 1991). To better comprehend the convergence tendencies of the double auction the development of a model of the price adjustment process is of paramount importance. As Davis and Holt (1993, p.167) conclude, the derivation of an accurate model based on logical reasoning may well be beyond (game) theorists, because of the 'rich message and action spaces' that characterise the double auction. Instead they advocate the development of models based on behavioural assumptions that derive from observations. These observations can be obtained by conducting series of 'boundary' experiments, designed to provide rigorous tests of a theory. Exploring the causes of a theory's failure allows the determination of the key variables and the range of parameters applicable. The role to be played by 'boundary' experiments in promoting advancement is clear. Guidance is given with respect to specific areas requiring additional theoretical refinement.

1.5 Proposed Research Programme

Previous experimental studies have incorporated trading period durations remaining constant for a given experiment. In addition, subjects have been knowledgeable of the duration. In a number of studies the time remaining in a period has been information readily available to subjects via computer screens, whilst in others subjects are actually warned when the trading period nears completion (for example, Ang and Schwarz, 1985). It is conjectured that the robust results detailing the efficiency of the double auction institution may be a product of such knowledge. In one of the few relevant theoretical discussions Friedman (1984, p.71) suggests that the predetermined, known time at which trade will cease is one of a number of institutional features of experimental double auction markets that enhance the informational and competitive efficiency of outcomes. The closer the end of a trading period becomes the more myopic a trader's behaviour will become if they wish to realise any remaining gains from exchange. Indeed, many of the previous studies of experimental double auction markets indicate an increase in the rate of trade in the closing stages of trading periods (see for example Plott and Sunder 1982, p.680 Figure 4).

Period duration may well be a key variable in the determination of the price adjustment process and the convergence to competitive equilibrium in the double auction institution. The intention is to extend previous work by conducting a series of experiments designed to determine the importance of trading period duration on observed market performance in experimental financial asset markets conducted under the rules of the double auction. The few theoretical models of bid, ask and transaction price behaviour in experimental double auction markets developed to date rely on assumptions concerning the time remaining until the end of trade. Indication of the importance of these assumptions for the convergence behaviour advocated by these theoretical models is necessary for future theoretical development. If proven to be a significant treatment variable then period duration, and knowledge of it, requires inclusion as an important variable in any theoretical model. A series of experiments have been conducted to directly evaluate the impact of period duration, amongst other things, on market performance, the results of which are reported and discussed in Chapters Five to Eight inclusive. The issue is clearly of substantive theoretical interest. The following section will explain why it is also of substantive practical interest.

1.6 Recent Developments in Electronic Networks

Recent years have witnessed the growth of virtual communities across electronic networks, of which the Internet is the best known network. Virtual communities constitute a body of members that share a common interest, such as real ale, mountain bikes or a particular musical taste. As such virtual communities represent both a communication channel between similarly interested and experienced customers and an aggregation of purchasing power for a specific product type or service. The emergence of virtual communities has resulted in a growth in trade across multi-media enabled electronic networks. Many businesses now offer services or the opportunity to buy products across electronic networks. Internet sites are being developed as virtual mega-stores, with sites such as CDNow and Amazon.com offering access to a wider range of music and literature than is conventionally possible.

Hagel and Armstrong (1997) argue that the emergence of virtual communities is the catalyst for a fundamentally new business model that will alter the way in which business has traditionally been conducted. The shift will be from a business model in which firms have traditionally 'pushed' products on target customers, to one in which customers actively seek out multiple vendors to elicit the best offer available. Hagel and Armstrong (1997) suggest that virtual communities will play a central role in the shift of economic value from the vendor to the customer and will result in the emergence of 'reverse markets' in which customers hold the power. Virtual communities bring together members with strong interests in specific products or services, allowing them to exchange information and purchasing experience. Customers, therefore, will have greater access to information relevant to their particular purchase interests. In addition, virtual communities bring together individuals with common purchase profiles, resulting in an aggregation of purchasing power and collective bargaining power. It is this increased information and purchasing power that Hagel and Armstrong (1997) suggest will result in the reversal of markets. Customers will make public their needs and invite competing firms to make tenders, thus creating a bidding war in which the customer obtains the best price. The classic microeconomic model in which the intersection of supply and demand determines the market-clearing price will no longer be applicable. The reversal of markets will result in the price more closely following the supply curve. The bidding process will result in each transaction effectively creating a mini-market. The trading environment will come to increasingly resemble on auction, requiring new business models to be developed.

The move to an auction like, on-line trading environment is already in process. There already exist a plethora of sites offering live interactive auctions (for example, eBay, Bid.com. and Yahoo! Auctions) with diverse items for sale ranging from celebrity memorabilia to computer software and hardware to cargo containers. Whilst not yet the trading environment that Hagel and Armstrong (1997) envisage, the fundamental change in the business model is well under way and gathering momentum. As the trade of products and services becomes more and more auction like, so the need to understand the price formation process and gains from exchange generated by specific institutional rules becomes more important. Also imperative is the ability to identify the importance of specific treatment variables on the price formation process. Thus the importance of trading period duration on the convergence tendencies of the double auction (and other forms of auction) is of substantive practical interest.

There are a '... myriad business models emerging in the primordial brew known as cyberspace' (Hagel and Armstrong 1997, p.xi). These markets are in their infancy and are just beginning to evolve. There is no singularly accepted business model that has proven to be superior to all others. In particular, the various sites that provide on-line auctions adopt different institutional rules. For example, eBay adopts the rules of an English auction where the bids rise until only one bidder is left, whereas Klik-Klok Productions adopt a Dutch auction in which the price falls until it is accepted by a bidder. Hybrids of conventional auctions will also become common place. It is essential that during these formative years guidance over the choice of a particular business model is available. The disparate price formation and gains from exchange characteristics of the different institutional rules, and their hybrids, must be fully researched and understood. There already exist large bodies of both theoretical and experimental literatures concerning the characteristics and properties of the various conventional auctions. From this research a number of hybrid auctions have already been developed and tested experimentally (for example, McCabe, Rassenti and Smith, 1993, develop a uniform-price double auction). The overwhelming evidence from the experimental literature on double auctions concerns the robust convergence of transaction prices to the competitive equilibrium price and the high percentage of gains from trade exhausted in these markets. Unfortunately, these properties of the double auction remain shrouded in mystery and there is no generally accepted consensus as to why the double auction is such an efficient institution.

Whilst this research focuses solely on the double auction, and more specifically on experimental financial asset markets conducted under the rules of the double auction, the results will be of interest to those individuals designing and implementing auction rules for the conduct of trade across electronic networks. The impact on observed market performance of uncertain period duration is the main treatment under investigation here. The effect of uncertain period duration will be of interest to the numerous sites that offer on-line auctions. Many, if not all, of these on-line auctions are conducted for fixed, known durations. For example, eBay allows sellers to choose durations for their own personal auctions of 3, 5 or 7 days. Any positive, or indeed negative, effect of uncertain period duration will be exceptionally useful information to the providers of on-line auctions.

1.7 Structure of Thesis

The content of the remaining chapters is now introduced. The following chapter focuses on the notion of informational efficiency, providing a definition of the term and discussion of theoretical models. Conventional empirical research is briefly discussed and a critique offered. The chapter concludes by introducing the various measures of efficiency as adopted in the experimental literature. Chapter Three offers a thorough review of the findings to date in the experimental financial asset market literature. Chapter Four provides a general discussion of both methodological and design issues in experimentation, the chapter also introduces the main experimental design adopted throughout the thesis. Chapters Five, Six and Seven document the results of the series of experiments. Each chapter begins with a short review of the relevant theoretical and experimental literature and introduces specific experimental design issues. The major discussion of each chapter is centred on an analysis of the results. Chapter Five looks at the impact of constant, variable and uncertain period duration on the market performance observed in markets with perfect information structures. The chapter includes a review of the findings of a pilot study of the impact of period duration on market performance, reported in Duxbury (1997). Chapter Six builds on the previous chapter by introducing an imperfect information structure to the design. Chapter Seven takes the designs of both Chapters Five and Six and introduces costly information via the implementation of a market for private information. The power of the experimental design adopted across the series of experiments is exploited in Chapter Eight, in which a holistic analysis of the results is presented using the data generated across the entire range of experiments conducted. It is left to Chapter Nine to provide a summary of the results and a discussion of the conclusions drawn and their implications for the experimental literature, the development of double auction theory and implications for the development of on-line auctions conducted across electronic networks.

Chapter Two

2 Informational Efficiency: Theory and Measurement

2.1 Introduction

The previous chapter highlighted the price formation characteristics and gains from trade generated in auctions with different rules of trade as being the central themes of this research agenda. The chosen institution of exchange was the DA, because of the similarities with features present on the world's financial markets. It is the purpose of this chapter to introduce the notion of market efficiency. A definition of an efficient market will be introduced and distinction will be drawn between the terms informational and allocational efficiency. Whilst the discussion is couched in terms of the pricing and trading of securities on financial markets, it is equally valid for a discussion of the efficiency of the on-line auctions emerging as a result of the growth in virtual communities.

The structure of this chapter is as follows. The next section defines the term 'informational efficiency' in the context of financial asset markets and distinguishes between the different types of market efficiency. Section 2.3 then discusses the static equilibrium models developed in the theoretical literature, commenting on their predictions concerning equilibrium prices and allocations. Section 2.4 briefly reviews the conventional empirical literature that has investigated the efficiency of financial markets and attempts to test the theoretical predictions of the static equilibrium models. The section goes on to provide a critique of the conventional empirical literature concerning the efficiency of financial markets. This critique forms the basis of an argument for the adoption of a different methodology, namely an experimental methodology. Section 2.5 is divided into two subsections. The first subsection reviews the static equilibrium models that have been introduced and developed in the experimental financial asset market literature, whilst the second discusses the different measures of market efficiency adopted in the experimental literature. Recognising that the static equilibrium models offer a limited interpretation of the price formation process due to their very nature, section 2.6 introduces the few theoretical papers that attempt to develop a dynamic theory of price formation and trading behaviour under the institutional rules of the DA. A dynamic theory of DA trading behaviour is required in order to understand why the DA is so efficient at pricing assets and exhausting gains from trade. The final section draws together the discussion in this chapter, which has been centred upon a discussion of market efficiency.

2.2 Definition of Informational Efficiency

The discussion in this section is centred around the concept of informational efficiency, however, initially it is useful to make the cursory distinction between the terms *operationally* efficient, *informationally* efficient and *allocationally* efficient capital markets. A market is said to be operationally efficient if the costs of conducting trade are small. Transaction costs include the payment of commissions on trades and dealers' bid-ask spreads. In an informationally efficient market prices fully reflect all available, relevant information at all times. If assets are held by those traders that value them most highly then all gains from exchange will be exhausted and the market can be said to be allocationally efficient. The discussion within this thesis will address both informational and allocational efficiency[1], but will not address the notion of operational efficiency. A more technical interpretation of informational efficiency will now be offered.

A market is deemed informationally efficient if 'prices *fully reflect* all available information and interpretations of that information' (Griffiths, 1990 p.46, emphasis added). Thus the efficient markets model asserts that prices are related to conditional expectations, such that the price of a security today is equal to the conditional expectation of its price tomorrow. Any difference in price between two dates in time is therefore analogous to a forecast error. Such forecast errors will be uncorrelated with any available information, consequently price changes are unpredictable. Security prices, therefore, follow a random walk, implying that technical analysis is redundant and the stock market represents a 'fair game' (has the martingale property) as it provides an equal opportunity for all. '[T]oday's forecast already embodies the best guess as to what tomorrow's forecast will be so expected profits cannot be made on the change in price' (Sheffrin, 1983, p.126). Thus the excess return (= ex post return - ex ante (expected) return) will be equal to zero, if the market truly represents a fair game. It may appear that this (the fact that the best estimate of tomorrow's price is today's) would imply an expected return of zero, however, this is not so, 'the implication is that the past price series contains no

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[1] For clarification, within the discussion whenever both informational and allocational efficiency are referred to the term 'market efficiency' will be adopted. When necessary the discussion will be more specific and use the terms 'informational efficiency' and 'allocational efficiency'.

information about the change [in price]' (Elton and Gruber, 1987, p.365).

In order to test the efficient markets hypothesis (EMH) it is necessary to be able to estimate the expected return in time period t+1. This is conventionally achieved using one of a number of equilibrium return models, including the capital asset pricing model (CAPM), arbitrage pricing theory and the single index model. The most extensively used being the Sharpe-Linter-Mossin CAPM (equation 2.1 below).

$$E(R_i) = R_f + \beta_i.[E(R_m) - R_f] \qquad 2.1$$

Where: $E(R_i)$ = expected return on the ith asset,

R_f = risk free rate of interest,

$\beta_i = cov.(R_i,R_m)/var.(R_m)$,

$E(R_m)$= expected return on the market portfolio.

Thus, in equilibrium the expected return on a security will be equal to the risk free return plus a market premium. It is this estimate of expected return that is required to empirically test the fair game model (the EMH).

2.3 Theoretical Models of Static Equilibrium

Having introduced the definition of informational efficiency in the previous section, the discussion will now turn to a consideration of the static equilibrium models developed in the theoretical literature. Those discussed include a fully revealing rational expectations equilibrium (FRE) and a partially revealing rational expectations equilibrium. The models predict the equilibrium price at which an asset should trade, the final allocation of assets and the value of information.

The rational expectations equilibrium model naturally assumes, in a world of differential information and uncertainty regarding asset values, that individuals exploit market prices to provide an additional source of information.

> Thus '(g)iven enough replications of the economy, the uninformed investor would eventually be able to construct a model linking share prices to the states of the world. The sophisticated trader would then use share price as an additional signal about the true state of the world.' Strong and Walker (1989, p.99).

An equilibrium price is a price function, which maps from possible information signals to equilibrium price vectors. The assumption that individuals act upon this price vector results in a rational expectations equilibrium (REE).

In the case where individuals have differential information[2] if the REE price function reveals to each individual the non-price information of all individuals collectively, then this is termed the fully revealing rational expectations equilibrium (FRE). Grossman (1976) proposes a theory of fully revealing asset prices which predicts that if individuals are able to invert the relationship between asset prices and private information, then they need not receive the message personally to react optimally as though they had. This is because prices will fully reveal the information, resulting in perfect aggregation and dissemination of private information. More technically, the REE price function is a sufficient statistic for the information signals received by all traders taken collectively. That is individuals are able to infer the private information signals of others by observing the publicly available price.

As with all the static equilibrium models the key characteristics of the FRE model are the assumptions made concerning the information individuals incorporate in their price forecasts. Traders form their forecasts of asset value by supplementing their own private information with the information available from bids, asks and transaction prices. These signals are publicly available to all traders. The values observed for these reflect other individual traders' private knowledge concerning the value of the asset. As a result, previously private information is made known to other individuals, who were not initially privy to such knowledge. In this respect, private information is disseminated through the market via the publicly available signals. This essentially addresses the notion of the *efficient markets hypothesis* (Fama, 1970). The equilibrium price is predicted to be equal to the highest amount paid to any trader holding the asset, given the state of nature. If transaction prices converge to this equilibrium price the market is deemed to be *informationally efficient*. The traders predicted to hold the asset are those with this highest dividend potential, thus all the gains from trade are exhausted and the market is deemed to be *allocationally efficient*. The value of private information is zero.

However, a paradox exists. If prices convey all information then there will be

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[2] Of which asymmetric is a special case, where one individual receives a finer (more informed) information function than another.

no incentive to actively collect 'costly'[3] private information, making it confusing to see how prices could reflect such information. Therefore, if no individual collects information, there will be an incentive to begin to do so. Thus the argument becomes circular and no equilibrium will result. In an attempt to remedy this criticism, and thus provide an explanation for the existence of costly information acquisition, Hellwig (1980) presents a theoretical model in which the equilibrium price does not fully reveal all information if sources of uncertainty other than simply price are incorporated. Grossman and Stiglitz (1980) develop a similar model in which additional uncertainty is represented via the random supply of risky assets. Thus 'noise' is introduced into the equilibrium price mapping function, which consequently only partially reveals all information and so a partially revealing rational expectations equilibrium (PRE) potentially exists. Traders choose between being informed or uninformed on the basis of the expected utility derived from each choice. In equilibrium they will be indifferent because the cost of becoming informed will directly offset any benefits (i.e. the expected utility of the two choices is identical). Furthermore, both the number of informed traders and the ability of prices to reflect information (perfectly or partially) are determined simultaneously in equilibrium.

Thus the theoretical literature was able to refine the notion of efficient markets in the light of criticism, by demonstrating that a PRE model provides incentives to gather private information, because if prices cannot fully reveal an item of information it is potentially valuable. As a result there will be a demand for the information and so it will be priced in the market place, becoming costly to acquire. As Strong and Walker (1989, p.142) suggest, 'costs of information are no less real than costs of production; no market failure is implied.'

To summarise, the main difference between FRE and PRE equilibrium models is that in the former prices fully reveal private information, whilst in the latter they only partially reveal it. Thus private information is worthless under the FRE model, but retains some value under the PRE model.

2.4 Review and Critique of Conventional Empirical Literature

Research into the informational efficiency of asset markets is widespread and has dominated the finance literature for a number of decades. The question of

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[3] In ways other than purely monetary, for example time consuming information search.

'efficient markets' is an important issue that requires consideration because of the role capital markets undertake as allocators of scarce resources. Fama (1970) offers a taxonomy of informational efficiency, making a three fold distinction for the classification of empirical tests. These are: strong form efficiency in which prices reflect *all* information, both public and private; semi-strong form efficiency in which *only public* information is impounded in asset prices; and weak form efficiency in which prices reflect the information implied by *prior price movements*. More recently termed private information tests, event studies and return predictability tests, respectively.

During the 1960s and up to the middle of the 1970s evidence in favour of the EMH began to mount. The Fama (1970) review article came to the conclusion that, although security markets were not strong form efficient and so did not reflect all available information, they were efficient with respect to past and public information and so could be classed as at least semi-strong form efficient. By the mid-1970s this had become the overwhelming viewpoint and the EMH had become virtually accepted as an uncontroversial fact (Mandell and O'Brien, 1992, p.500). However, around the same time, both empirical and theoretical work became increasingly critical of the notion of informational efficiency in its strongest sense. Empirical research began to report a volatility in stock prices that could not be justified by the view that such prices reflected the discounted present value of a share's future dividend stream (that is fundamental economic value). Furthermore, other empirical anomalies exist, such as the size effect, small firm effect, price/earnings ratio effect and numerous calendar effects that violate the EMH. Consequently, by the mid-1980s, the weight of evidence against the EMH called into question the concept of informationally efficient markets (Mandell and O'Brien, 1992, p.503). Due to the limitations on space and the vast number of studies concerned with the EMH it is not possible to cite all the references used to arrive at this overall view of the current state of the empirical literature. However, many surveys exist and it is to these that the reader is directed. Griffiths (1990) offers a limited review of the research, whilst Elton and Gruber (1987, Ch. 15) provides a comprehensive review of the research into weak, semi-strong and strong forms of efficiency and also the various anomalies unearthed by this research. The emergence of variance-bounds (volatility) tests pioneered by Shiller (1981) and LeRoy and Porter (1981) is documented in the surveys by West (1988) and Cochrane (1991), with critiques provided by Flavin (1983) and Kleidon (1986, 1988). For an additional review of both the theory and empirical findings in the EMH literature, LeRoy (1989) provides a useful study.

The results of empirical studies concerning market efficiency are not as 'sound' as would initially appear to be the case, due to the problems and weaknesses inherent in such studies. Consideration will be given to the general limitations of the empirical literature beginning with the testing of the relevant theories, the problematic definition of informationally efficient markets and moving on to Roll's (1977) critique and the joint hypotheses problem.

Empirical papers have preceded those aimed at providing a theoretical concept of informational efficiency. The theories developed subsequently have been based on the concept of static equilibria. However, empirical research is unable to provide adequate tests of such equilibrium theories due to the constant and ad hoc arrival of new information, resulting in a perpetual adjustment of prices. Griffiths (1990, p.48) argues that the empirical research into the EMH is concerned with reaction time of the market to new information and that it is 'misleading to stress the concept of equilibrium in the context of financial markets.' This would suggest that static equilibrium theories are redundant. Nevertheless to argue for a concentration on reaction time to new information, one must know in what direction the share price should move (that is react) to reflect such information. It is this role that static equilibrium theories fulfil. At a given point in time, with a given information set, the equilibrium theories predict the price of the stock to reflect the available information. If the price is below the predicted equilibrium value competitive pressures will cause it to rise, conversely if the price is above the predicted equilibrium value it will fall towards the predicted price. Static equilibrium theories, therefore, give an indication of the direction of change, or reaction to information, of the price if it is in disequilibrium. Thus static equilibrium theories cannot be dismissed out of hand and will require testing before adoption by the finance literature.

Unfortunately, the empirical research is inadequate for such a task due to a major weakness, the inability to strictly control important variables. Specifically, the private information used by traders is, by its very definition, unknown and thus uncontrollable when using field study data. The same is true of the arrival of new information. A further problematic area is the definition of an 'insider'. Elton and Gruber (1987, p.389) state that 'investors who own more than a certain percentage of outstanding shares or at a sufficiently high management level are considered insiders.'

This begs the obvious question; what parameters should be used to determine an insider (that is, what percentage and at what level in management)? An arbitrary choice that is consistent across studies would permit a comparative analysis. Unfortunately this approach is inadequate because the choice of parameters would seem to be company specific. However, the use of company specific parameter values would inhibit the ability to generalise results to the market level.

Moving to a further problematic area, the definition of an informationally efficient market causes concern due to an inability to provide precise meanings for such terms as 'fully reflect', 'available information' and 'unbiased'. A related problem when using empirical techniques is the fact that an informationally efficient market is unobservable. As a result, the asset price that would prevail in an efficient market must be modelled. This requires the estimation of expected returns in period t+1 via a model of equilibrium returns such as the Capital Asset Pricing Model (CAPM) and so consideration must be given to Roll's (1977) critique of tests of the CAPM. The problem of joint hypotheses testing is introduced as 'the test of market efficiency is confounded with a test of the asset pricing model' (Lundholm, 1991, p.486). A test of the EMH is a joint test of informational efficiency and the assumed equilibrium model of price determination. Thus it is difficult to determine whether evidence inconsistent with the joint assumption is evidence against informational efficiency or the chosen equilibrium model. This problem can be illustrated by the debate over whether volatility tests are evidence of inefficiency or whether the findings are a result of the model employed (see West, 1988, and Kleidon, 1986, 1988).

The preceding problems and weaknesses suggest that the conventional empirical methodology may not be sufficient to test for efficient markets and to evaluate the predictions of the competing theories of static equilibrium. The conventional method may be beneficially supplemented by the adoption of another complementary method, that of experimental economics. The following section introduces the various theoretical models of static equilibrium studied in experimental asset markets since the 1980s and discusses the different measures of market efficiency used to evaluate the models' predictions.

2.5 Theoretical Models and Measures of Market Efficiency in the Experimental Literature

2.5.1 Theoretical Models of Static Equilibrium

In order to test the theories proposed in the finance literature and the various forms of market efficiency, experimentalists design static equilibrium models with differing assumptions as to the information individuals are assumed to incorporate into their forecasts. This results in the different models making diverse predictions about equilibrium prices and allocations. These are exploited by comparing theoretical predictions to actual outcomes in order to evaluate the various models. Reference should be made to Table 2.1 as this provides a summary of the various models, including acronyms, definitions, and price, allocation and value of information predictions. Any models that are equivalent to other models are not discussed in the main body of text, but are referred to in the table. These models will be referred to in greater detail in the literature review of Chapter Three. It should be noted that when experimental studies refer to a rational expectations equilibrium (REE) they are in fact generally referring to the fully revealing model, FRE. Thus within the body of this text the acronym FRE will be used whenever other studies have used the acronym REE, so as to clarify the situation. Also, when other equivalent models are discussed in the literature this paper will attempt to make use of one acronym to refer to them.

The concept of rational expectations has been extended to the allocative properties of experimental financial asset markets. These experimental markets have been used to test the theoretical predictions of the static equilibrium models. Markets are conducted for assets that pay an uncertain, state contingent dividend. These uncertain dividends may vary from trader to trader, thus creating possible gains from exchange. In many of the markets conducted in the experimental literature some, but not all, traders receive information about the state of nature. In one of the earliest experimental asset market studies Plott and Sunder (1982) introduce a fully revealing rational expectations (FRE) model in which equilibrium prices reveal the state of nature. In this model traders supplement their own private information with the public information available from price signals which reflect others' private information. As a result the equilibrium price is predicted to be equal to the highest dividend of any trader type given the state of nature. The traders predicted to hold the asset are those with this highest dividend potential. The vast majority of experimental studies into asset market efficiency also invoke this model or those models that are equivalent. A prediction of this model is that private information is fully revealed and so consequently has no value.

Plott and Sunder (1982) also introduce a prior/private information (PI) equilibrium model under which individuals condition behaviour and expectations on private information only, ignoring any information to be gained by observing the market price. Thus expectations are exogenous to the price formation process, which is determined by the intersection of supply and demand as in a Walrasian market. As described by Plott and Sunder (1988), the PI model is premised on three principles of individual action: 1) traders apply Bayes law to determine the likelihood of a state having occurred given any private prior information; 2) traders act on the above probability; 3) individuals' actions follow the expected utility hypothesis (EUH). Given these presumptions, the market price predicted by the PI model is equal to the highest *expected* dividend value among all traders. Those traders with the highest expected value (EV) are predicted to hold all assets. If a market were to behave as such a model predicts, it would be classed as weak form efficient and any private information known by individuals would have a positive value, because the equilibrium market price would not reveal it.

The above two models are by no means the only ones employed to prescribe the behaviour of asset markets, different studies have invoked different models depending upon the assumptions made about the information sets of traders. Friedman, Harrison and Salmon (1984) develop an uninformed rational expectations (URE) model in which no private information is available for incorporation into prices, only public information. This URE equilibrium therefore corresponds to the notion of semi-strong form informational efficiency. A further model equivalent to semi-strong efficiency is the ordinary rational expectations (ORE) equilibrium proposed by Copeland and Friedman (1987), in which individuals combine private information with public knowledge to refine conditional probabilities, but are unable to infer the private information of others.

Model	*Definition*	*Predictions*
Fully revealing rational expectations equilibrium (FRE)	Equilibrium prices reveal the private information of all individuals, thus revealing the state of nature with certainty	**Price**: Equal to the highest state contingent dividend **Allocation**: Assets held by traders with highest dividend given state **Information**: Zero
Rational expectations equilibrium (REE)	Individuals form expectations of the underlying state conditioned on both price and non-price information	**Price**: Equivalent to FRE **Allocation**: Equivalent to FRE **Information**: Zero
Perfect foresight (PF)	Equivalent to FRE	**Price**: Equivalent to FRE **Allocation**: Equivalent to FRE **Information**: Zero
Telepathic rational expectations equilibrium (TRE)	Equivalent to FRE	**Price**: Equivalent to FRE **Allocation**: Equivalent to FRE **Information**: Zero
Partially revealing rational expectations equilibrium (PRE)	Equilibrium prices only partially reveal the private information of all traders, thus the state is not revealed with certainty	**Price**: Within the interval defined by the FRE and PI predictions **Allocation**: Traders with highest dividend value given state and imperfect signals **Information**: +ve
Noisy rational expectations equilibrium (NOIRE)	Equivalent to PRE	**Price**: Equivalent to PRE **Allocation**: Equivalent to PRE **Information**: +ve
Private information equilibrium (PI)	Individuals condition expectations on private information only, not on prices	**Price**: Equal to highest expected dividend value given state and private information **Allocation**: Traders with highest expected dividend value **Information**: +ve
Ordinary rational expectations equilibrium (ORE)	Traders combine private information with public information to form expectations, but are unable to infer the private information of other individuals	**Price**: Equal to highest expected dividend value given state, private information and the use of some public information **Allocation**: Traders with highest expected dividend value **Information**: +ve
Nonrevealing rational expectations equilibrium(NRE)	Identical to ORE	**Price**: Equivalent to FRE **Allocation**: Equivalent to FRE **Information**: +ve
Uninformed rational expectations equilibrium (URE)	Individuals condition expectations on publicly available information such as bids, asks and transactions. No private information available	**Price**: Equivalent to ORE **Allocation**: Equivalent to ORE **Information**: n/a
Naive expectations equilibrium (NEE)	Individuals initially expect to only be able to make a gain in period A (each market day split into period A and B)	**Price**: Period A and B specific **Allocation**: Period A and B specific **Information**: +ve
Maximin equilibrium (MM)	Individuals act only on certainty and do not purchase unless price is below the minimum they could receive given prior information	**Price**: Equal to maximum (across traders) minimum (across states) dividend value **Allocation**: Traders whose dividend determined the equilibrium price **Information**: +ve

Table 2.1 Description of Static Equilibrium Models

In line with the theoretical model of Hellwig (1980), Copeland and Friedman (1991) develop a partial revelation equilibrium (PRE) model that assumes traders can infer some, but not all, privately held information from observable market data and so private information will have a positive value, albeit smaller than predicted by PI models. The model is intended to bridge the gap between semi and strong form theories.

The FRE model in equilibrium identifies the state of nature with certainty, and so its predictions about equilibrium price and allocations are free from any assumptions about the risk preferences of the traders. However, the other models above must all make the assumption of risk neutrality. In contrast, both Plott and Sunder (1988) and Forsythe and Lundholm (1990) propose a model based on the assumption that traders are risk averse. The maximin (MM) model is based on the hypothesis that traders act only on certainty, and so do not purchase unless the price is less than the minimum they could possibly receive given their prior information. Traders with the maximum minimum dividend will hold all assets and the equilibrium price will be equal to this dividend. Under this model private information has positive value.

In summary, the main models introduced above differ with respect to the information it is assumed people use in forming their expectations of prices. As a result they make different predictions regarding equilibrium prices and allocations and the value of private information.

2.5.2 Measures of Market Efficiency: Informational and Allocational

There are a number of measures used in the experimental literature to evaluate the diverse predictions of the different models when compared to actual outcomes. These measures can be divided into the five areas of price, allocation, efficiency, profit and analysis of the bid-ask spread. These will be discussed briefly below and Table 2.2 provides a selective summary of some of the measures adopted and further comments.

Comparison	*Measures*	*Comments*
Price Convergence	• Mean absolute deviation • Mean squared deviation • Root mean squared deviation • Time-weighted mean squared deviation • Regression of mean observed price on predicted	Non-parametric Signs, Wilcoxon rank sum and Mann-Whitney tests are used to determine significance of convergence.
Asset Allocation	• Root mean squared deviation • Asset transfer prediction (direction of trade)	Final occurrence of each state of nature used as it will give allocations more akin to equilibrium values.
Efficiency Gains from Trade	• $\frac{TSA}{TSE}$ • $\frac{(TSA-TSI)}{(TSE-TSI)}$	FRE results in 100% efficiency.
Profit	• Percentage deviation • Sum of squared deviations from mean • Prediction of whether uninformed buy or sell differs between models resulting in different profit predictions • Deviations between gross and net profit	Essentially a measure of allocative efficiency, with misallocations weighted according to the reduction in gains from exchange. FRE predicts all traders will earn same profit regardless of decision to purchase information but PI predicts gross and net profit will differ.
Bid-ask Spread	• Observation • Regression of spread against time • Average of bid-ask spread used as a proxy for price	Useful when trade is thin and there are few transacted prices.

Table 2.2 Measures of Market Efficiency

Price Convergence: In measuring the accuracy of equilibrium price predictions, these predictions are compared to the experimental outcomes observed. There are various alternative measures that can be used for such a comparison, such as the mean squared (e.g. Copeland and Friedman, 1991) or root mean squared (e.g. Friedman, Harrison and Salmon, 1984) deviations of predicted prices from those observed. Table 2.2 offers some alternative measures. However, when no trade takes place the above measures will not be strictly defined.

Asset Allocation: Rubinstein (1975) raises the issue that theories of efficient markets should explain asset allocations in addition to prices. Models that make different assumptions about traders' information sets will make different allocation predictions, which when compared to observed outcomes will give a measure of the misallocation of assets. This measure is contained in, amongst others, Friedman, Harrison and Salmon (1984) and Copeland and Friedman (1991).

The above measure is inadequate if the predictions of one model are a subset of those of another, as it will be biased in favour of the latter model. This frequently occurs with the predictions of the PI model being a subset of those of the FRE model. Of those subjects who are members of the trader type receiving the highest dividend, given the state of nature, the PI model predicts that the informed (insiders) will purchase the asset at a price equal to their reservation (dividend) value. On the other hand, those who are uninformed and so use expected value to determine the worth of the asset to them, will sell to the informed. This will result because the expected value to the uninformed, who do not know the state and under the PI model cannot infer it by observing prices, is lower than the reservation price of the informed. In contrast the FRE model is based on the premise that uninformed traders are able to infer the private information of the informed, and thus the state of nature, from the publicly available price. As a result, the subjects in any given trader type will have the same reservation price, thus both the informed and uninformed of the trader type with the highest dividend will hold the asset. It is clear, therefore, that the PI model prediction of the informed with the highest dividend holding (I) is a subset of the FRE prediction of both the informed and uninformed holding (I+U). Notationally, $I \subset I+U$. This is a valid criticism of the paper by Plott and Sunder (1982).

As a result a number of papers have provided various alternatives. Plott and Sunder (1988) used the security transfer predictions of the models rather than final holdings. Given that the various models result in different asset valuations for different traders, they also, therefore, make different predictions as to which traders will buy/sell in certain states. Forsythe and Lundholm (1990) found that the predictions of MM were contained in those of FRE in every state. To overcome this they divide the number of properly allocated units by the number of traders predicted to be in the holding group by the conflicting theories, thus normalising the measure. Camerer and Weigelt (1991) make use of the fact that FRE predicts that uninformed traders with the highest dividend will purchase whilst PI predicts that they will not be buyers. Thus providing a 'novel' test of predicted allocations, although not dissimilar to that in Plott and Sunder (1988).

Efficiency Gains from Trade: The incentive mechanisms adopted in the literature mean that individuals will trade until there are no further gains to be sought, providing a benchmark for efficiency of 100%. A second benchmark is provided by the initial allocation prior to trade, which corresponds with an efficiency of 0%. This follows the procedure in Forsythe, Palfrey and Plott (1984) that defines the total surplus of an allocation as the sum, across all traders, of dividend earnings under that allocation. Resulting in a measure of the percentage possible gains from trade realised of the form in equation 2.2 below:

$$\%Gain = \frac{(TSA - TSI)}{(TSE - TSI)} \qquad 2.2$$

Where: $\%Gain$ = Percentage gains from trade exhausted,

TSA = total surplus of actual allocation,

TSI = total surplus of initial allocation,

TSE = total surplus of efficient allocation.

Forsythe and Lundholm (1990) define trading efficiency as the percentage of the maximum gains from trade that are realised, where the maximum gains equal total dividends paid under a fully efficient allocation minus those paid under zero trade. Therefore, if the market is in FRE equilibrium 100% of the gains from exchange will be exhausted. The above two measures are equivalent.

Profit: It may be the case that in certain states, given the parameters incorporated in the experimental design, the models under analysis render identical price predictions. This is the case with the PI and FRE models when the G (good) state occurs in Camerer and Weigelt (1991), to overcome this a 'novel' profitability test is formulated. When the G state occurred the two models predicted different trading behaviour for uninformed traders with the highest dividend given the state. In this situation the FRE model predicts such a trader will buy (at a price < the EV if informed) whereas the PI model predicts that they will sell (at a price > the EV if uninformed). These different ways of calculating profit will result in diverse profit predictions, these can be used to evaluate the models.

Sunder (1992) utilises the fact that the FRE model predicts that all traders will earn the same profit regardless of their dividend type or decision to purchase. Consequently, the price of private information will be zero, as discussed above, and gross and net profits will be equal. This will not be the case in models where the value of private information is positive (e.g. PI model) and so comparison of gross and net profits will allow differentiation between the models under consideration.

Bid-ask Spread: When trade is thin or non existent analysis of the bid-ask spread can provide some evidence as to whether or not prices were converging to the value predicted by a certain model. Cursory evidence can be gleamed by simple observation of a graph of the spread over time, however, more precise insight can be gained from a regression of the spread against time. Alternatively, Copeland and Friedman (1991) propose using the average of the bid and ask prices to proxy the price at which a trade may take place, thus exploiting the trading opportunities implicit in bid and ask prices.

The observed outcomes incorporated in the above measures are taken from varying times in an experiment. When calculating the overall accuracy of a model the data from the whole of the experiment is utilised. In contrast only data from the final occurrence of each state is incorporated when calculating terminal accuracy, which shows the models in a 'better light'. This is because the whole data set includes disequilibrium trades, whilst end period trades are more consistent with the static equilibrium predictions of the models. The studies also have a tendency to compare the measures calculated from 'early' in an experiment to those from 'late' on in the same experiment, showing whether there is a convergence towards predicted values.

2.6 Double Auction Theory

The theoretical models of static equilibria introduced above, particularly the FRE model which predicts a competitive equilibrium outcome where no excess supply or demand exists, generate accurate predictions of end period prices and allocations. Experimental evidence reports convergence of transaction prices and asset allocations to, or close to, these theoretically predicted equilibrium values (Chapter Three offers an extensive literature review). However, these models say nothing of the process by which prices and allocations converge to equilibrium values. In order to begin to understand why the DA institution is so efficient at pricing assets and exhausting gains from exchange, a dynamic theory of individual trading behaviour under the DA trading rules is required. Unfortunately, there is little by way of theoretical literature attempting to fill this void. Those papers that have attempted to model trading behaviour in DA markets are introduced below.

After observing flurries of trade late in a trading period but noting that experienced traders rarely miss out on profitable trades by waiting too long, Friedman (1984) offers a 'no-congestion equilibrium'. The no-congestion condition requires that at the end of the trading period no trader wants to adjust, or accept, the closing bid or ask. The condition ensures that closing prices and allocations will be almost efficient, only one trade away from Pareto efficiency. However, the paper does not directly model the dynamic process of price convergence, but instead offers various institutional features that influence efficient outcomes. The paper does not explain how the no-congestion condition will occur, nor does it generate testable predictions concerning the process of price formation.

Wilson (1987) incorporates a game theoretic approach to develop a model of sequential equilibria in bid-ask markets. Traders experience an 'impatience' to trade that arises endogenously as a result of competitive pressures due to multiple buyers/sellers and the potential for any one trader's opportunity to trade to be usurped by a competitor. Traders are, therefore, predicted to trade at the earliest profitable opportunity. Wilson (1987) makes the distinction between 'serious' and 'non-serious' bids and asks, such that traders' beliefs and strategies are not dependent on the magnitude of non-serious offers. Assumed common knowledge of valuation parameters allows traders to infer which offers are serious, update their beliefs and strategies accordingly and compute the associated equilibrium. The usefulness of a game theoretic interpretation for modelling individual trading behaviour is severely limited. Strict common knowledge assumptions are required that are not satisfied in experimental markets and individuals would require exceptional computational abilities to solve the equilibrium outcome. Indeed Wilson (1987, p.411) questions whether game theoretic hypotheses will prove useful models for the explanation of observed experimental outcomes. Wilson's (1987) model is further at odds with many experiments as it assumes that once buyers and sellers have traded a single asset they become inactive. Many experimental designs permit traders to buy and/or sell greater than one asset.

Friedman (1991) proposes a model of price formation in double auction markets. Whilst the theoretical models, introduced above, make use of individuals' reservation prices to make predictions concerning the *static* equilibrium price attained in a market, the Friedman (1991) study utilises such reservation prices to develop optimal trading strategies. Thus, the study aims to develop a model of the *dynamic* nature of the price formation process, via the use of a game theoretic approach. The 'model generates specific predictions as to the time and nature of the next event in the Double Auction.' (p. 62). To achieve this intention the paper employs the very strong simplifying assumption that traders neglect strategic feedback effects. Traders behave as if they are playing a 'Game against Nature', in that each agent 'neglects the possibility that his current bid or ask may affect other agents' contingent behaviour and thus affect his own future trading opportunities.' (p. 48). This assumption, together with a number of other subservient assumptions, allows the development of a model of optimal trading strategies. An aggressive reservation price strategy, where the trader betters the outstanding bid/ask, is found to be an optimal trading rule, providing a model of double auction markets that predicts bid, ask and acceptance behaviour. The paper makes the simplifying assumption that traders can be either buyers *or* sellers, but not both within the same trading period. In the majority of financial asset market experiments, traders can simultaneously be *both* buyer and seller. Friedman (1991, p.63) acknowledges that such a feature would necessitate significant modifications to the existing model. A discussion of the necessary extensions is found in Friedman, Harrison and Salmon (1984, Appendix A). This and the previous cited study both adopt a further assumption in their attempt to model bid, ask and acceptance behaviour. Trade is permissible over a finite interval time [0, T]. Friedman's (1991, p.52) BGAN3 assumption allows for the random generation of new bid and ask prices at random times. The exact distribution of such prices is unknown, however, it is assumed that agents have sufficient knowledge of the distribution of times to compute the expected number of new prices available to them before the end of the trading period. To achieve this traders require information regarding the time at which trade ceases in the period, thus there is implied knowledge of the trading period duration. It seems that this is a fundamental assumption if the model is to predict convergence of prices and allocations to almost Pareto optimal outcomes (see Proposition 3, op cit p.58).

Easely and Ledyard (1993) attempt a first pass at a positive theory of price formation by constructing a theory premised upon certain assumptions concerning individual behaviour. Individuals are assumed to act as if they adopt a range of 'boundedly rational' rules-of-thumb and engage in optimal behaviour. The fundamental assumption concerns individuals' reservation prices possibly differing from their true values (induced value parameters). Individuals' reservation prices will then impact upon their willingness to better, or accept, any outstanding offers. The reservation prices are assumed to be a function of time. Reservation prices are adjusted subject to individuals learning not to buy for too high a price (or sell for too low a price) and not to wait too long to trade such that they miss out on profitable opportunities. Competitive pressures drive prices up if too low and down if too high. Easely and Ledyard (1993) show that theoretically, after sufficient repetitions, prices will remain in a narrow interval around the competitive equilibrium price. They test the predictions of convergence against experimental data. The results do not provide conclusive evidence in favour of their model but do offer support for its plausibility. Easely and Ledyard (1993, p.88) offer a deterministic theory and conclude that whilst it seems to describe what happens in DA experiments, it does not completely describe the path of bids, asks and transaction prices. As a result, they offer the model as the beginning of a positive theory of price formation rather than the finished article.

Friedman (1991) and Easely and Ledyard (1993) offer insight into the modelling of trading behaviour in DA markets. Considerably more research in this vein is required to provide a more thorough understanding of the dynamic price formation process in DA markets. Friedman (1984) concludes that, amongst other features, the knowledge of the preset time at which trade will end is an institutional feature of experimental double auction markets which enhances the informational and competitive efficiency of outcomes. As the end of trade approaches the opportunities to gain from holding back on transacting decreases, thus traders are more likely to accept or, more importantly, *better* (offer a higher price/ask for a lower price) existing bids and asks. It is the impact upon trading behaviour, and thus upon market efficiency, of knowledge of exactly when trade will end that is the main focus of investigation in this thesis.

2.7 Discussion and Conclusions

The focus of this chapter has been a discussion of market efficiency. Definitions of informational and allocational efficiency were first introduced, followed by a discussion of the static equilibrium models developed in the theoretical literature. These models make disparate predictions regarding equilibrium prices and allocations, and the value of private information. The FRE model corresponds to Fama's (1970) strong form market efficiency. The limitations of conventional empirical studies of the EMH were recognised in section 2.4 and used to form the basis of an argument for the adoption of an alternative methodology for the investigation of financial market efficiency. The different static equilibrium models tested in the experimental asset market literature were introduced, with their disparate predictions highlighted. The two main models that will form the basis of comparative analyses in Chapters Five to Eight are the FRE and PI models. The various measures of market performance employed in the experimental literature were also introduced in section 2.5. Section 2.6 reviewed in detail the few theoretical studies that have attempted to develop dynamic theories of price formation and trading behaviour in DA markets. It was recognised that in order to offer justifications for the robust convergence of prices and allocations to competitive equilibrium outcomes in the DA market a greater understanding of the price formation process is required. To date the theoretical literature falls short of providing such an understanding. It is the intention of this research to focus on the effect of period duration on observed market performance in an attempt to provide insight into the convergence tendencies of the DA and thus guide future theoretical refinement.

Understanding why certain institutional trading rules result in the attainment of higher levels of informational and allocation efficiency is of substantive practical interest. The employment of the most efficient trading institutions in particular scenarios is central to the creation of economic wealth via gains from exchange and thus the well-being of society as a whole. Whilst particular institutional rules are already entrenched in certain markets (for example, the DA in the world's financial markets), the search for more efficient, refined trading rules should be a continual process. The issue is of fundamental importance for newly developing on-line auctions and the increase in trade across electronic networks that is becoming evident due to the growth of virtual communities. These newly established markets do not adhere to traditional business models and do not yet have entrenched institutional rules of trade. They are, therefore, at a crucial stage of development where an informed choice of trading environment must be made. A greater understanding of the price formation process under different institutional rules is of paramount importance. It is for this reason that insight into the price formation process at the heart of the efficiency of the DA market is of imperative importance.

Chapter Three

3 Experimental Financial Asset Markets

3.1 Introduction

There exist a substantial number of experimental studies researching the performance of experimental DA markets. The purpose of this chapter is to provide a detailed review of the major experimental results. A distinction is drawn between 'commodity' market and 'asset' market experiments. Sunder (1995, p.445) distinguishes asset markets from other commodity markets by two defining characteristics, the informational role of prices and the dual role of traders as simultaneously (within a trading period) both buyer *and* seller of assets. This review concerns the experimental financial *asset* market literature, in which the DA market plays a key role. To review all the experimental literature on the DA market would be onerous and too consuming of space, therefore DA experiments in which traders are either buyers *or* sellers are excluded. A few important exceptions are included when the results warrant discussion. Whilst the experimental studies into market efficiency have a number of common design features, they also have a plethora of disparate features. The earlier studies design experiments with simple laboratory markets, whilst later studies add varying degrees of complexity to these market designs. Below is an account of how these treatment variables impinge on information aggregation and dissemination, and thus upon market efficiency.

An outline of the structure of the chapter follows. Section 3.2 contains a discussion of the key themes and results reported in the experimental asset market literature. The discussion in subsections 3.2.1 through to 3.2.5 includes the effect of stationarity, the number of periods in an experiment and so the effect of experience, the number of participants, the types of assets traded and the dividends received. The majority of studies are very similar in these areas and only a few depart from convention. The remaining areas discussed, in subsections 3.2.6 through to 3.2.12, are the effect of information structures, markets for information, the existence of mirages, futures and options markets, institutional rules, differing risk preferences and specialist trading rules. These provide the key areas of consideration within the literature, albeit with differing degrees. Also included in subsection 3.2.13 is a review of important, relevant results from computer simulation studies. Section 3.3 offers a comparison of the experimental results to the results of conventional empirical studies. The final section summarises the experimental findings and draws conclusions. The content of the following discussion draws extensively on the review article by Duxbury (1995). An additional survey of the evidence from experimental asset markets is provided by Sunder (1995).

3.2 Key Themes and Results

3.2.1 Stationarity

Grossman (1978) suggests that replication is necessary for the occurrence of a FRE equilibrium because without it traders are unable to acquire information about future prices. In the early studies by Plott and Sunder (1982) and Forsythe, Palfrey and Plott (1984), markets were designed so that each period was a perfect replicate of the other periods, with respect to the underlying distribution of returns. Both found that after a number of replications the equilibrium price converged to the FRE prediction, the ramification being that subsequent studies have adopted the same strategy (e.g. Copeland and Friedman (1987, 1991) and Forsythe and Lundholm (1990), etc.).

However, there are a few papers that neglect to incorporate stationarity into their design. In Ang and Schwarz (1985) the equilibrium prices of both the FRE and PI models are not stationary, because the number of informed traders, common knowledge of their existence and the information they receive are all subject to change. In Smith, Suchanek and Williams (1988) reinitialisation of endowments does not occur because multiperiod lived assets are traded. Asset holdings and working capital are determined endogenously, and so stationarity is violated. Despite this the paper reports that prior to the last trading period, prices converge to 'near' the FRE prices. In Campbell, LaMaster, Smith and van Boening (1991) supply and demand schedules are shifted by the addition of a random constant (positive or negative) so stationarity does not exist. However, this last paper addresses the concept of off-floor trading rather than simply market efficiency, and so comparison is not possible.

3.2.2 Periods

Given that a number of studies found that replication in a stationary environment facilitated the convergence of price to the FRE equilibrium level, it seems logical to determine how long this process takes (that is the number of replications necessary). Unfortunately, comparison across studies is not valid due to the disparate designs and parameter sets employed. Smith, Suchanek and Williams (1988) conducted experiments with 15 or 30 trading periods, but their concern was with the existence of asset market bubbles and so the results are of no direct consequence. Despite this they do provide the view that expectations are adaptive and that given time the adaptation is to FRE equilibrium outcomes, 'when asset value 'fundamentals' remain unchanged over the horizon of trading.' (p. 1148).

Of more direct applicability to the convergence of prices to predicted equilibrium levels is the amount of experience that participants have. Plott and Sunder (1982) suggest that experience may result in the possible existence of a learning curve effect. To allow for this possibility Camerer and Weigelt (1991) divided the set of periods of each state type into two subperiods, 'early' and 'late'. Findings suggested that prices converged to FRE predictions in the later subperiods but approximate PI predictions in the earlier subperiods, supporting the view that experience provides traders with the ability to learn. Forsythe and Lundholm (1990) used participants with no prior experience and conducted experiments spanning two nights, with the parameters remaining unchanged. Thus by the second night participants had specific experience in the environment they faced. Results indicated that FRE did not perform well in the first night of the markets, even by the last occurrence of each state. By the end of the second night of the market the FRE model accurately predicts prices and allocations. However, they felt that it may be due to the very specific type of experience gained by participants (i.e. constant parameters) and so they designed markets to give a more general type of experience, by including different sets of traders, parameters and the non randomising of trader types. Finding that FRE significantly outperformed both PI and MM, they concluded that a specific type of experience was not necessary for a FRE equilibrium and traders could infer information from market data in different environments, once they had experience in a double oral auction. However, it was also found that experience is not a sufficient condition for convergence and that other conditions may be necessary (e.g. common knowledge of payoff schedules, discussed later).

Smith, Suchanek and Williams (1988) supply evidence that increased experience results in the tendency for expectations and prices to converge to intrinsic values, but deviations still existed. Camerer and Weigelt (1991) furnish evidence that allocative efficiency is improved as experience is gained and FRE becomes better than PI in later periods. In studying the way in which individuals make inferences from public information, McKelvey and Page (1990) demonstrate that experienced participants have a higher relative efficiency than inexperienced ones, suggesting an improvement in inference through learning.

Despite what appears to be very strong confirmation for the view that experience facilitates convergence, the issue is not so clear cut, as Copeland and Friedman (1987) find only weak evidence that convergence is superior in later periods.

As the studies all invoke periods of equal length for any given experiment it is possible that there are behavioural effects occurring towards the end of the period that are not being picked up. One avenue of research would be to randomise the length of periods within an experiment, without informing participants of the length of each period. A priori it would seem probable that trading would be concentrated more towards the beginning of each period under such circumstances than if participants knew the duration of the period. This avenue of research represents the major contribution to the experimental literature that the current research programme offers.

3.2.3 Participants

In analysing asset market efficiency experimentalists are interested in aggregate behaviour. The theories under consideration use models of individual behaviour that are too simple (because this eases the problem of mathematical aggregation) in the belief that the rational model could capture market behaviour even though it may be a poor description of individual behaviour. One reason for this belief stems from the cancellation hypothesis[4] which states that if individual errors are randomly distributed about the rational outcome then, by the law of large numbers, a market with many participants will show no bias (i.e. zero average error) and thus be rational[5]. This renders the question of how many traders are required to conform with the cancellation hypothesis. Again comparison across papers incorporating disparate numbers of traders is not possible because of inconsistencies in designs and parameter sets.

Plott and Sunder (1988) provide an ex post conjecture that, with the number of traders as a variable, an increase will not improve the FRE formation process. It is only a conjecture because the ceteris paribus condition required to provide an adequate control is violated. The same criticism can be levied at Camerer and Weigelt (1991) as the number of possible insiders and the prior probability of states

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[4] Camerer (1992) p.240.

[5] However, a systematic bias will occur if individuals err in the same direction, resulting in correlated errors and an individual bias that may reinforce itself when aggregated.

were both altered, although a consideration of the effect of the number of traders was not their intention. The same can be said for the papers by Smith, Suchanek and Williams (1988), O'Brien and Srivastava (1991) and Sunder (1992), all of which varied the number of traders but did not directly address its effect.

Fortunately Lundholm (1991) explicitly addressed the effect of varying the number of traders and constructed markets that incorporated 6 (N6) or 12 (N12) traders. There was no significant difference between the two markets with respect to price predictions but the speed of convergence was significantly faster for N6 markets within a period. Furthermore, the N6 markets were significantly more efficient with respect to final asset allocations. Lundholm's (1991) findings suggest that the cancellation hypothesis sheds no light on the efficiency of markets.

3.2.4 Assets

The earlier studies (e.g. Plott and Sunder (1982), Forsythe, Palfrey and Plott (1984), Friedman, Harrison and Salmon (1984), Banks (1985) and Copeland and Friedman (1987), etc.) and a large number of the more recent ones (e.g. Lundholm (1991), Camerer and Weigelt (1991), Copeland and Friedman (1991,1992) and Sunder (1992), etc.) all designed laboratory markets where a single asset was traded. If participants are required to trade more than one type of risky asset, thus forecasting the value of a number of securities, additional complexity is introduced. Plott and Sunder (1988) compared the behaviour in single security markets with that in markets with a complete set of state contingent securities. Somewhat perversely it was found that FRE outperformed both PI and MM in the markets with complete sets of state contingent claims when any of the measures (discussed above) were employed. This was not the case in the simpler environment of the single asset markets, which is why the results are described above as perverse, because the notion of the FRE model performing better in complex settings than in more simple ones is counterintuitive. However, these findings maybe a product of the design implemented in the markets with a complete set of state contingent assets. Three different assets were traded (x, y and z) and three states of nature were possible (X, Y and Z). Assets of type x yielded a positive return when the underlying state of nature was X and a return of zero otherwise. The same procedure is followed for assets y and z. Thus a portfolio of one of each type of asset is equivalent to a portfolio of one security in the single asset market. Given the method of information distribution (i.e. assuming the state was X, half the informed traders would receive the message 'not Y' and the other half would receive 'not Z', thus there is aggregate certainty), it is possible that the action of one individual offering to sell a certain asset, is construed by others to imply that the offerer has received information about the state informing them that the asset is worthless (e.g. if the asset were of type x the message inferred would be 'not X'). Thus traders will be able to infer the preferences of other traders and the task of valuing the securities will become simpler. This knowledge of other traders' preferences (discussed in more depth in the next subsection) is not accessible in the single security markets and so the design used does not realise an increase in complexity via an increase in the number of different assets traded.

O'Brien and Srivastava (1991) conducted experiments for markets with three (M3) or four (M4) different stocks, with each market year divided into two periods. The dividend in period 2 was dependent upon the dividend in period 1, therefore the state space (and thus complexity) was larger in period one. Results showed that FRE relative to PI performed poorly in period 1, but improves to become slightly better in period 2. When regressing the expected stream of dividends on price, little difference in behaviour was found between M3 and M4, but there is only one stock difference between the two markets. The two studies that have allowed for differing numbers of types of securities were not adequately designed to address the issue of how this will impinge upon information aggregation and thus upon market efficiency.

O'Brien and Srivastava's (1991) use of assets with two period lives is unconventional as it is usual within the literature to invoke single period lived assets which allows stationary replication (discussed above). This raises the issue of whether the use of multi-period lived assets would result in reduced information aggregation due to the increased complexity involved with calculating their uncertain value. Smith, Suchanek and Williams (1988) use such assets to test the theory that the current market value of a share tends to converge to the discounted present value of the rationally expected future dividend stream, and to search for the existence of price bubbles followed by crashes which deviate from the intrinsic value of a share, thus conflicting with the theory. They find that bubbles and crashes do occur, with a possible role for risk aversion, and conclude that the FRE model of asset pricing is only supported as an equilibrium concept that underlies an adaptive capital gains price adjustment process. The findings of these two studies indicate that the increased complexity resulting from the use of multi-period lived assets frustrates the convergence of prices to the FRE predicted levels.

The introduction of studies incorporating multi-period lived assets opens up the issue of the 'swingback hypothesis' (Forsythe et al, 1982, p.546). The swingback hypothesis implies that prices in 'later' market periods converge to predicted values before they do so in 'earlier' periods. Convergence in the earlier market periods only occurs after replication. Thus the convergence of asset prices 'swings back' from later market periods to earlier ones with repeated games. With respect to the literature in experimental asset markets, each market can be viewed as a single shot game. Thus, repeated play is possible in experiments with greater than one market year (the vast majority of experimental markets). Coupling this aspect with an experimental design that includes multi-period lived assets renders it possible to test the swingback hypothesis in an experimental asset market setting. Friedman et al (1984) provides a theoretical example of the hypothesis.

At the first impression the obvious study to allow an analysis of this effect would seem to be Smith et al (1988), because the design incorporated multi-period lived assets that lived for 15 or 30 trading periods. Unfortunately this design is analogous to a single shot game, because it effectively incorporates only one market year and therefore does not allow repeated play. However, early studies into the impact of futures markets in experimental settings satisfy both criteria and so permit such an analysis. For example, Forsythe et al (1982, 1984) design experiments which include two periods in each market year, P_A and P_B.

The swingback hypothesis, convergence in P_A follows convergence in P_B, can be expressed via a testable form via the inequality in equation 3.1.

$$\left|\overline{P}_A^t - P_A^F\right| > \left|\overline{P}_B^t - P_B\right| \quad \forall t \qquad 3.1$$

Where: $\overline{P}_A^t$ = average price during period A in year t,

P_A^F = FRE predicted price in period A,

$\overline{P}_B^t$ = average price during period B in year t,

P_B = maximum dividend across all traders in period B,

t = market year.

Forsythe et al (1982) report evidence in support of the swingback hypothesis in all experiments, with the inequality in equation 3.1 being satisfied in every year. Thus the last period converges first and the convergence works back from this to earlier periods as the market years replicate. Friedman et al (1984) also offer results in support of the hypothesis in their 'Appendix B' narrative.

Forsythe et al (1984) propose that the adoption of preferences linear in asset holdings in earlier studies may have biased previous tests in favour of the swingback hypothesis, because the equilibrium price in the final year is independent of trade in earlier periods. They remove this potential bias by introducing time-interdependent-preferences into the experimental design. Despite this adjustment they report results (p. 372) in favour of the hypothesis in 97% of cases in the presence of futures markets, but only 57% in the absence of a futures market (see later for a discussion of the role played by futures markets).

With respect to external validity considerations the swingback hypothesis abstracts from reality due to the requirement of a finite time horizon. Participants must be able to observe the end of the game and then apply the experience thus gained to subsequent replications (market years). With respect to common shares (especially so for large p.l.c.'s) the assumption of finite lives is not strictly valid. (There may, however, be a case to be made in association with bonds.) Such a criticism draws attention to the possible comparison to be made between finite and infinite time horizon games.

The study by Camerer and Weigelt (1993) allowed assets to live from period to period with a probability, $(1\text{-}p) = 0.85$, and pay a constant market clearing dividend, $D = 100$, at the end of each period. The design induced infinite-lived assets, removing the ability of participants to witness the end of the game and then repeat the same game. Thus the ability of prices to converge as a result of the swingback hypothesis is removed. Assets had an intrinsic value given by the discounted dividend equation in 3.2,

$$D + D(1-p) + D(1-p)^2 + \ldots\ldots + D(1-p)^\infty = \frac{D}{p}. \qquad 3.2$$

Camerer and Weigelt (1993) report that prices were very slow to converge to FRE predictions and sometimes overshot the intrinsic value. Markets with experienced participants appeared to converge quicker than markets with inexperienced participants. A comparison of finite and infinite-lived asset market results offers the conclusion that the ability to observe the end of a game and then replicate it allows participants to 'learn' quicker relative to infinite horizon markets where the pace of learning is hindered. Camerer and Weigelt (1993, p.380) conclude that single-period markets converge quickly to equilibrium values in the informationally rich DA institution, but multi-period markets converge more slowly, in the absence of futures markets, because traders lack information concerning prices in future periods. In the stochastically lived asset markets of Camerer and Weigelt (1993), convergence is even slower still, because participants are not able to repeatedly observe the entire asset life and learn via swingback.

The notion of multi-period lived assets has only briefly been touched upon by the literature thus far, with the tentative conclusion that the added complexity involved in estimating the present value of future dividend streams (asset value) hinders the convergence of prices to the levels predicted by the FRE model. This would seem to be an intuitive conclusion to reach, however, intuition has no place in hypothesis testing. To arrive at a conclusion with any level of conviction will require additional experiments explicitly designed to address the problem of multi-period lived assets. The trading of multiple assets as an additional source of complexity is a further area that has yet to be fully considered.

3.2.5 Dividends

Within the experimental literature, trade amongst participants has conventionally been invoked by creating the existence of gains from exchange. This has been achieved by paying diverse dividends between trader types given the underlying state of nature. This has formed the custom for the majority of papers, but some have not adhered to the convention of artificially invoking diverse preferences. Plott and Sunder (1988) design their series A markets with dividends differing between trader types and their series B markets with uniform dividends resulting in identical preferences. Messages were given to insiders with no single trader being given perfect knowledge but with the existence of aggregate certainty (elaborated upon in 3.2.6). In the series A markets FRE provided a poor description of behaviour and was outperformed by both PI and MM, although there was no overall best model. This was not the case in series B, in which FRE was the superior model, indicating that to achieve FRE equilibrium required homogenous trader types.

Smith, Suchanek and Williams (1988) also designed markets in which traders holding the same type of stock were paid identical dividends, with the explicit intention of investigating whether participants would trade when all faced identical uncertain dividend payout schedules. They argued that artificially induced differences in preferences were not necessary to ensure trade, as participants would have 'homegrown' differences. The results allowed the conclusion that sufficient homegrown diversity in subjects' price expectations and risk preferences existed, inducing subjective gains from exchange. Other studies incorporating uniform dividends include Lundholm (1991) and two of the experimental markets in Sunder (1992).

Finally, O'Brien and Srivastava (1991) were concerned with the existence of arbitrage relationships and so designed experiments with multiple asset types which paid an identical dividend to any subject holding a given asset type at the end of a period. They found the arbitrage relationships, suggested by the dividend structure incorporated, held. However, the markets were generally inefficient with respect to full information aggregation. Knowing this they tested the random walk hypothesis using the Dickey-Fuller test for unit roots, which provided evidence against the rejection of the implied hypothesis of an informationally efficient market. Their overall conclusion being that the lack of arbitrage opportunities and the failure of standard tests to reject market efficiency are not sufficient to deduce that a market is informationally efficient.

In compliance with the notion that stationarity (see above) is required for convergence to FRE equilibrium many studies (early examples include Plott and Sunder (1982) and Friedman, Harrison and Salmon (1984), etc.) maintained individuals' payout schedules constant across periods. A notable exception being Ang and Schwarz (1985) who allowed payoffs to trader types to vary across periods thus creating a more uncertain environment in which to trade. Unfortunately, additional complexities were present and so direct comparison is not possible. Furthermore the objective of their paper was to analyse the effect of risk preferences on price variability, not solely an investigation into information aggregation.

Knowledge of ones own payout schedule is prevalent within the literature and it is common for information concerning others schedules to be nothing more than the knowledge that they may differ, thus resulting in an endogenous uncertainty as to what the price of an asset should be. This is the case in, amongst others, Friedman, Harrison and Salmon (1984), Plott and Sunder (1988), Camerer and Weigelt (1991), Copeland and Friedman (1991) and O'Brien and Srivastava (1991). In contrast to this technique Forsythe and Lundholm (1990) and Lundholm (1991) both allow common knowledge of the payout schedules of all trader types. The following discussion will focus on the former paper as this permits comparison with Plott and Sunder (1988), in which the FRE model performed no better than the exogenous information models (PI and MM) in markets with a single asset and traders with diverse preferences (that is the series A markets). The design in Forsythe and Lundholm (1990) differed in three ways: 1) All market parameters were common knowledge. 2) Markets were conducted over two consecutive nights with constant parameters and rotation of trader types, resulting in gained experience. 3) Increased number of traders. Comparison with Plott and Sunder (1988) showed the first night of each market to behave similarly in that prices were relatively insensitive to the state of nature. However, in the second night of trade FRE significantly outperforms both PI and MM with respect to price and allocation predictions. To evaluate the effect of the common knowledge of dividends on the performance of the FRE model, Forsythe and Lundholm (1990) conducted experiments in which this was absent and consequently so was trader type rotation. They found that the FRE model fails to predict accurately even by the end of the second night of trade and so conclude that the common knowledge of payout schedules has a significant influence on the success of the FRE model, as it simplifies the task of inferring information from other traders' activities. However, from the results in the first night of each market it is clear that common knowledge of both payout schedules and trader types, and an increased number of traders is not sufficient to ensure a FRE equilibrium, suggesting that the poor performance in Plott and Sunder (1988) was not due solely to a lack of common knowledge. Forsythe and Lundholm (1990, p.341) conclude that 'common knowledge of dividends and a similar prior experience are jointly, but not separately, sufficient to achieve an [F]RE equilibrium.'

3.2.6 Nature of Information Received by Insiders

The main area of concern focused upon by the literature into informational efficiency is the aggregation and dissemination of private information held by a few select individuals. It is for this reason that in many experiments news messages concerning the underlying state of nature are sent to a number of 'insiders'. Various studies consider different aspects of the type of information given (i.e. perfect or imperfect, and homogenous or heterogeneous), the manner in which it is given (i.e. simultaneously or sequentially) and the determination of insiders. It is to these issues and the findings in this area that the discussion now turns.

Perfect Information: Plott and Sunder (1982) distributed clue cards simultaneously to all traders, half the cards contained perfect, homogenous information as to the underlying state of nature and the other half were blank. The blank cards were distributed so as to conceal the identity of the insiders, from whose actions and the influence they have on prices, the uninformed had to infer the state, thus requiring implicit Bayesian judgement (see Camerer, 1992). Results suggested that the four measures, price, allocation, efficiency and profit (see above), tended towards FRE predictions over time as experience grew, implying that with experience the uninformed were able to infer the state of nature. However, it is not clear that they were using the market price to do so, as other observables (e.g. signs of emotion from other traders which may have identified the insiders, this could have been controlled via the use of networked computers situated in various rooms) were not adequately controlled for. Friedman, Harrison and Salmon (1984) conduct similar experiments in which a third of traders (one out of three from each of the three trader types) are given perfect information, and the effect of futures markets on the behaviour of the asset market is considered (discussed below). They find that the market outcome evolves over time to the FRE prediction. Banks (1985) criticises the above two studies on the grounds that the same traders were informed in almost every period and states that the possibility cannot be ignored that the uninformed guessed the identity of the informed and used observed behaviour to infer the state as opposed to market prices, bids and offers. To limit the possibility of this Banks replicated Plott and Sunder (1982) but randomised (as far as participants knew, but predetermined in reality) the identity of the informed participants, finding that the fixed information structure in Plott and Sunder (1982) was not responsible for the convergence of price to the FRE level, but concluding that the claim that the uninformed infer the state from observing market price is weakened.

DeJong, Forythe, Lundholm and Watts (1991) investigate whether prices alone carry information. The FRE model predicts uninformed traders condition their beliefs about the underlying state of nature by observing market prices only. As suggested above, it is not clear that participants in Plott and Sunder's (1982) markets were using only the market price to infer the private information of insiders. Other observables such as signs of emotion from other traders may have identified the insiders. DeJong, Forythe, Lundholm and Watts (1991) examine to what extent results in earlier experiments were the consequence of the richer information sets available in oral DA markets compared to computerised markets, by computerising some of Plott and Sunder's (1982) markets. The results support the convergence of prices and allocations to FRE predicted equilibrium values. However, the convergence process is much slower, indicating that the dissemination of information takes longer when price is the only market signal available.

To investigate the impact of the presence of insiders on market outcomes Watts (1993) examines Plott and Sunder's (1982) markets. The presence of insiders is not guaranteed. Each period it is equally likely that there will be either zero or six insiders. Uncertainty over the presence of insiders reduces the markets ability to converge to FRE predictions.

Imperfect Information: The previous studies all provided messages about the state of nature that were perfect and, therefore, are only concerned with the dissemination of information. A number of studies have been concerned with the possibility that the market may be able to aggregate individual information that is partial, and so does not exactly identify the underlying state, and disseminate it through out the market. Plott and Sunder (1988) investigate the issue of information aggregation in the situation where traders have diverse information as to the state of nature, such that no individual knows the state, but if individuals pool their information the state can be identified with certainty (thus there is aggregate certainty). They found that information aggregation was poor and FRE equilibrium was difficult to achieve (series A). Convergence to FRE predictions required a complete set of state contingent markets and homogenous trader types (that is identical payoffs). O'Brien and Srivastava (1991) also construct markets with, on the whole, complete information, splitting each year into two periods and trading two-period lived assets. The use of markets with complete information allows the FRE equilibrium to be independent of risk preferences and so allows the assumption of risk neutrality. They discovered that information aggregation was much better in the second period due to the increased complexity involved in calculating the assets value in period one (due to the increased state space), but that markets are generally inefficient from the view point of full information aggregation. Forsythe and Lundholm (1990) is a further paper in which individuals receive partial information which results in aggregate certainty, but a contrasting design to that of Plott and Sunder (1988) permits the conclusion that a common knowledge of all payout schedules and a similar prior experience are jointly sufficient to ensure convergence to FRE predictions. Thus the removal of uncertainty with respect to other traders' incentives to trade results in a sufficient decrease in the noise inherent in the market for the uninformed to infer the market signal.

With aggregate certainty as part of the information structure, Lundholm (1991) states that participants are able to calculate the FRE equilibrium ex ante. This is not the case with aggregate uncertainty in which the sum of all traders' information does not perfectly identify the assets payoff. In this situation, the equilibrium price will be contingent upon traders' risk preferences which are unobservable, thus negating participants ability to identify others' incentives to trade. Consequently, Lundholm (1991) provided traders with messages that only eliminated two out of four states, resulting in aggregate uncertainty. Other features were incorporated in the design that should have facilitated convergence relative to other studies with aggregate certainty (e.g. common knowledge of parameters and additional experience). Despite these aids the aggregate uncertainty markets were considerably less efficient. Such findings cast doubt over FRE and the informational efficiency of markets when diverse information requires aggregation in the presence of aggregate uncertainty.

Differential Information Content and Arrival Times: In a key paper in the experimental literature Copeland and Friedman (1987) manipulated the arrival time of news messages to insiders, allowing them to arrive simultaneously or sequentially. The sequential arrival of news messages is analogous to the way in which information is received on actual stock exchanges. They also manipulated the informational content of the news messages, allowing them to be homogenous or heterogeneous. The heterogeneous information messages are analogous in reality to different individuals having diverse interpretations as to the implications of the same item of information. Having predicted that prices and allocations would be closer to the final equilibrium predictions (equivalent to FRE predictions) in the simpler environments (simultaneous and homogenous) than in the more informationally heterogeneous environments (sequential and heterogeneous), they found fewer misallocations (marginally significant) in the simultaneous than sequential markets and insignificantly better price and allocation convergence in simultaneous than sequential and in homogenous than heterogeneous markets. Thus providing only weak support for their predictions. In a similar situation Copeland and Friedman (1991) find that FRE is inconsistent with heterogeneous data and NRE inconsistent with homogenous data, whilst their PRE model is generally supported. This model is partially successful in reconciling the support for FRE in asset prices with that for NRE in information auctions. It is the literature into this latter auction that will now be discussed.

3.2.7 Market For Information

In the analysis above consideration is only given to those findings related to the costless distribution of information. However, the various models under evaluation give different predictions for the value of such information. The FRE model predicts the value of private information to be zero, thus if a market for information was conducted the FRE model would predict the price to fall to zero. The price would remain positive according to the PI model in which information remains valuable because it is not revealed. These differences in price predictions for the models provides another means with which to discriminate between them and has been exploited by a few papers. Copeland and Friedman (1992) extends on Copeland and Friedman (1987) by incorporating a pretrade auction for information in which traders bid to receive their news message before each trading period opens. Messages are given anonymously to the three highest bidders, at the fourth highest bid price, in a uniform-price sealed-bid auction. Consequently, the identity of those traders who receive information is determined endogenously, this is in contrast with such studies as Plott and Sunder (1982, 1988) in which the identity is determined exogenously. In the simple simultaneous/homogenous environments the market value of information declines and tends to zero over time. However, in the more complex setting of the heterogeneous markets, the market value remains positive providing evidence in favour of the NRE model. Copeland and Friedman (1991) attempt to design a model that bridges the gap between semi- and strong form efficiency, which partially reveals private information, PRE. In the context of information markets PRE predicts that in homogenous environments the value of purchased information will decline to zero because the trading behaviour of individuals will unambiguously signal their private information, whilst in the heterogeneous environment the value will remain positive because the signal-message correspondence is not perfect and so private information is only partially revealed. Their results from the information market are reasonably consistent with PRE, whilst heterogeneous data is definitely inconsistent with FRE and homogenous with NRE. Finally, Sunder (1992) investigates the proposition that in competitive equilibrium asset prices reveal information in such a way that net returns to the production of information are zero, using two different designs for the information markets. In series A the supply of information is fixed at four traders with the price determined by the market (i.e. fifth highest bid price), whilst in series B the price is fixed and the number of buyers is determined endogenously. Series A results show a decrease in the cross-sectional standard deviation of net profit and thus convergence to the equality of profit across traders over time. These results provide support for the FRE prediction that the price of information in equilibrium is zero and there is no difference between gross and net profit. The results of the series B markets are less supportive. The distribution of profit does not converge to the full revelation (FRE) benchmark even with experience and all market observables point towards the lower informativeness of the series B markets relative to series A. Despite this the net profit of informed and uninformed traders were statistically indistinguishable.

In a slightly different context Camerer (1992) reports of experiments in which worthless information is auctioned off, with the prediction that its value should be zero. One group of uninformed participants were requested to guess the 1980 earnings-per-share (EPS) for a number of actual companies, based on data concerning the companies during the previous decade. A further set of participants then traded assets whose dividends were equal to the average of the estimates of the uninformed participants. In order to value the asset correctly the traders had to estimate what the uninformed thought the actual EPS's would be. Prior to the market for the asset, the actual EPS was auctioned off to the four highest bidders, at the fifth highest price. Initially bids were at high prices close to the asset value, but by the fifth auction prices had converged to zero. The results show that with experience participants realised the value of the information was zero. The worthlessness of the information is equivalent to that of the private information in a fully revealing situation and so these results have some implications for the efficiency of markets, although not directly.

In the above mentioned studies that have focused on auction markets for information, the private messages bid for always revealed the payoff state with certainty, thus these studies have addressed the question of information dissemination. It seems probable that the increased complexity introduced by incorporating imperfect signals into the design, via the need for the aggregation of information, will have some bearing on the efficiency of the experimental market and on the convergence of the price of information to zero. Ackert, Church and Shehata (1997) incorporate costly, imperfect information in their experimental design and directly address the value of imperfect information and dissemination and aggregation of imperfect information. They conducted 12 markets each of which consisted of 12 or 11 traders divided among two trade types with disparate state contingent dividends. Half the markets were conducted with inexperienced traders and the other half with experienced traders. The markets were conducted under the rules of oral double auctions, with a single asset traded at a time. Two states of nature were possible, X and Y, drawn randomly from a deck of 50 cards, comprising 30 X and 20 Y. A market for information is conducted prior to trade under the rules of a sealed-bid auction with the four highest bidders acquiring the clues at the fifth highest bid price. Clue accuracy was determined by the draw of a card from a deck of 40, labelled A for accurate and I for inaccurate. Clue accuracy was manipulated to lie between 0.60 and 0.90 to determine the sensitivity of the market to the chosen parameter values. At the end of each trading period the state of nature and clue accuracy (accurate or inaccurate) were revealed to all participants.

In seven out of the twelve markets prices converged to predicted Bayesian prices. Of the remaining five markets, four experienced under-reaction and one market generated prices that over-shot the Bayesian price (over-reaction). Price convergence was found to be affected by clue accuracy with all five cases of failure to converge occurring under clue accuracy of 0.60 and 0.75. Those markets with the least uncertainty (0.90) never failed to converge. The results support at least partial dissemination of information with prices moving away from those predicted by a naive benchmark (reflecting only prior probabilities) in nine out of the twelve markets. Ackert et al (1997) also investigates the allocational efficiency of their markets. In those markets with inexperienced traders and the lowest level of clue accuracy (0.60) the majority of assets were held by the wrong trader type under state X, whereas the other markets obtain asset allocations ranging between 60-96% accurate. Under state Y the 63-100% of assets were held by the correct traders.

Ackert et al (1997) report that the value of the imperfect information decreases over time and tends to zero in some markets. Information value is lower in experienced markets than inexperienced markets, in one of which prices strangely increased over time. Overall, however, prices converge to a value that is above zero and below a computed upper bound (based on an assumption concerning the number of assets an individual buys). Thus Ackert et al (1997, p.71) conclude, '.... traders perceive imperfect information has value' and this is consistent with imperfect information being slowly disseminated through the market. Like Sunder (1992), the study compares the profit of informed and uninformed traders. Comparing the average *gross* profit of the two, Ackert et al (1997) find that the uninformed outperformed the informed. Though not explicitly reported, this result would have been further exacerbated if the comparison had been on a net of information acquisition cost basis. Ackert et al (1997) relate this difference in average gross profit to the degree of clue accuracy, reporting that informed traders were able to earn a greater profit in those markets with a high degree of clue accuracy than in the low clue accuracy markets in which their ability to trade profitably suffered.

3.2.8 Mirages

In Sunder (1992) there were a number of occasions when the market converged to the FRE prices of a state that did not occur and so the market seemed to have been 'fooled'. This leads on to the phenomenon of informational mirages, to be discussed in this section.

Ang and Schwarz (1985) incorporate a design that allows them to create the illusion that some traders have superior information when they do not. Consequently some market participants may ignore their own prior information and attempt to infer the nature of the 'superior' information, thus generating false information[6]. The issue of mirages is not their main aim and so direct conclusions are limited, however, they do conclude that speculative, as opposed to conservative, investors appear to be more rational and less likely to respond to false information. Copeland and Friedman (1991) conclude their discussion by stating that the existence of mini-bubbles may be the result of traders rationally attempting to extract information from imperfect market signals. A price rise due to noise may be misread as a response to private information, provoking a further price rise. The existence of bubbles and crashes was investigated by Smith, Suchanek and Williams (1988) who found that whilst experience reduced the number of bubbles it did not eliminate them. King, Smith, Williams and van Boening (1990) report that allowing short sales does not reduce the propensity for bubbles to occur, nor the size of the bubbles, contrary to widely held views based on the notion of better-informed traders making money at the expense of others and so disciplining them.

More recently Harrison (1992) designed a series of experiments that allowed an investigation into the existence of price bubbles in the presence of futures markets and programmed arbitrage traders. An interpretation of the results suggests that the existence of a futures market may actually promote price bubbles in spot markets.

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[6] As noted by Ang and Schwarz (1985) p.829, the tautological nature of FRE means there can be no such thing as false or irrelevant information, because all information is incorporated into prices.

However, introducing varying maturity futures reduces the potential for this to occur. The reported results also support the conclusion that programmed arbitrage between the spot and futures market is 'crucial for ensuring the informational efficiency of the spot market' (p. 60) despite being positively active in the existence of bubbles and crashes. The reasoning behind such an interpretation stems from the notion that arbitrage actually reduces the duration of a bubble by forcing the market to crash, thus removing the necessity for participants to trade at disequilibrium prices.

The first paper to directly address the existence of information mirages was that by Camerer and Weigelt (1991), the design of which was very similar to Plott and Sunder (1982) except that before each period commenced a coin toss determined whether there would be any insiders in that period or not. Regardless of the existence of insiders everyone received a clue card and if there were no insiders that period then all cards were blank, therefore, nobody was able to infer when there were insiders. The results showed the existence of only a few permanent mirages and these always occurred early on in the experiment. Trading was slower when there were no insiders, and with experience traders were able to learn that the pace of trading was a sign as to the existence of insiders, which is the reason for the existence of permanent mirages only early in an experiment. The results further showed that for every sustained mirage, prices followed those of an earlier period with insiders that took a similar path, thus lending support for the representativeness theory.

As mentioned above, Sunder (1992) observed a few occasions when the market converged to the wrong price. In contrast to the above study this tended to occur in later periods, the reason being the focus of the study. The intention was to investigate the purchase of costly information, it was found that the price and purchase of information tended to converge towards zero. Thus in later periods there were relatively few traders with information, and this is when convergence to the incorrect price occurred.

3.2.9 Futures Markets

There is a commonly supported belief (see Hardy (1940)[7]) that trade in futures is merely a form of gambling, and as it is speculative the spot price will exhibit greater volatility in the presence of a futures market than in its absence. Thus futures markets will result in inefficiencies, because price volatility will induce suboptimal

[7] cited in Forsythe, Palfrey and Plott (1984) p.956.

asset allocations. Contrary to this view Hicks (1939)[8] suggests the presence of futures markets may eradicate two potential sources of disequilibrium, namely the inconsistency across traders of future plans and price expectations. Future plans and prices are directly observable in the presence of futures markets, allowing an efficient equilibrium to arise. Grossman (1978) further advocates the benefits of futures markets, arguing that they alleviate the need for replication to achieve equilibrium, because traders can learn about prices tomorrow by examining current prices in the futures market. The last two studies above reflect the notion that futures markets are able to confer private information about the future, thus aiding equilibrium and improving efficiency. The effect of futures markets on spot price volatility and market efficiency is examined by a couple of 'early' experimental investigations, these will now be considered.

Forsythe, Palfrey and Plott (1984) designed a series of experiments that built upon their earlier, preliminary study (Forsythe, Palfrey and Plott, 1982) of the role of futures markets in experimental asset markets. In order to examine this role, some markets operated in the presence of futures markets whereas others did not, thus providing a control. Those markets operating in the absence of a futures market were conducted with participants that had greater experience than their counterparts, resulting in a bias in the design against the futures markets. The reasoning being that this would provide a strong test of the ability of futures markets to speed the convergence of the spot market to FRE equilibrium. The results were 'unambiguous', providing strong support for the view that futures markets did in fact speed convergence, as their earlier study had initially suggested. A further finding was the increased volatility of spot prices (i.e. increased variance) in the presence of a futures market, providing some support for the view expressed by Hardy (1940) and supported by Svenson (1976) who also believes they are destabilising.

However, Friedman, Harrison and Salmon (1984) provide a study with contrasting results. Their design incorporated a three period market year (as opposed to two period in Forsythe, Palfrey and Plott, 1984) and three trader types (as opposed to two types in the above study). Futures contracts were written in either of the first two periods and then delivered in the final period within a year. Comparable to the study of Forsythe, Palfrey and Plott (1984), they found that markets converged to

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[8] cited in Forsythe, Palfrey and Plott (1984) p.957.

FRE equilibrium and this was robust to the inclusion or exclusion of futures markets. The disparity between the two papers is in relation to their results on the volatility of spot markets with the presence of a futures market. As reported above, Forsythe et al (1984) found an increased volatility, whereas Friedman et al (1984) concluded that the presence of a futures market tended to stabilise spot prices. This discrepancy may be a product of the treatment variables investigated, because Forsythe et al (1984) used the joint variable of 'futures market and inexperience', whilst Friedman et al (1984) separated out the two effects and found that futures markets reduced the 'coefficient of variation' of prices, but that inexperience caused it to increase. It therefore seems possible that the 'inexperience effect' was dominating the 'futures market effect' in Forsythe et al (1984).

A novel finding of the study by Friedman et al (1984) is that futures markets promote the 'leakage' of inside information (that is dissemination to the rest of the market), as supported by the result that the PF model (strong form efficiency, equivalent to FRE) outperformed the URE model (semi-strong form efficiency) only in the presence of a futures market.

Harrison (1986) provides an additional study of experimental asset markets where futures markets exist, however, comparison with the previous cited studies is not possible as the existence of a futures market was not the treatment variable under consideration (all the markets in the series of experiments contained a futures market, resulting in no effective control). Three experimental markets were conducted, each of which consisted of three trading periods in each market year, denoted PA, PB and PC (futures market). The series of experiments were designed to allow the impact of event uncertainty (state contingent dividends) and inside information on the convergence of asset prices to theoretical equilibria. Thus, this three way experimental design provided for an analysis of comparative market behaviour in the presence of futures markets. Harrison (1986) reports pooled results for PA and PB in each market year which support the conclusion that event uncertainty and inside information have strong and offsetting individual effects on the RMSD of transaction prices from FRE levels. Event uncertainty reduces efficiency whilst inside information improves efficiency, with the two effects approximately netting out. The impact of the two treatment variables on the propensity to hedge via the futures market was also reported, with event uncertainty discouraging and inside information encouraging the use of futures hedges.

Introducing the notion of stock-flow analysis, and thus explicitly recognising the interdependence of current production, consumption and asset holding plans, Harrison (1992) extends his previous study. The experimental design was adjusted to incorporate twice experienced participants trading over 5 market years each consisting of 8 periods. In the series 2 experiments a futures market operated in period 8 of each year, whilst in series 3 and series 4 such a market operated in periods 4 and 8. The distinction between series 3 and 4 was simply the introduction of programmed arbitrage in the latter series. The experimental design, therefore, permits analysis of the role of futures markets, the term structure of futures markets and programmed arbitrage by comparison to the control, series 1.

Results from the series 2 experiments support the belief that futures markets convey information signals concerning the likely equilibrium price, resulting in an increased speed of convergence. However, transaction prices tended to overshoot the equilibrium price in the initial periods (price bubbles) and a higher variance in spot prices was observed. The series 3 experiments also exhibited an increased volatility of spot prices, however, less overshooting of the equilibrium price was reported. Prices 'converged more rapidly and less violently' (p. 60) to final equilibrium prices. This suggests that increasing the number of varying term futures may offer a better guide to the dynamic path of prices. In addition Harrison (1992) found that the arbitrage traders in the series 4 experiments constrained the duration of any price bubbles that formed in the spot markets and so facilitated informational efficiency.

Due to the conflicting results reported by the earlier studies into the role of futures markets no firm conclusion can be drawn with respect to their effects on spot price volatility. However, the evidence in support of increased spot price volatility reported in Harrison (1992) may point opinions in this direction. Despite this possible dysfunctional aspect to the impact of futures markets Harrison (1992) suggests they convey valuable information concerning equilibrium prices and so facilitate the speed of convergence towards such prices. Furthermore, the impact upon volatility is reduced the more maturity dates are available for various futures. Unfortunately not one study stands out as providing conclusive evidence and so additional research is required to clarify the role futures markets play.

3.2.10 Options Markets and Arbitrage

In a study of the relationship between arbitrage and informational efficiency, O'Brien and Srivastava (1993) introduce options into the experimental design of DA markets. The markets trade four different securities; two different two-period lived assets plus an American call option and an American put option, both with exercise prices of 30. The dividend payout from each asset is dependent upon both a first-period and a second-period realisation of an uncertain state, X, Y or Z. The dividend is only paid in the second period, thus, the first period dividend is zero. The two assets have identical dividend distributions, but differ because the state realisation per period is drawn independently for each asset. The information structure is imperfect ('Not x', 'Not Y' etc.) with aggregate certainty. At the beginning of period two all traders are informed of the state for period one. At the commencement of each trial (period one plus period two) traders were given one of three endowments; cash plus 100 units of asset one, cash plus 100 units of asset two or 100 units of asset one and 100 units of asset two. The trading rules permitted unlimited borrowing and unlimited short sales.

O'Brien and Srivastava (1993) initially suggest that the relationship between arbitrage and informational efficiency may offer a dynamic story of convergence to FRE, with arbitrage opportunities disappearing over time. However, the evidence from their markets does not support this view, indeed in certain markets the persistence of arbitrage increased over time. The experimental investigation into the implications of arbitrage opportunities and options is limited. It is clear that further work in this area would be beneficial.

3.2.11 Risk Preferences

The FRE model in equilibrium identifies the state of nature with certainty and so consequently its predictions are free of any assumptions about the risk preferences of participants. However, Lundholm (1991) observes that this will not be the case when aggregate uncertainty is present. In this situation the union of all traders' private information will not identify the state with certainty, thus the equilibrium price will be dependent upon risk preferences. In addition, the models of PI, URE, ORE, and PRE all require the assumption of risk neutrality, whilst the MM model requires the different assumption of risk aversion. It is therefore surprising that the investigation of risk preferences as a treatment variable has been given scant consideration within the literature.

LeRoy and LaCavita (1981) believe that risk aversion is a source of 'excessive' volatility in prices, but acknowledge the fact that this cannot be investigated with the use of empirical data on stock prices because the degree of risk aversion must be determined from the same price data as used to measure volatility, and so is not obtained independently as is required. This problem is of such a nature that it is readily overcome by employing an experimental methodology, which allows the determination of subjects' preferences and the segregation of the market to control for such a variable, prior to trade.

The earliest experimental paper to directly address the notion that risk preferences may have an influence on the functioning of asset markets is Ang and Schwarz (1985). They design two physically separate markets, one with risk averse traders (conservative) and the other with less risk averse traders (speculative)[9]. The results show there is a difference in the behaviour of prices when participants are speculative, as compared with when they are conservative. Conservative investors were found to demand higher risk premiums and were slower to adjust their portfolio to reflect the arrival of new information. Ang and Schwarz (1985) suggest that this latter point is due to either a longer memory toward past price history or a greater dependence upon current wealth. In addition, it was found that markets with speculative investors exhibit greater price volatility, thus contradicting the theoretical predictions of LeRoy and LaCavita (1981), discussed above. However, it may be argued that this is not dysfunctional from an economic efficiency viewpoint, as such markets also display a number of advantageous properties. Namely, in markets with speculative investors, prices tend to converge closer and faster to equilibrium values and a higher level of allocational efficiency is achieved. Furthermore, speculative investors are less likely to be 'fooled' by 'false' price information.

O'Brien (1992) also conducts oral DA markets with risk preferences of central concern. Five markets were conducted in which the dividend distribution was common knowledge and the only source of gains from exchange was disparate, controlled risk preferences. The risk preferences of marginal traders were controlled and manipulated across the five markets. In four of the markets traders were either buyers *or* sellers, whilst in Market 4 they were permitted to be both buyers *and* sellers. Therefore, only Market 4 is of interest here, however, the results are consistent across the five markets. The results indicate that risk preferences can be

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[9] This was achieved by giving 70 subjects two psychological tests on preference taking behaviour. A high score signifying least risk aversion and a low score signifying most risk aversion. The twelve subjects in each of the polar opposite extremes (that is the twelve highest and twelve lowest scores) were used to perform the experiment.

controlled in DA markets via a set of incentive contracts between the experimenter and each trader, of the binary lottery form developed in Berg, Daley, Dickhaut and O'Brien (1986). Also, the DA market attains high levels of market efficiency, averaging 92%, in markets where gains from trade result solely from disparate risk preferences, indicating trade towards efficient risk sharing.

It is clear that further research into the effects of disparate risk preferences is necessary, not only because many models of equilibrium require assumptions about such preferences, but because these preferences may have a role to play in the determination of price patterns prior to equilibrium. The behaviour of prices prior to convergence to equilibrium is of prime importance because of the insight such information provides with respect to an individual's decision making process and expectation formation. These are areas requiring additional theoretical and empirical research.

3.2.12 Specialist Trading Rules

The structure of the market institutions that govern the trade of financial assets are constantly under review to see if changes can be made to improve both operational and market efficiency. To introduce whole scale changes to market structure and trading rules is potentially very risky and costly. Experimentation has a productive role to play, providing a test bed in which new market structures and trading mechanisms can be explored and evaluated before their implementation on the world's stage. The implications of trading suspensions, off-floor trading and specialist traders, amongst others, have been investigated in the experimental literature. Discussion will now turn to a brief review of these papers.

In an experimental design similar to that of Plott and Sunder (1982), Coursey and Dyl (1990) introduce trading suspensions and price change limits to the experimental design. In a control market of fifteen trading periods, after the fifth trading period, they adjusted the probability of occurrence of the two states by an amount unknown to participants. This design was repeated with the inclusion of a trading suspension. During periods 6-10 trading was suspended but participants were still informed of the state of nature and received the corresponding dividend. In a second treatment market the control design was repeated with the introduction of a 4% price change limit. The price convergence process was faster and more precise in the control market, which also achieved higher allocative efficiency. In the market with trading suspension, prices did tend to the predicted equilibrium after the trading suspension was removed, but more slowly and less accurately than the control market. The market with the 4% price change limit also exhibited slower convergence and reduced allocative efficiency.

In Campbell et al (1991) supply and demand schedules are shifted by the addition of a random constant (positive or negative) so stationarity does not exist. This paper addresses the concept of off-floor trading and block trading. Off-floor trading was more prevalent in those markets with a wider bid-ask spread and those that permitted block trades.

Benabou and Laroque (1992) offer a theoretical analysis of privileged insiders' ability, and their incentives, to manipulate public information and asset prices. Whilst not explicitly addressing the theoretical analysis of Benabou and Laroque (1992), Friedman (1993b) explores the profitability of specialist trader privileges and market behaviour. Only those privileges under the DA institution are discussed here. Four treatment variables offering privileges were considered; POST (the ability to enter bids and asks, market making), DELAY (earlier access to orderflow information), ARB (ability to arbitrage crossing of the bids and asks) and BOOK (complete orderflow information, outstanding bids and asks). The least profitable privilege is the complete orderflow information, which was effectively worthless. Earlier access to orderflow information offers statistical improvements in profitability of in excess of 70 cents per period. These two privileges did not impair market performance and even improved efficiency. The arbitrage privilege generates an excess profit of $1.00 per period. The market making privilege was exceptionally profitable, generating excess profits averaging $3.32 per period and three times the level of unprivileged traders' profits. This privilege is statistically very harmful for informational efficiency and market depth, but less so for volume and allocational efficiency. Friedman (1993b, p.533) concludes that, with the exception of market making, most privileges do not have the expected adverse impact on market efficiency.

3.2.13 Computer Simulation

The previous section highlights the importance of individual trading behaviour on the price formation process, however, a number of studies concerning trading behaviour in DA markets adopt a computer simulation approach. Whilst not being experimental, these studies warrant discussion here due to the implications of their findings for the trading rules of the DA.

Gode and Sunder (1993a) compare trading behaviour observed in experimental markets with that generated under simulated markets with 'zero-intelligence traders' (ZI) represented by computer programmes. The market design adopted did not incorporate the dual role of traders as *both* buyers and sellers simultaneously, traders were either buyer *or* seller. As a result the design is more akin to the early commodity markets investigated in the experimental literature than the asset markets that are the focus of this study, however, the importance of Gode and Sunder's (1993a) findings requires their inclusion here. The ZI traders generated random bids and asks depending upon whether they were assigned as buyers or sellers, with each market comprising six buyers and six sellers. Two types of ZI traders were investigated, ZI unconstrained (ZI-U) and ZI constrained (ZI-C). The former's bids and asks were generated from a uniform distribution of prices that encompassed the feasible range of prices, the latter were restricted to random bids and asks that would result in non-negative profits, as determined by their reservation prices.

Gode and Sunder's (1993a) control markets with human traders converged to competitive equilibrium prices and allocations in most markets after only a few trading periods. However, in comparison the ZI-U markets were very erratic with no convergence of prices and poor efficiency of allocations. The interesting results from the simulated markets concern the ZI-C markets. The transaction prices converged close to competitive equilibrium prices and a high level of efficiency was attained, though not as high as the 100% efficiency observed in the experimental markets. Importantly, the transaction prices later in a trading period were generally closer to the competitive equilibrium than prices from early in a period, thus mirroring the nature of price convergence observed in the experimental markets. Given that the ZI-C traders were incapable of learning Gode and Sunder (1993a) were able to show that the institutional rules of the DA, rather than solely individual rational behaviour, promote the high levels of efficiency and convergence of transaction prices to competitive equilibrium values. Gode and Sunder (1993a) conclude that the 'market discipline' imposed on traders resulting from the structure of the DA institution produces aggregate (market) rationality with or without the presence of individual rationality. In a related study, Gode and Sunder (1993b) attempt to determine the lower bounds of expected efficiency (surplus extraction) in DA markets under 'continuous' and 'synchronised' trading rules and investigating the effects of extra-marginal traders. Under the rules of a continuous DA traders are permitted to submit bids and asks as and when they desire. The essential difference in a synchronised DA is that all traders are simultaneously solicited to submit bids and asks, the highest and lowest of which become, respectively, the current bid and the current ask. As usual, a binding transaction occurs when the current bid and ask cross. Gode and Sunder (1993b) report that the worst case expected efficiency of the synchronised DA market is 81% compared to 76% for the continuous DA. Gode and Sunder (1993b) conclude that this reduction in relative efficiency is the result of extra-marginal traders displacing intra-marginal traders being more likely to occur in continuous DA markets than the synchronised DA markets. Extra-marginal traders are those that, given the demand and supply schedules derived from induced cost and redemption values, are predicted not to trade

Gode and Sunder's (1993a, 1993b) results were generated using single markets, Bosch and Sunder (1996) generalise their findings to the multi-market level. In each market buyers and sellers submit randomly generated bids and asks, subject to a non-negative profit constraint. The markets are governed by the rules of the DA institution. Each market is inter-related and linked by the presence of arbitrageurs that are permitted to sell in one market and buy in the next. Initially, these arbitrageurs are permitted to trade subject to constraints upon their opportunity set, requiring them to submit only bids and asks that can be immediately and simultaneously executed, thus their inventory is zero at all times and they too are restricted from making a negative profit due to price changes. Under these restrictions Bosch and Sunder (1996) report transaction prices that gradually and noisily converge to the competitive equilibrium price and allocations that are highly efficient. Relaxing the constraint on arbitrageurs' inventories, allowing them to hold long and short positions, Bosch and Sunder (1996) report a marked drop in the level of allocative efficiency attained, allowing them to conclude that 'scarcity' is one of the sources of order imposed on a market that promotes efficiency.

In a further paper, Jamal and Sunder (1996) generalise and extend Gode and Sunder's (1993a, 1993b) findings to an asset market, where traders are permitted to be both buyer and seller, with an imperfect information structure. The simulation design investigates the market behaviour of three different types of computer trader, all of which are zero intelligence strategies with randomly generated bids and asks subject to a non-negative profit constraint. Bayesian traders observe the imperfect signal and compute a posterior expected dividend value that defines the feasible set of bids and asks. Actual market transactions do not impact on bidding behaviour. Empirical Bayesian traders use the realised frequency of each state of nature (X and Y), the given base rate probability of occurrence of the two states is ignored. Expected dividend values are computed from the observed frequencies and so are subject to change each period. Representativeness and anchor-and-adjust heuristics are combined to give biased heuristic traders. These traders overreact and set initial aspiration levels based on the imperfect signal as though it was perfect. These initial aspiration levels are then updated subject to a simple anchor-and-adjustment procedure. Biased heuristic traders, therefore, do not process information in a Bayesian manner.

Jamal and Sunder (1996) report that the price observed under the Bayesian traders, as expected, converged to the Bayesian predicted price. The empirical Bayesian traders generated prices that initially deviated substantially from the Bayesian predicted price and were very erratic, however, prices gradually converged overtime as traders observed higher frequencies of each state given the imperfect signal. Prices generated by the biased heuristic traders begin close to the representativeness price but then, due to the anchor-and-adjustment process, exhibit a progressive tendency to move closer to the Bayesian predicted price. Importantly, Jamal and Sunder (1996, p.285) are able to conclude that the '[b]iased heuristics of individual traders do not directly translate into biases in aggregate market level outcomes.' With respect to median allocative efficiency, Bayesian traders consistently attain levels of 100%, whereas the empirical Bayesian traders generate initial efficiency levels of approximately 92%, which then converge close to the 100% level. In contrast, the biased heuristic traders generate median efficiency levels of between 93% and 95% and exhibit much greater dispersion of values.

The main advantage of a computer simulation method over an experimental method is the increase in the number of periods and market duration. Experimental markets with human participants are prone to participant fatigue and boredom, which restrict the duration of markets to generally 15-20 periods. There is no such limitation imposed in computer simulated markets. Jamal and Sunder (1996, p.285) offer the possibly premature termination of human experiments as one reason for the mixed results generated. Had markets that exhibited non-convergence continued for many more periods they may well have converged to predicted values, because participants would have observed far more occurrences of each signal-state combination. The obvious limitation of computer simulated markets is their inability to say anything about individual behaviour at the micro-level. Admittedly, this is not the intention of such studies. Individual behaviour is strictly controlled, permitting a clean investigation into the impact of specific institutional rules and structures. It is apparent that simulation and experimentation can, and should, exist side by side. Simulation is of use in the creation and exploration of theoretical models, whilst experimentation is useful for observing behaviour and the adaptation of strategies in light of learning and experience.

3.3 Direct Comparison with Conventional Empirical Results

The results reported in the experimental literature will now be compared with those previously generated within the conventional empirical literature. However, before this is undertaken it must be noted that such a comparison is severely limited because of the disparate foci of the two techniques. The experimental literature has primarily concerned itself with the identification of the market conditions and institutional rules under which competing static equilibrium models best predict observed experimental outcomes. In contrast, the empirical literature focuses on the testing of the three forms of informational efficiency, as defined in Fama (1970), and the ability to generate excess returns.

One area where comparison is possible is the impact of futures markets on spot price volatility and market efficiency. Empirical evidence is inconclusive with some studies suggesting futures markets stabilise spot prices whilst others report increased volatility (see Cox (1976) for a review). Unfortunately, evidence from the experimental literature reflects the empirical literature with respect to inconclusive results. For example, Forsythe, Palfrey and Plott (1984) report an increased variance in spot prices in the presence of futures markets, as is also evident in Harrison (1992), whilst Friedman, Harrison and Salmon (1984) find results to the contrary. No firm conclusions can therefore be drawn.

A second possible avenue of comparison concerns the existence of arbitrage opportunities. The empirical literature offers the inability to profit from mechanical trading rules and the absence of arbitrage opportunities as evidence in favour of informationally efficient markets. However, Plott and Sunder (1988) calculated the returns generated by various filter trading rules in informationally inefficient experimental asset markets and found them to be dominated by a simple buy-and-hold strategy. O'Brien and Srivastava (1991) report strengthening evidence. In addition, they use the generally adopted Dickey-Fuller test for unit roots to test the random walk hypothesis. On the basis of this test previous empirical studies draw conclusions concerning the informational efficiency of asset markets. O'Brien and Srivastava (1991) apply the technique to experimental asset markets that were informationally inefficient with respect to full information aggregation and surprisingly were unable to reject the hypothesis of informationally efficient markets. It is evident, therefore, that a lack of arbitrage opportunities and an inability of conventional statistical tests to reject market efficiency are not sufficient to characterise a market as informationally efficient. These findings directly call into question the strength of conclusions in much of the empirical literature.

3.4 Discussion and Conclusions

This chapter has reviewed the results reported in the experimental financial asset market literature to date. The discussion was broken down into a number of areas of key themes and results. A brief summary of the most robust findings follows. Early experiments report the importance of replication of stationary environments for the convergence of observed behaviour to that predicted by the FRE model. A further important treatment variable is the level of participant experience in the trading environment. The greater the experience the greater the convergence to FRE predictions. The type of information structure also plays an important role in the degree of convergence that a market exhibits, and thus the level of market efficiency attained. The efficiency observed in perfect information markets is generally much higher than that witnessed in similar markets, but with imperfect information structures. The presence of aggregate uncertainty in imperfect information markets reduces the level of market efficiency still further. A number of studies have conducted pre-trade auctions for private information and report results that are generally in line with the FRE model's prediction of zero value of private information. Whilst not always reaching a zero value, the price paid for information tends to converge towards zero over time.

The main concern of the studies reviewed in this chapter has been the extent to which experimental markets are able to aggregate and disseminate diverse, private information and to determine what conditions hinder the ability to do so. The FRE model was found to predict well in the simple settings of homogenous information structures with simultaneous message arrival, as analysed by earlier studies. This is interpreted as evidence of high levels of informational and allocational efficiency achieved in simple experimental markets. However, with the introduction of more complexity in later studies the FRE model did not accurately predict the outcomes observed in some experiments. In environments with heterogeneous information and sequential arrival, the PRE model predicts better in asset markets, whilst the NRE provides a better description of information auctions. In summary, the most general conclusion to draw from the experimental literature concerns the strong convergence tendencies towards competitive equilibrium outcomes of markets governed by the DA institutional rules with simple trading environments. Whilst the FRE model does not perform as well in more complex trading environments, many studies still report some degree of convergence of market performance to FRE predicted values. However, theoretical models more akin to semi-strong market efficiency supersede the FRE model in these more complex environments. With greater levels of experience, however, it is possible that the FRE model may better represent participants' behaviour. This is evidenced by the numerous studies that report an increased convergence tendency the greater the experience level of participants (for example Forsythe and Lundholm, 1990). The computer simulations of Jamal and Sunder (1996) further substantiate this result.

Two very minor criticisms of the literature will now be offered. As is readily apparent from the review above, a criticism of the experimental literature as a whole, as opposed to individual papers, is the inability to collectively compare results across papers because of the number of variables that vary from study to study, thus violating any ceteris paribus conditions. In order to arrive at an overall view of the area it would be preferable to make the studies more comparable, this would in turn provide stronger support for any findings. In a similar vein, the studies can be criticised for introducing different terminology to describe what are essentially the same equilibrium models. The use of different acronyms for the same models makes for confusing reading. Consequently, in reviewing the literature this chapter has attempted to refer to a certain model with one acronym only, even if it is not the one used in the actual study under discussion.

Chapter Four

4 Methodological and Design Issues in Experimentation

4.1 Introduction

In the search for decisive insight concerning financial asset market efficiency a new method of investigation has been embraced by the research, one of experimental economics. The fundamental objective of experimental economics is the creation of an environment that can be controlled, manipulated as desired and which allows accurate measurement of variables (Wilde, 1980). This chapter is intended as an introduction to the experimental method as employed in the economics literature. The chapter is intentionally double focused. It deals initially with general issues as they relate to experimental work, discussing both methodological and experimental design considerations. Included are an address and rebuke of criticisms made against experimental economics as a legitimate research tool and a justification for the adoption of this method in the study of financial asset market efficiency. Secondly, the chapter moves on to a more specific and detailed discussion of the choice of experimental design at the heart of this research programme.

An outline of the structure of the chapter follows. The next section offers a general discussion of the experimental economics method. Included is a comparison of the experimental method with the conventional empirical research method in economics. This is followed by a discussion of the components that comprise an experiment and the different purposes of experimentation in the economic discipline. Section 4.3 highlights general design considerations in experimentation and includes detail on the necessary conditions required for experimental control and the generally adopted method of motivating participants. Section 4.4 addresses generally voiced criticisms of the experimental method in economics and offers argument against such criticisms. Also included is an argument detailing the justifications for the adoption of an experimental method in the research of financial market efficiency. Section 4.5 signals the introduction of the second major focal point of this chapter, the experimental design adopted in the current research programme. The section introduces general design features that permeate through out this study and are, therefore, observed in all eighteen experimental markets conducted. In contrast section 4.6 is more specific in focus and deals with the disparate design features of each group of experiments (detailed discussions of the specific designs are included in subsequent chapters). The final section summarises the content of the chapter and reiterates the applicability of the research method and experimental design for the research programme studied here.

4.2 Experimental Methods in Economics

The discussion to follow in this section introduces the general experimental method as adopted in the economic discipline and discusses the method's specific applicability for the investigation of financial asset market efficiency.

4.2.1 The Interaction between Theory and Data

Economics is endowed with numerous theories that, to a greater or lesser extent, abstract from the naturally occurring economic environment in order to overcome the complexities associated with economic processes. These complexities arise with respect to trading institutions and/or the structure of preferences and information. The convention within the economic discipline is to derive the propositions of a theory under strict *ceteris paribus* conditions, consequently the theory is well defined and clearly specified. This is especially so of theories developed within the Neo-classical paradigm, for which the 'rules of the game' and agents' objective functions are clearly specified. There exists a hard core proposition that is surrounded by a number of auxiliary hypotheses (Lakatos, 1978).

Rice and Smith (1964) recognise that hypothesis formulation and testing is a primary means of extending scientific knowledge, and thus improving economic theory. Furthermore, Rice and Smith (1964, p.259) argue that simply subjecting a theory to the test of logical completeness is not sufficient to provide understanding. It follows, therefore, that comparison to empirical observation is required to fundamentally test the propositions of economic theory. Theory and data interact continuously over time. Economic theory offers propositions concerning economic behaviour under certain *ceteris paribus* conditions. These propositions provide the motivation for empirical investigation of their validity. The theory states which economic variables are relevant and which irrelevant. Regular empirical observations serve to refine the theory and the alternating cycle, of theory followed by empirical work giving way to theoretical refinement, continues. This is the process by which scientific knowledge progresses.

Control is the substance of experimental economics, providing for the *ceteris paribus* conditions specified by the theory to be satisfied. A carefully designed laboratory experiment can achieve greater precision than is possible with empirical research. This permits the testing of theoretical predictions in a domain where the theories make unambiguous predictions. Indeed, Roth (1995, Ch.1, p.10) suggests '… insights gained from designing an experiment are … often of value [in theoretical refinement] even apart from the actual conduct of the experiment. Thus there is an interplay, on many levels, between theory and experiment.'

4.2.2 Conventional Econometric v Experimental Techniques

In the following discussion the distinction between experimental and non-experimental data is drawn and a number of problems inherent in the use of non-experimental data in the evaluation of economic theory are introduced. The dominant advantage afforded by the adoption of an experimental methodology is then expressed.

Traditionally within economics observations derived from the 'natural' economic environment have been the sole source of data to stimulate the revision of economic theory. However, recent decades have witnessed the gradual integration into the economic journals of research incorporating an experimental methodology. Thus there is a new source of data with which to refine economic theory. Distinction needs to be drawn between the above two forms of data. The naturally occurring field data is *created* by the economy and simply gathered in. In contrast, experimental data is *generated* by experimentation in carefully controlled laboratory conditions. Thus, it is the origin of the data that determines the classification. Whilst this distinction is simplistic it is sufficient for the current discussion[10].

Field data is generally collected by government agencies, and the like, for non-academic purposes. As a consequence there is the possibility of omission of relevant or interesting (as determined by the theory) variables. In such circumstances the use of (crude) proxies is required and so the validity of the field data may be questioned. The controlled environment in which experimental data is generated means that such (internal) validity questions are not an issue (Friedman and Sunder, 1994, p.5).

The above weakness of field study data renders its use problematic, however, when the objective is to evaluate the predictions of economic theory it is not the fundamental weakness. The essential frailty of field study data in the evaluation of theoretical predictions derives from the manner in which it is arises. The data is generated in the natural economy with the complete absence of any form of control, allowing key variables to fluctuate over time. Thus, the data and the theoretical

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[10] See Binmore (1987, pp. 257-259) for a more precise distinction based on replication.

predictions being tested are generally not generated under the same conditions. The *ceteris paribus* conditions specified by the theory are violated. As variables fluctuate, confounding extraneous factors serve to frustrate the evaluation of the theory. Davis and Holt (1993, p.3) recognise that '[t]hese problems have become more severe as models have become more precise and intricate.' The absence of direct control renders interpretation of the data, and subsequent directions of causality, less precise than is achievable with experimental data generated under controlled laboratory conditions.

Within the informational efficiency literature, conventional empirical papers have preceded those aimed at providing a theoretical concept of informational efficiency. The theories developed subsequently have been based on the concept of static equilibria (Grossman (1976), Grossman and Stiglitz (1980) are examples). However, empirical research is unable to provide adequate tests of such equilibrium theories due to the inability to control important variables, specifically the private information of traders (unknowable by definition) and the arrival of new information. The major benefit accorded by the adoption of an experimental methodology is the ability to control relevant variables so as to maintain the *ceteris paribus* conditions specified by the theory under consideration. Alternatively, a specific treatment variable can be set at different levels across different experimental sessions or at different points in time in the same experimental session, in order to assess the impact of its variability on the predictive ability of the theory. It is this potential that enables the investigation of static equilibrium theories, which is not conventionally possible if one or more variables fluctuate rapidly. To place the discussion in the context of an experimental analysis of informational efficiency, theories have been developed which predict the extent to which prices reveal information in equilibrium. Attempting to evaluate such theories using conventional methodology is problematic because the variable 'information' fluctuates greatly and so convergence will constantly change towards different equilibrium values.

Hey (1992, p.87) argues that the testing of economic theory under conditions other than those under which it was derived, results in conventional (econometric) tests becoming combined tests of whether the theory is correct under the specified *ceteris paribus* conditions and if it also survives the transition to the real world. The result is the inability to critically test the theory and draw conclusive inferences about its predictions when using field study data. In an attempt to overcome the obstacles inherent in the use of this type of data econometricians have developed various high powered econometric techniques. However, these techniques usually require numerous auxiliary hypotheses that can be relaxed in order to save the hard core proposition. Once more the analysis becomes an investigation of joint hypotheses. This issue is well illustrated in the efficient markets literature. A test of the EMH is a joint test of informational efficiency and the assumed equilibrium model of price determination, generally the capital asset pricing model (CAPM). Roll's (1977) critique demonstrates that previous tests of the CAPM are invalid. Without the 'true' market portfolio it is not possible to validly test the CAPM. Thus it is difficult to determine whether evidence inconsistent with the joint hypothesis is evidence against informational efficiency or the chosen equilibrium model. Further, in conventional tests the definition of an informationally efficient market causes concern due to an inability to provide precise meanings for such terms as 'fully reflect', 'available information' and 'unbiased'. An operational definition of informational efficiency is elusive. Fama's (1976) revised definition, in which a market is efficient if it uses all information to determine prices and uses it correctly, contains the ill-defined term 'the market'.

Related to the notion of total control is the complete knowledge of all parameters by the experiment designer. The private information used by traders is, by its very definition, unknown when using field study data. This does not pose a problem, however, when examining experimental asset markets, as both the public and private information sets of participants can be controlled and manipulated as desired. This ability to control the temporal distribution of traders' private information when using experimental techniques makes such a method of analysis ideal for studying the question of asset market efficiency and evaluating static equilibrium theories. Strict control allows the theory's predictions to be computed and compared to observed outcomes.

A possible critique of conventional econometric methodology is that it may encourage the changing of a model's specification in a way suggested by the empirical results, in order to obtain a better fit for the data used. The problem with such an approach is that the model can become sample specific and in addition any tests of significance on the 'new' model utilising the same data become meaningless. The advantage of experimental techniques in this context is the ability to run additional experiments to test the revised theory. Such a technique is subject to one qualification however, the cost of running additional experiments. Not only would participants have to be rewarded but further resources, in the form of computing facilities and the researchers own time etc., would also be taken up. If such costs were substantial then they would limit the ability to rerun experiments, however, it would seem that the relevant costs would be exceeded by the benefits (in the form of advancements in theory) of running supplementary experiments.

There are very few cases where the effectiveness of econometric techniques is directly evaluated. A notable exception is LaLonde (1986) in which simple statistical analysis provided a significant difference in mean earning values across a 'control' group and a 'treatment' group when analysing experimental data. However, when treating the data as field study data (as if the control group did not exist), the use of various econometric procedures failed to correctly estimate the treatment effect, with estimates and signs varying across procedures. The econometric techniques adopted in economics are not infallible.

The discussion above has cast doubt on the efficacy of using conventional econometric techniques in the analysis of financial market efficiency. An experimental methodology was suggested as an alternative research tool that avoids the problems inherent in the conventional analysis. The following subsection discusses the various component parts of an experiment.

4.2.3 Components of Experiments

When testing economic theory using an experimental methodology the key elements of the theory must be captured by the experimental design. Smith (1982b, 1994) identifies three essential ingredients of economic theory that serve to form the essential components of economic experiments. The *environment* of the theory consists of the collection of all agents' characteristics. The experimental environment, therefore, specifies participants' initial endowments, preferences and cost/revenue functions etc., all of which provide the motivation for trade via the existence of gains from exchange. In experimental economics this environment is controlled via the procedures of induced value theory derived in Smith (1976) and the payment of monetary rewards (discussed below). The *institution* in the theory defines the language of communication between agents and specifies the characteristics of the commodity to be traded. The experimental institution is specified in the instructions and defines the rules governing the exchange of information and the trade of assets, in addition to the method of communication (bids, asks and acceptances). The final ingredient of economic theory is agents' *behaviour*. The theory makes assumptions about agents' behaviour (maximise utility or profit etc.) given the environment and institutional rules governing their actions. In the experimental design the environment and institution specified by the economic theory are controlled and the resultant individual behaviour is observed. Any inconsistency between predicted and observed behaviour is borne by the behavioural assumptions of the theory. Thus, laboratory market experiments test the behavioural assumptions of economic theory.

4.2.4 Purposes of Experimentation

The type of experiment and the subsequent design depend upon the purpose for which the experiment is conducted. Various experimentalists offer alternate opinions as to the purposes for conducting experiments in economics (see Hey (1992), Friedman and Sunder (1994, Ch.1), and Smith (1994) for examples). Reported here is a synthesis of those opinions.

1. Test a theory. To evaluate a theory the predictions are compared to observed outcomes. As argued above there are situations where conventional econometric analysis does not allow critical tests of economic theory. Observed behaviour may deviate from theoretical predictions because, either, the theory is incorrect or because the *ceteris paribus* conditions specified by the theory do not hold. Thus, conventional econometric tests of a theory are not a test *per se* (Hey, 1991, p.8). No conclusive inference can be drawn, because it is possible to salvage the hardcore proposition by suggesting that the auxiliary assumptions are violated. Falsification of the theory is not possible. This obstacle can be avoided when economic theory is tested using an experimental methodology. The intention is to design an experiment which captures the essential features of the environment and institution specified by the theory, whilst controlling for all other factors. If the observed behaviour contradicts the predictions of the theory to a degree that can not be explained be chance or simple error, then the theory is disputed. An experimental methodology allows determination of the validity of a theory to be separated from the determination of whether it survives the transition from *ceteris paribus* conditions to the real world.

2. To discriminate between competing theories. In order to discriminate between two or more theories conventional tests require the natural occurrence of a situation where the competing theories predict measurably different outcomes and the data allows the separation of these predictions. On the rare occasions when such a situation arises naturally, other confounding extraneous may factors serve to cloud the issue. The adoption of an experimental methodology nullifies this problem as it is perfectly feasible to design a single experiment where the competing theories do predict measurably different behaviour and the usual thorough control is exercised over all other factors. When attempting to differentiate between a number of competing theories, the intention is to design a single experiment in which the chosen parameters ensure that the different theories predict measurably different outcomes and to then compare these predictions to the experimental outcomes. This is the technique employed in the experimental asset markets literature. Smith (1982b, p.784), however, offers a word of caution, suggesting that the testing of theories in the exact domain of their assumptions is sterile unless it forms part of an intention to extend the theory into the domain of the field environment.

3. 'Stress Tests'/'Boundary Experiments'. Experiments can be designed to provide rigorous tests of a theory, exploring the causes of the theory's failure. These experiments investigate the extreme or boundary conditions under which a theory fails. This type of experiment allows the determination of the key variables essential to the theory and the range of parameters applicable. Guidance is, therefore, given with respect to which areas require additional theoretical development. To illustrate reference is once more made to the experimental literature on financial asset markets. The experimental design of Plott and Sunder (1982) provided certain traders ('insiders') with information that perfectly revealed to them the value of the asset to be traded. With a perfect information structure the FRE model outperformed the PI model. In a subsequent study Plott and Sunder (1988) provide insiders with imperfect information and as a result the predictive ability of the FRE model was weakened.

4. Discover empirical regularities. Empirical regularities that can not be explained by existing theory provide a basis for the suggestion of new theory. This notion relates to the cycle of scientific progress discussed above. Empirical observations throw up areas where the current theory is deficient, provoking theoretical development in those areas. An example directly relevant to experimental asset markets is the empirically documented high levels of efficiency of gains from exchange available with the double auction trading institution. Modelling the equilibrating processes of the double auction has lagged behind the incorporation of the institution in experimental designs. Recent attempts to remedy this situation were discussed in Chapter Two and include Friedman (1984, 1991).

5. Comparison of the efficiency of different institutions. Trading institutions differ with respect to their rules of exchange. Comparison of efficiency levels across institutions, under identical environments, provides a comparative ranking of the properties of the various trading rules. Kagel (1995) reviews the auction literature, evaluating the comparative market performances of various trading institutions.

6. Policy proposal evaluation (pre-tests). Policy proposals such as new forms of exchange can be cost-effectively investigated prior to implementation via the use of experimental methods. The predicted properties of a new institution for exchange can be evaluated in the laboratory, at low cost, before the institution is implemented for testing in the real world, thus reducing the subsequent possibility of expensive failure to deliver expected results. An illustration is the experimental testing of the uniform price double auction and the subsequent finding of efficiencies comparable with the continuous double auction (McCabe, Rassenti and Smith, 1993). Other examples include the investigation of specialist trader privileges on market performance (see Chapter Three for more detail).

It is clear, therefore, that there exist a preponderance of purposes for which the methodology of experimental economics can be fruitfully employed. Within the financial literature the experimental investigation into informational efficiency initially provided a means of discriminating between competing theories and has subsequently become a vehicle for the stress testing of theory, identifying important variables.

4.3 General Design Issues in Experimentation

4.3.1 Introduction

The first dilemma to rear its head when determining the specific design of an experiment is whether to pursue a policy of realism, and so mimic reality as accurately as is possible, or to precisely reproduce the specifications detailed in the theory under investigation. The two generally differ, because simplifying assumptions of the theory abstract from reality. Friedman and Sunder (1994, p.10) argue that neither of these polar extremes is singularly appropriate. It is impossible to capture all the intricacies of the natural environment in an experimental design. Even if the theory is so explicit as to allow exact replication in the laboratory, this too is unproductive. There is no scope for learning, because observations consistent with the predictions of the theory only provide evidence that there is no logical flaw in the theory and only offer limited evidence of the theory's predictive ability. Thus, Friedman and Sunder (1994, p.12) conclude that '... a laboratory experiment should be judged by its impact on our understanding, not by its fidelity either to reality or to a formal model.' A simple design that captures the essential and interesting features of the theory offers the greatest scope for improving understanding. A simple experimental design enhances control and consequently provides a clearer interpretation of observed behaviour. The intention is to design an experiment that magnifies the effects of treatment variables and removes as far as possible the noise due to nuisance variables and confounding effects of other variables. Once more the discussion turns to the issue that is fundamental to experimental economics, control.

4.3.2 Conditions for Control

Control is the substance of experimental economics and is achieved using a reward structure to induce specific monetary values on given actions and the resulting outcomes. It is, therefore, possible to control agents' preferences. However, to accomplish this an experiment must satisfy a number of sufficient conditions, which Smith (1982a) terms precepts. Each of these conditions will be discussed in turn.

Nonsatiation: Utility is a monotone increasing function of the monetary reward, thus an autonomous individual will choose (prefer) the action with the highest reward. Such individuals do not become satiated and always act so as to increase their level of the monetary reward.

Saliency: In order to have a motivational effect the reward structure must be related to the actions of individuals, thus an individual's reward will depend upon the action chosen. A fixed payment for participation is not salient because it is not dependent upon the actions, and resultant observed outcomes, of individuals. However, a monetary reward related to (say) the level of experimental profit earned is salient and motivates individuals to choose actions that maximise the level of experimental profit earned.

Dominance: To guarantee control over an individual's preferences, the reward structure must suppress any subjective costs associated with that individual's participation in the experiment. Consequently, the overwhelming influence on individuals' utility from participating derives from the monetary reward structure. This is most likely to be the case the higher is the salient monetary reward. Thus, the increase in monetary reward that an individual experiences as a result of a given action dominates any other influence on that individual's choice of action.

Privacy: Participants are given information only with respect to their own payoff alternatives, thus there is incomplete information. The potential for loss of induced value (preference) due to interdependent utilities is eradicated. Thus, irrespective of whether participants care about the reward earned by others, the removal of such information, via privacy, ensures that the induced value is solely the result of the individual's own monetary rewards.

Parallelism: Parallelism occurs when the conclusions drawn from the experiment are equally valid for field data under similar *ceteris paribus* conditions.

The first four of the above precepts provide for controlled microeconomic experiments and ensure the achievement of control over agents' characteristics. It is viable to impose any relationship between the intrinsically worthless asset and the monetary reward, thus inducing value upon the asset. This induced value will hold providing that the relationship is made explicit to the participants (saliency), whom are motivated by the monetary reward (nonsatiation and monotonicity) rather than other confounding influences (dominance and privacy). These conditions are sufficient if the purpose of the experiment is to test predictions derived from theoretical models. The parallelism precept allows the conclusion that experimental results carry over into the field.

4.3.3 Motivation

It is clear from the above discussion of induced value that participants in economic experiments are motivated to 'do as well as possible' by the payment of a reward for performance. The theoretical justification for this is provided by Neo-classical economics, which requires the maximisation of an objective function. Within experimental economics participants attempt to maximise their reward for participation. The payment for participation in economic experiments is in contrast to the situation in psychology, where salient monetary payments have been deemed relatively unimportant (Hey, 1992, p.85), with individuals asked to consider hypothetical questions.

It is standard practice within experimental economics for the reward medium to be money. Monetary payment negates, to a large extent, the problems arising with respect to heterogeneous individual dispositions concerning the reward medium (disparate private preferences). In addition, monetary rewards are likely to fulfil the requirement of nonsatiation, with individuals always preferring more money to less. It is usual within the literature to employ an experimental currency that is converted into domestic currency at the end of the experiment (for example Plott and Sunder (1982) incorporate francs in their experimental design). The use of an experimental currency permits the disparate theoretical predictions of competing models to be separated more readily.

The previous experimental literature suggests that the provision of payment for participation reduces the variability of performance. Empirical evidence on the impact of financial incentives is mixed, however, their provision does appear to reduce the rate of occurrence of errors (in performance) due to confusion or carelessness, but does not improve the average performance (Camerer, 1992, p.245). In the specific context of double auction markets Jamal and Sunder (1991) conclude that whilst the payment of performance-based monetary rewards is not a necessary condition for the convergence of transaction prices to theoretical equilibrium, they do increase the reliability of laboratory results.

When inducing value on the experimental asset via a monetary reward structure caution must be exercised to ensure that the cost to a subject of departure from optimal behaviour is significant. If this is not the case then significant departure from optimal behaviour in terms of decisions may have insignificant implications for a subject in terms of loss of monetary reward and departure from maximum payoff (Harrison's, 1989, 'marginal payoff critique'). If the costs of making a decision are greater than the marginal monetary reward from making that decision, then participants may 'rationally' depart from theoretically optimal behaviour.

It is also conventional in the majority of the experimental literature for an appearance fee to be paid to participants to encourage them to participate. Davis and Holt (1993, p.26) suggest that the '[p]ayment of a preannounced fee facilitates recruiting of participants, establishes credibility, and perhaps provides some incentive for participants to pay attention to instructions.'

4.3.4 Types of Design

The particular design of any experiment is determined, to a significant degree, by the intended purpose of the experiment. The purpose of a given experiment determines those variables that are treatment variables and those that are nuisance variables. When designing an experiment the intention is to 'sharpen the effects of focus variables and minimise the blurring due to nuisance variables' (Friedman and Sunder, 1994, p.21). To achieve this, control must be exercised over the variables, either as treatments or constants. This is possible directly or indirectly. Direct control of a treatment at different levels across an experiment allows the variable's impact on observed behaviour to be determined. Holding a variable constant across treatments ensures that the impact of the particular variable on observed behaviour is removed. However, some variables are impossible to control directly (for example, participants' cognitive capabilities). Fortunately it is possible to negate the impact of such uncontrollables on observed behaviour by ensuring that they are independent of the treatment variable. This is achieved via randomisation, which provides indirect control by ensuring the eventual independence of uncontrolled variables across treatments. The basic procedure is to assign the uncontrolled variable at random to the various levels of the treatment variable. For example, to prevent results being subject specific it is preferable to assign participants to treatment groups at random, thus negating the influence of subject specific characteristics.

Both Davis and Holt (1993, Ch.9) and Friedman and Sunder (1994, Ch.3) include a detailed and practical discussion of the various types of experimental design. Boniface (1995) also offers an excellent coverage of experimental design. The interested reader is directed to these references for a more comprehensive coverage of the various experimental designs possible and the benefits of utilising a given design.

4.4 Experimental Economics: A Critique

4.4.1 Address and Rebuke of Criticisms

There exist a number of commonly voiced limitations of the experimental methodology, the discussion will now address these concerns and where possible answer any criticisms.

A fundamental attack on experiments in economics focuses on their simplicity. Experiments are too simple to describe the real world, which is a far more complex phenomenon. However, as argued by Hey (1992, p.91), if the intention of the experiment is to replicate the domain of a theory and test its predictions, then *a fortiori* the theory is too simple. The unrealism reflects parameters that are absent from the theory. If this is the case, the above is primarily a criticism of the theory, as the experiment merely reflects the conditions under which the theory was developed. In fact simplicity may be a virtue of experimentation rather than a weakness, because it permits a clear interpretation of the observed behaviour. If the theory fails to predict observed behaviour in a simple setting then its validity in a more complex environment is fundamentally questioned. Experiments utilise reward motivated individuals, thus capturing human behaviour and providing a more complex environment than may be parameterised by theories. Therefore, an experiment is an adequate vehicle to falsify a theory because it captures behavioural considerations and so abstracts less from reality. If a theory is falsified this implies that an assumption it makes about the behaviour of economic agents is not a valid one. However, an experiment is designed to replicate the circumstances under which the theory was developed, therefore, an experimental analysis only allows one to study behaviour in the context of the economic environment represented. If such a representation is incorrect then the analysis may not improve our knowledge.

Following on from the above discussion, an obvious point of contention for cynics is that, due to their simplicity, experiments are artificial and abstract from reality. It is possible to suggest that individuals will behave differently in the real world. Hey (1991, p.13) 'counters this by arguing that, in experiments, the participants (who are undoubtedly real) are tackling a real problem for real money, that their payment depends on their decisions and that everything about it is real.' It may be further argued that inducing value on abstract outcomes is not equivalent to 'real' preferences, however, economic systems do produce intangible assets for which value is induced via property rights for the holder (an obvious example being financial instruments). Smith (1982a, p.262 ft.11) suggests; 'to argue that preferences based on cash-induced value [are] ... different than homegrown preferences ... is also to argue that preferences among intangible instruments in the field are ... different than commodity preferences.' Control over participants' preferences is obtained by the use of a reward structure and property system to induce monetary value on abstract outcomes. This notion of induced value is based upon the precept of nonsatiation (see earlier), however, there are some qualifications which require consideration.

Firstly it is possible that participants attach nonmonetary subjective costs to the procedure of making individual decisions. These are termed 'subjective costs of transacting' (SCT) and include such things as the cost of thinking, calculating, deciding and acting. If these costs are not negligible, the link between monetary reward and the control of individuals' preferences will be weakened, resulting in some loss of control over the induced value. Fortunately it is possible to reduce the SCT by designing experiments with simple, transparent tasks or by the use of computers to reduce the computational burden. Any SCT that remains can be eradicated by ensuring the reward structure 'dominates' the cost.

In addition, it is possible that individuals are not autonomous own-reward maximisers and so there may be an interdependence of utility, resulting in diminished control over preferences. Such a situation can be avoided by invoking the privacy precept and only providing incomplete information with respect to other individuals' payoff schedules (that is, inform individuals of their own payoff schedule only). Consequently no individual can gain utility from the payoff of another and control over preferences is maintained. Furthermore, control over preferences will be lost if participants attach 'game value' to the experimental outcomes, such that they derive utility purely by participating in the experiment. It is for this reason that abstract names and tags (neutral terminology) have been used in experiments.

It is conceivable that different categories of individuals behave in significantly different ways. Thus the use of students as the predominant recruitment background for participants results in a potential criticism of experiments. What can the study of 'naive' students in an alien environment provide by way of insight into the behaviour of experienced professionals? However, Duh and Sunder (1986) and Anderson and Sunder (1992) find that students behave in the same manner as professionals, and the only difference is that the results are amplified when professionals are used. Thus such a criticism is not as damning as it would initially seem.

A final limitation of the experimental methodology derives from the fact that it only really works well with theories based around well structured axioms, thus rendering them refutable. Consequently, the experimental literature has focused heavily on theories steeped in the neo-classical paradigm, such as rational expectations and competitive equilibria, whilst neglecting other ideologies.

To conclude this section, it remains to remark that close critical scrutiny of the experimental economics literature by sceptics can only benefit the discipline by ensuring checks on the reliability and validity of experimental results. The implication is continuing improvements in experimental method and design.

4.4.2 Experimental Financial Markets: A Validation

What are the benefits from the adoption of an experimental methodology in the investigation of financial asset market performance?

The use of laboratory markets allows efficiency to be measured directly by comparison of the experimental market to a control in which all information is disseminated. Thus the price in the control market is the efficient price by definition. The private information used by traders is, by its very definition, unknown when using field study data. This does not pose a problem, however, when examining experimental asset markets, as both the public and private information sets of participants can be controlled and manipulated as desired. This ability to control the temporal distribution of traders' private information when using experimental techniques makes such a method of analysis ideal for studying the question of asset market efficiency.

The use of experimental asset markets will not allow the question of whether naturally occurring markets are informationally efficient to be resolved. However, it will allow the identification of features of markets and of information structures that facilitate or frustrate efficiency. In addition, an experimental analysis enables the testing of theories previously proposed in the finance literature, but which require a number of assumptions abstracting from reality, thus rendering them untestable using naturally occurring field study data. The experimenter is free to design the laboratory market so that it conforms to the conditions required by the theory in question.

The overwhelming result to derive from the experimental literature on asset markets is that institutions are important. The rules of trade which are governed by the institution determine the information (bids, asks and acceptances in a double auction) available to individuals and their incentives. Thus, 'institutions matter because incentives and information matter.' (Smith, 1994, p.116). The experimental literature indicates that the rules of trade governing exchange in a continuous double auction result in the maximisation of gains from exchange and the convergence of transaction prices to the FRE equilibrium value.

In conclusion, experimentation is a valuable additional research tool that compliments the more conventional methods of analysis in economics.

4.5 Details of the Experimental Design

4.5.1 Introduction

'[Experimentalists] have learned patiently to introduce only a few novel features at a time in to the laboratory environment, because only then can they confidently disentangle each feature's direct and interactive effects.' Friedman (1993b, p.517). With this advice in mind the experimental design adopted here is similar to the earlier design of Plott and Sunder (1982), as adapted by Banks (1985) and further developed by Sunder (1992). The novel feature of the experimental design adopted is the introduction of period duration as a treatment variable. Other treatment variables investigated include perfect versus imperfect information structures and costless versus costly private information. The following paragraph gives an overview of the design, whilst the remainder of this section details the general experimental design.

The eighteen experimental asset markets conducted as a part of this research programme provide an insight into the impact of period duration on the market efficiency of experimental stock markets. The experiment is therefore designed to reflect certain conventions that the London Stock Exchange exhibits. Participants in the experiment are endowed with assets that pay an uncertain dividend at the end of each trading period and working capital that permits them to purchase the dividend paying assets from other participants should they desire. Thus a market in the dividend paying asset is established and trade between participants is permissible for the duration of the trading period. Each trading period runs sequentially, thus removing the possibility of operating a futures market. Participants assume the dual role of being simultaneously buyers and sellers. Trade is conducted under the following general rules of double auction markets. New bid and ask prices are subject to the 'improvement rule'[11]. Within a trading period, the current bid and ask, and a history of transaction prices are publicly available. No queuing system for bid and ask prices is utilised and after each transaction the bidding process begins afresh. No short sales or borrowings were permitted. No payment of a commission on trade was adopted. The reason participants would be willing to trade the risky asset stems from the payoff parameters utilised in the design, which are discussed later.

4.5.2 Experimental Markets

A control market is required to isolate the effect of period duration upon the trading behaviour of experimental financial asset markets. The control incorporates trading periods of constant (C) and known (K) duration. It is against this control market that the performance in the treatment markets (incorporating varying period duration) is gauged. In order to distinguish between the effects of varying period durations and knowledge of the period durations, two different groups of treatment markets are conducted. Markets are conducted with varying (V) but known (K) durations to isolate the effect of simply incorporating a variable period duration.

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[11] Any bid/ask must better the current bid/ask. That is, new bids/asks must be higher/lower

Markets are also conducted with varying (V) and unknown (U) durations to determine how removing knowledge of when trade will cease impacts on trading behaviour.

The total number of periods, P, in all markets is identical and equal to 15, thus controlling for the impact of the number of trading periods on a individual's ability to learn from experience gained in earlier periods. Thus if p_j denotes a given period, then the set

$$P = \{p_j \in Z^+ : 0 \leq j \leq 15\}, \qquad 4.1$$

applies for all markets in the experimental design, regardless of period duration.

In the CK markets the length of each of the 15 trading periods, l_c (subscript c denotes constant duration), is held constant at 240 seconds[12]. Thus the set, L_c, of all possible period lengths contains only one element,

$$L_c = \{l_c \in Z^+ : c=240\}. \qquad 4.2$$

The length of each trading period was common knowledge to all traders, who also had access to information concerning the time remaining in the prevailing trading period.

In contrast, both the VK and VU markets incorporate differential period durations that permit the length, l_v, of any period to vary between 120 and 360 seconds (where subscript v denotes variable). Strictly speaking the set L_v (possible period lengths in VK and VU markets) contains all the real numbers represented by the interval [120,360], because time is continuous. However, for the purposes of this research it is sufficient to allow period duration to vary by increments of one second. As a result l_v will take positive integer values and the set L_v can be represented as

$$L_v = \{l_v \in Z^+ : 120 \leq r \leq 360\}. \qquad 4.3$$

There may exist a minimum length of time that traders take to organise themselves and to evaluate the situation they are faced with, and it is for this reason that a minimum time limit is incorporated in the design.

The actual duration of any period in the VK and VU markets was generated

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than outstanding bids/asks.

[12] Plott and Gray (1990) suggest a rule of thumb of eight seconds is required per trade in a computerised double auction. The PI model predicts a volume of trade of twenty units, which is higher than the FRE prediction of sixteen units. The period duration of 240 seconds should permit the

randomly by computer from a uniform distribution prior to the experiment[13]. In the interest of controlling for the experience gained by participants whilst actually taking part in the experiment, l_v is subject to the further constraint that the total trading time available in all the experimental markets be equal. Thus

$$\sum_{j=1}^{15} l_c(p_j) = \sum_{j=1}^{15} l_v(p_j) = 240 \times 15 = 3{,}600\, seconds. \qquad 4.4$$

In VK markets participants know the duration of the trading periods, and they also have access to information concerning the time remaining in the current trading period. In VU markets participants do not know the duration of the trading periods, nor do they have access to information concerning the time remaining in the current trading period, for obvious reasons. Participants are simply informed that the trading period may close at any time.

4.5.3 Experimental Assets

Each trader is endowed with two types of financial asset at the beginning of each trading period. One asset is riskless, paying no return and acts as the numeraire within the experiment. Participants are endowed with a sufficiently large amount of this asset (working capital in the form of an *interest free loan* repayable in full at the end of each trading period), so as never to be a binding constraint. Thus the demand function for the risky asset is elastic because traders face no effective wealth limit. This experimental currency is entitled an emu (experimental monetary unit) and the endowment each period is 50,000 emus. The second type of asset offers an uncertain payoff ($D_{j,i}$) at the end of each trading period. This feature of the experimental design replicates the dividend paying attribute of common shares traded on the London Stock Exchange. As the asset has no intrinsic value and expires at the end of each trading period, this uncertain payoff represents its value. Each period, each trader is endowed with a finite amount of the discrete, homogenous 'risky' asset and short sales are prohibited. All traders are endowed with identical volumes of both the risky asset and the numeraire. The endowment of risky assets for each trader is 2,

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required number of trades under either equilibrium prediction.

[13] Traders are informed of the manner in which randomisation of all such parameters occurs. To ensure they believe these parameters to be randomly determined, behave as though they are and do not attempt to preguess subsequent values, individuals are told they can inspect the values utilised for all the randomly determined parameters in the experimental design, upon completion of market trading.

therefore, because of the restriction on short sales, the total supply of risky asset in any one market is fixed at 24 units in all periods.

At the end of each period participants have their initial endowments of both types of asset taken back, any difference remaining is profit. Each market is reinitialised at the beginning of each trading period, when traders are again endowed with the same magnitude of the two kinds of asset.

Within each market assets are traded using the experimental monetary units (emus). The reason for incorporating such a technique here, and in earlier experimental designs, stems from the need for relatively high nominal asset prices so as to ensure the separation of the theoretical predictions made by the equilibrium models under consideration. The convention is further maintained so as to remove any preconceived biases individuals may have otherwise held with respect to the use and 'value' of pound sterling.

4.5.4 States of Nature

The dividend is uncertain for any given trader because it is conditional on the 'state of nature' prevailing throughout the period. In the experimental design there are 3 possible states X, Y and Z. Thus, if S represents the set of states of nature, then letting s_k be a subset of S containing 3 elements (states) gives

$$\mathrm{X}, \mathrm{Y}, \mathrm{Z} \in s_k \subset S, \qquad 4.5$$

where the subscript k (= x, y, z) identifies the particular state that has occurred. For example, the notation s_x indicates that state X has occurred for the particular period in question. Each state of nature has an equal probability of occurring, thus P(X) = P(Y) = P(Z) = 1/3. The sequence of states in each market was randomly generated in advance by computer. The state of nature that exists in a particular period is revealed to all traders at the *end* of the period in question. Those traders who receive information concerning the state of nature governing a particular period prior to its conclusion are termed 'insiders' (see below).

4.5.5 Participants and Motivation

The experimental markets were conducted during November 1996 through May 1997. The participants were a mixture of undergraduate and postgraduate students, drawn from the entire population of students at the University of York. Students were recruited via advertisement posters and mailing lists, asking them to sign up for an experimental session. Two further experimental markets were conducted using undergraduate students at the University of Leeds.

So as to control for the number of traders as a variable, all markets comprise 12 participants (subscript n=1, 2 ... 11, 12, and identifies a given trader). The set T of the 12 participants is divided equally among into 3 trader type groups denoted t_i, where subscript i = 1, 2 or 3 and refers to the trader type.

$$T = \{t_i \in Z^+ : 1 \leq i \leq 3\}. \quad 4.6$$

These trader type groups differ with respect to the uncertain dividends payable to them at the end of each trading period. Traders in the same group receive the same uncertain dividend per asset held at the end of a trading period ($D_{j,i}$), conditional upon the state of nature pertaining, whereas, across groups the state contingent dividend will differ. It is the diverse dividend payout across trader types that introduces the possibility of gains from exchange and thus induces trade among individuals.

An individual's distribution of returns, $D_n(s_k)$, is private, known only by themselves. Participants were instructed not to reveal this information to any other trader. The only information given to participants with respect to other individuals' distribution of returns is that they may differ from their own. They were not aware of the identity of the other traders in the same trader group. The result is an endogenous uncertainty as to what the asset price should be in any given period. This particular feature of the experimental design replicates earlier studies such as Plott and Sunder (1988) and O'Brien and Srivastava (1991). Table 4.1 illustrates the state contingent dividends[14] paid to trader types. Two different parameter designs were used throughout the experiment, though only one parameter set was applicable for any given experimental market. In each of the individual 'results' chapters to follow the discussion will make clear which parameter set was in play for a given market. Note that whilst the expected emu dividend differs across trader types, the expected dividend in pound sterling terms is identical (expected emu dividend multiplied by the relevant conversion factor).

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[14] Note that it is these state contingent dividends that determine the equilibrium price predictions of the FRE and PI models under consideration.

Trader Type	*State* X	Y	Z	*Conversion Factor*
1	350	200	200	0.000667
2	100	300	200	0.000833
3	300	200	700	0.000417

Panel A: Parameter set A

Trader Type	*State* X	Y	Z	*Conversion Factor*
1	250	300	350	0.000833
2	200	350	950	0.000500
3	200	400	600	0.000625

Panel B: Parameter set B

Table 4.1 State Contingent Dividend Distributions (emus)

As the risky assets have no intrinsic value of their own, preferences (values) for them need to be induced via the procedures derived by Smith (1976). A redemption function, denominated in emus, is assigned to each trader of the form given in the equation below:

$$Profit_n = \sum_{j=1}^{15} [R_{j,n} - C_{j,n} + D_{j,i}(s_k).h_{j,n}] \qquad 4.7$$

Where;

$Profit_n$ = profit earned by trader n during the entire experiment,

$\sum_{j=1}^{15}$ = summation over all periods,

$R_{j,n}$ = revenue of trader n from the sale of risky assets in period p_j, summed over all periods,

$C_{j,n}$ = cost in period p_j of the purchase of risky assets for trader n, summed over all periods,

$D_{j,i}(s_k)$ = dividend for trader type i given the state prevailing in period p_j, summed over all periods,

$h_{j,n}$ = number of assets held by trader n at the end of period p_j,

Note that the loan of initial working capital of 50,000 emus is reclaimed each period and does not constitute profit. Thus it is omitted from the redemption function. Each individual's redemption function is private information and thus, as already indicated

$D_i(s_k)$ is not common knowledge.

As is the convention in experimental economics, individuals are motivated to perform to the best of their abilities by the existence of salient financial rewards. The orthodoxy in previous studies has been to convert individuals' experimental currency profits into 'domestic' currency and pay participants exactly what they earn for participating. Thus providing participants with an incentive to earn as much experimental profit as possible. The payoff structure in this experimental design adheres to this convention, in addition participants were given a £2.00 attendance payment.

Given the reward structure adopted, it is clear that bankruptcy is a real issue. It is possible that an individual's experimental profit, when converted to pound sterling, may be so highly negative that the net payment to the participant, including the £2.00 attendance payment, is still negative. The 'best way to deal with the bankruptcy problem is to design the experiment in such a way as to minimise, if possible, eliminate, the chances of bankruptcy.' (Friedman and Sunder, 1994, p.52). With this advice in mind, the parameter designs were chosen so that the expected value of participating in the experiment, assuming the markets achieved 100% efficient allocations, was a minimum of £9.75 (when private information was costless) and rose to £10.80[15] (when private information was costly). Unfortunately, it was not possible to eradicate the possibility of bankruptcy from the design and so it was necessary to devise a plan of action should a participant end the experiment bankrupt. It was decided to permit traders to make a maximum trading loss of £2.00, equal to the attendance payment they received. Thus resulting in a minimum net payment for participation of zero. This was announced to all participants prior to the start of the experiment. Whilst not ideal, due to potentially induced risk-seeking behaviour in participants with highly negative profits, this procedure did allow participants to make some financial loss, thus the payoff structure was not entirely one

[15] This latter figure is expressed gross of any cost of private information. Not knowing in advance what the endogenously determined cost of private information would be, it was impossible to guarantee that the net expected value across the two types of design would be identical. It was decided to adjust the parameters of the design to increase the expected value of participation in those markets with costly information acquisition. This would compensate participants for having to pay for information and also maintain the highest possible degree of comparability between the costless and costly information markets, on a net expected value basis.

sided. Furthermore, other options such as dismissing participants from the experiment as soon as they became bankrupt were not possible due to the constant number of traders required each period of each experimental market. Fortunately, despite Friedman and Sunder's (1994, p.52) advice that '[n]o matter how carefully you design the parameters, an occasional bankrupt will occur' none of the participants in the eighteen experimental markets conducted became bankrupt. Table 4.2 offers some descriptive statistics summarising the payments made to participants across all eighteen experimental markets.

All Sessions	***£***
Mean	8.55
Median	8.40
Standard Deviation	1.62
Maximum	14.74
Minimum	3.15
5th Percentile	6.30
95th Percentile	11.52

Table 4.2 Summary of Payment to Participants

Each session had places for sixteen volunteers to sign up to attend, although only twelve were required for the experimental markets. The four 'spare' places were included as insurance to try to guarantee exactly twelve participants were available for all markets. On those occasions when greater than twelve volunteers signed up and attended the session, twelve were randomly drawn to stay and take part in the experiment, whilst the others were thanked for attending, paid the £2.00 attendance payment and asked to sign up for another session. On those occasions when less than twelve volunteers turned up to take part, the session had to be cancelled and rescheduled. Those that had turned up were thanked, paid the £2.00 attendance payment and asked to sign up for another session.

Participants were issued the instructions prior to the beginning of an experimental session so they could familiarise themselves with the requirements. At the beginning of each experimental session the experimenter reviewed the instructions and answered any questions that the participants had. Before each market commenced trading proper a nine minute practice period[16] was played out so that

[16] Nine minutes was chosen to provide sufficient time for all participants to familiarise themselves with the trading process and to witness a number of transactions. In VU markets traders

individuals could familiarise themselves with the computer screen layout, the key strokes required to enter bids and asks and the whole process by which trade took place. After the practice session any further questions were addressed and the experimenter made sure that all participants appeared to understand the trading rules and the relationship between their trading performance and their ultimate payment for taking part in the experiment. Details of the instructions used are contained in Appendix One. The convention of identifying markets with the labels CK, VK, VU, P, and I is adopted to indicate where the instructions differed across markets. Any text contained in square brackets was only included in the instructions for those markets identified by the label in parentheses after the square brackets. All emphasis was contained in the original instructions.

Each experimental session lasted approximately 90 minutes. Trading was conducted over a total of sixty minutes and each practice period lasted nine minutes. The remaining time was taken up with clarification of instructions, questions and payment to participants. On average, participants received, in cash, £8.55 for 90 minutes of their time. This is equivalent to an hourly rate of £5.70, far more than would be available to students through part-time jobs such as bar work or waiting tables. The reward structure and parameters adopted, therefore, meet the requirements of salient, dominant rewards.

4.5.6 Information Structure

In all the experimental markets, six individuals, termed 'insiders', are provided with private information at the beginning of each period. Those individuals not so privileged (uninformed) only learn the identity of the state of nature with certainty at the end of the trading period. Their clues simply contained the word 'Blank'. The identity of insiders was concealed in all periods of all markets, to ensure that the only public information utilised by uninformed traders to determine their trading behaviour are the bids, asks and transaction prices observed in the market. It is the role of prices as disseminators of private information that the series of

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were informed that the duration of the practice period could not be interpreted as indicative of the duration of the subsequent trading periods. Note also that traders did not receive information concerning their state contingent dividends until after the practice period was over. This information was withheld to prevent the practice trading session from revealing any information to traders concerning other individuals' state contingent dividends.

experimental markets is designed to capture, not the ability to identify an insider.

The number and the manner in which insiders were determined each period were common knowledge in all markets. Also common knowledge was the fact that all traders would receive clues, even if they were 'Blank', so as to conceal the identity of insiders in all periods. The type of information (perfect and imperfect) given to insiders and the manner in which individuals were chosen to be insiders (exogenous and endogenous) differ between the four groups of experimental markets and so will be detailed in later, relevant chapters.

4.5.7 Computerised Double Auction

All the markets were conducted using a computerised double auction. Illustrations of the screens participants saw during each trading period are contained in Appendix Two and are briefly reviewed here. At the beginning of all trading periods participants viewed an 'initial endowments screen' that identified the number of the forthcoming trading period and reconfirmed to participants that reinitialisation of endowments had occurred since the last period. Their endowments of assets and emus were reset to values of 2 and 50,000, respectively, and their profit for the forthcoming period was reset to zero.

At the signal of the experimenter the trading period began and the computer moved to the 'trading screen.' This screen continuously displayed and updated the current bid and ask prices, plus the participant's holdings of assets and emus. Also displayed were the period number and a continuously updated history of the transaction prices to date in that period. These prices were displayed across the screen in green, unless the trader was involved in a particular trade in which case that price was displayed in red on their screen. If an individual wished to enter a bid (ask) they would press the letter 'b' ('a') on the keyboard. This would open up the box at the bottom left (right) of the screen, allowing them to enter the value in emus at which they would like to buy (sell) an asset. Traders then had to confirm this value for the computer to then enact the instruction. The current bid and ask prices were displayed on the screen in white, unless a particular trader held the current bid or ask in which case it was displayed in pale blue on their screen. If the market was designated a CK or VK market then the trading screen also displayed the time, in seconds, remaining in the current trading period. If the market was designated a VU market then the screen simply displayed a question mark where the time would have been.

The rules governing trade (discussed in subsection 4.5.1) were imposed on traders by the computer. For example, the no short sales rule was enforced and if a trader tried to sell an asset when their current holding was zero a message to the effect 'too few assets' would be displayed on the screen. If a trader tried to enter a bid to buy an asset for a price higher than their current holding of emus a message to the effect 'too few emus' would be displayed on the screen. The improvement rule concerning permissible bids and asks was enforced and if a trader tried to submit a bid/ask that was below/above the current bid/ask a message to the effect 'bid/ask too low/high'.

At the end of trading in a period, signalled by an audible beep, the computer screen moved on to display the 'state of nature screen'. This screen displayed, to all traders, what the state of nature was for the period just ended. After a short time allowing participants to take this information in, the computer moved on to display the end of period financial position for the trader. The 'financial position screen' displayed the number of assets held by the trader at the end of the period and the dividend that would be paid for each asset held. Also displayed was the end of period holding of emus less the initial loan, and the computed end of period profit in emus.

On the signal from the experimenter the next trading period commenced and the computer cycled through the above four screens. This process repeated until the 'financial position screen' of the fifteenth and final trading period had been displayed. The 'closing financial position screen' then displayed the emu profit the trader made in each of the fifteen trading periods and converted the total emu profit into an amount in pounds.

The experimental sessions conducted at the University of York were run over a network of PCs connected to a server running Novell netware 3.12. The server machine was an Elonex 486DX2 (66MHz) with 8Mb ram. The networked PCs were a mixture of Elonex 386SXM16 (16MHz) PCs and Elonex PC88c XT (9.54MHz) PCs, with one of the former specifications being designated the control machine. All these PCs had 1Mb ram and no hard disk drive. At the University of Leeds the server was a Hewlett Packard Pentium 133MHz with 128Mb ram, running Novell netware 4.11. The networked PCs were 386SX25 (25MHz) with 40Mb hard disk drives and 8Mb ram. The 'control' and 'participant' programmes were written using Turbo Pascal v7. Versions of these were produced that enabled the 'participant' PCs to simulate human trade. Each generated bids and asks as appropriate and several hours of simulation were run to enable checks to guarantee the data was being saved correctly. The speed of responses being produced by the PCs was far in excess of those actually produced by human participants in the subsequent experimental sessions.

To briefly summarise the general experimental design, the novel feature of this experiment is the inclusion of varying period duration as a treatment variable in experimental financial asset markets. The CK markets incorporate constant period duration and act as the control against which to contrast the trading behaviour in the VK and VU markets. The following section introduces the disparate design features of the four groups of markets comprising the experiment, however, discussions of the specifics of these designs are left until the relevant subsequent chapters.

4.6 Specific Experimental Designs: An Overview

4.6.1 Experimental Group 1

In the first group of experimental markets insiders are given perfect information (P) free of charge, thus no market for information (N) is conducted. The ability of markets to disseminate private information is investigated. These factors are held constant across all six markets in this group. The markets differ with respect to the type of period duration in existence. Two markets are conducted with constant known (CK) period durations, two with variable known (VK) durations and two with variable unknown (VU) durations. These markets are identified with the acronyms CKPN, VKPN and VUPN, respectively, with 1 and 2 referring to the parameter design adopted (see Table 4.3). Thus each cell of the experimental design is replicated once, giving a total number of trading periods in each cell of thirty. All participants were inexperienced in so much as they had not taken part in a double auction asset market previously.

4.6.2 Experimental Group 2

The design in the second group of experimental markets replicated that in the first group with only one change. The previously perfect insider information was replaced with imperfect information (I). Again, no market for information (N) was conducted and the information was free. The ability of markets to simultaneously aggregate and disseminate private information is investigated. As with the group one markets, two markets were conducted for each of the three period duration types, giving a total of six markets. These markets are identified with the acronyms CKIN, VKIN and VUIN, with 1 and 2 referring to the parameter design adopted (see Table

4.3). Each cell of the experimental design is replicated once, giving a total number of trading periods in each cell of thirty. All participants were once more inexperienced.

4.6.3 Experimental Group 3

The design in the third group of experimental markets replicated that in the first group with only one alteration. A market for information (M) was conducted prior to trade in every period. Traders took part in a sealed-bid auction, entering the price at which they were prepared to purchase the perfect information (P). Appendix Two illustrates the 'information auction screen' the participants faced and also indicates how the 'financial position screen' was amended to include information costs. In contrast with the group one markets, only one market was conducted for each of the three period duration types, giving a total of fifteen trading periods in each cell of the design. These markets are identified with the acronyms CKPM, VKPM and VUPM. All participants were experienced in so much as they had taken part in one of the experimental markets from group one or two.

4.6.4 Experimental Group 4

The design in the fourth group of experimental markets replicated that in the second group with only one alteration. A market for information (M) was conducted prior to trade in every period. Traders took part in a sealed-bid auction, entering the price at which they were prepared to purchase the imperfect information (I). The screen illustrations in Appendix Two are once more relevant. In contrast with the group two markets, only one market was conducted for each of the three period duration types, giving a total of fifteen trading periods in each cell of the design. These markets are identified with the acronyms CKIM, VKIM and VUIM. As with the group three markets, all participants were experienced in so much as they had taken part in one of the experimental markets from group one or two.

Period	Parameter set 1		Parameter set 2		Parameter set 3a		Parameter set 3b	
	State	Duration	State	Duration	State	Duration	State	Duration
1	Z	186	X	178	Z	133	Y	133
2	X	251	Y	319	Y	249	Y	249
3	X	130	X	175	X	181	Z	181
4	Y	303	Z	138	X	129	Z	129
5	Z	319	Y	244	Z	360	X	360
6	Y	175	Y	351	Z	287	Y	287
7	Y	128	X	128	Y	327	X	327
8	Z	301	Z	213	Y	156	X	156
9	X	286	X	338	Y	226	Z	226
10	Z	140	X	182	X	349	X	349
11	Y	338	Z	350	X	328	Y	328
12	Y	197	X	327	Z	147	Y	147
13	X	347	X	130	X	129	Z	129
14	X	359	Y	355	Y	339	X	339
15	Y	140	Y	172	X	260	Y	260
Total	n/a	3600	n/a	3600	n/a	3600	n/a	3600

Table 4.3 Summary of Parameter Designs

4.6.5 Full Factorial Design

The preceding discussion highlights how each group of experimental markets builds upon the previous groups, thus adding additional layers to the overall experimental design. Table 4.4 provides a summary of the overall design. The combination of all layers of the experimental design results in a 3x2x2 full factorial design. A discussion of the strengths of the chosen design follows.

Exp. Group No.	Information Structure	Cost of Information	Duration		
			Constant Known	Random Known	Random Unknown
1	Perfect	No market (free)	CKPN1 [a] CKPN2 [b]	VKPN1 [a] VKPN2 [b]	VUPN1 [a] VUPN2 [b]
2	Imperfect	No market (free)	CKIN1 [a] CKIN2 [b]	VKIN1 [a] VKIN2 [b]	VUIN1 [a] VUIN2 [b]
3	Perfect	Market	CKPM [c]	VKPM [c]	VUPM [c]
4	Imperfect	Market	CKIM [d]	VKIM [d]	VUIM [d]

Key: [a] Parameter set 1
[b] Parameter set 2
[c] Parameter set 3a
[d] Parameter set 3b

Table 4.4 Summary of Experimental Design

The strength of the experimental design follows from the ability to isolate certain treatment effects by blocking out other effects. Each of the groups of experimental markets can be analysed in isolation to determine the impact of period duration on trading behaviour and market efficiency. In all such comparisons the only treatment (or nuisance) variable that changes is the period duration type, thus its effect is not confounded with the effects of any other parameter changes. A comparison of experimental markets between groups permits the effects of information structure and information costs to be isolated and also investigated absent of any confounding effects.

The major strength of the chosen design results from the ability to investigate the impact of the treatment period duration type using all experimental markets, thus improving the sample size and power of statistical tests, whilst blocking out the confounding effects from information structure and information cost changes. The same argument is true for both information structure and information cost as treatment effects. The use of a full factorial design, whilst being more demanding of time and money than a fractional factorial design, allows all treatment variables to be manipulated independently[17] and thus offers the clearest possible picture of their effects.

At this point it is necessary to address a couple of methodological design concerns previously raised in the experimental literature. Roth (1994) raises methodological concerns regarding data selection and the definition of exactly what constitutes the 'experiment'. The approach taken here is in line with Roth's (1994) method of planned experimental design, in which the entire experimental design (all experimental markets) was conceived prior to the conduct of any one market. All the cells in the 3x2x2 factorial design constitute the 'experiment' and all the observations are reported. Thus, Roth's (1994) concerns over selective data reporting, resulting from the method of independent trials in which each trial is regarded as an experiment

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[17] Many experimental asset market papers have changed greater than one variable across markets, thus strict comparison of a theoretical model's performance is not possible due to confounding effects. In these situations care most be taken in drawing conclusions, it is not possible to say that the change in the relative performance of the model is due to the change in a particular treatment. For example, in Copeland and Friedman (1992) the number of trading periods differs dramatically across markets, at the same time as their treatment variables change across markets. Their results are valid, however, as they compare disparate theoretical predictions within markets and draw no inferences about how a treatment variable impacts on a given model's relative performance.

and is designed sequentially, are not an issue. Sunder (1991) concurs that there is no justification for less than full disclosure, even of exploratory experiments used to guide the subsequent design of future experiments. Sunder (1991) criticises two-step, sequential designs suggesting that it is not defensible to present the results as if the cells were designed at once, because statistical tests across the cells become problematic to interpret. The experimental design adopted here is not subject to this criticism due the one-step nature of its conceptual design. This draws to a close the discussion of experimental method and design contained in this chapter. Subsequent chapters will go on to consider specific design considerations that are not applied generally across the entire experiment and will go on to analyse the data and report the results of the investigations carried out in this research.

4.7 Discussion and Conclusions

The chapter began with an introduction to the method of experimental economics, which also compared the applicability of conventional econometric and experimental techniques in the investigation of financial market efficiency. Via commentaries on both the inherent weaknesses of the econometric methods applied to field data and the rigorous control provided by the experimental method, the discussion questioned the use of conventional econometric techniques. The adoption of an experimental method was offered as an alternative research tool that could overcome the problems associated with conventional methods, specifically the lack of control of important variables. The experimental method is a versatile research tool that can be put to many uses, of which the testing of theoretical predictions is only one. Subsection 4.2.4 reviewed the other purposes of experimental methods in economics. This was followed by a detailed discussion of the necessary conditions required to achieve control via an induced reward structure. Economic experiments are characterised by the incorporation of monetary rewards in the experimental design. It is this feature that separates economic experiments from psychology experiments. Generally voiced criticisms of the experimental method in economics were considered in section 4.4, which concluded with a justification of the adoption of the method in the investigation of financial asset market efficiency.

The focus of the chapter changed with the discussion in sections 4.5 and 4.6. These sections detailed the specifics of the experimental design employed in the current research programme. Eighteen experimental asset markets were designed that, when combined, formed a 3x2x2 full factorial design. The markets differed with respect to three treatment effects, period duration, information structure and the incorporation of a pre-trade information auction. It is the inclusion of period duration as a treatment variable that is the novel feature of this experimental design.

Control is the substance of experimental economics. The ability to strictly control treatment variables ensures that an experiment can be designed in which the ceteris paribus conditions specified by a given theory are not violated. This ability means that experimental methods are ideal for such purposes as the evaluation of theoretical predictions, the discrimination between competing theories and the comparison of market performance observed under different institutional rules of exchange. It is the control offered by experimentation that ensures the method has a role to play in the development and choice of institutions of exchange for adoption by the emerging on-line auctions and the growth of trade centred around virtual communities. Thus, whilst the experiment was not designed specifically to address these issues, it is able to offer general insights concerning the effect of uncertain period durations on observed market performance and the level of market efficiency obtained.

Chapter Five

5 Impact of Period Duration on Experimental Asset Markets with Perfect Information Structures

5.1 Introduction

The focus of this chapter is an investigation of the impact of trading period duration, as a treatment variable, on the market performance observed in experimental financial asset markets. The high level of market efficiency observed, and gains from exchange exhausted, under the rules of the DA are well documented in the experimental literature. Unfortunately, why the DA is so efficient is a question that is still to be answered. The purpose of this chapter, and a fundamental objective of the thesis as a whole, is to consider the influence of period duration on the market behaviour observed in experimental asset markets. It is possible that the high level of efficiency witnessed in experimental DA markets is a result of the use of trading periods in which the duration of trade remained constant and was known by traders. The closer the end of a trading period, the more myopic an individual's trading strategy must become if they are to realise any potential gains from trade available. This adds to the competitive pressures that are driving the transaction price towards the competitive equilibrium price. It is possible that the high level of market efficiency is the product of constant, known period durations.

As this is the first major study of such an effect the markets studied are intentionally simple, drawing on earlier experimental designs. The treatment variable takes on three levels; constant known (CK), variable known (VK) and variable unknown (VU) period durations. Six experimental markets are conducted in this first group of sessions, two in each of the treatment levels. The information structure, identical across all six markets, is intentionally simple in design, providing some traders with perfect information. Thus, the markets studied are only required to disseminate private information, and information aggregation is not necessary. Chapter Six considers markets with imperfect information structures, therefore, requiring both information aggregation and dissemination.

The following section briefly reviews relevant experimental and theoretical literature, providing the motivation for this research. Section 5.3 introduces a number of testable hypotheses. Section 5.4 discusses in detail the findings of Duxbury (1997), a pilot study of the impact of random period duration. Specifics of the experimental design, not included in the earlier general design chapter, are introduced in section 5.5. Section 5.6 provides analysis and reports the results of the study. Discussion and conclusions are contained in section 5.7.

5.2 Review of Relevant Literature

Previous experimental studies of the convergence of asset prices and allocations to theoretically predicted equilibrium values, have incorporated trading period durations that remain constant for a given experiment. Participants in such experiments have known the trading period duration they face. For example, Copeland and Friedman's (1987) experimental design incorporates a constant period duration of 5 minutes, as does Sunder (1992), whereas studies by Forsythe, Palfrey and Plott (1984) and Banks (1985) invoke period lengths of 7 minutes. In many of the studies the time remaining in a trading period has been information readily available to participants via computer screens. In addition, in some studies participants have been warned when the trading period nears completion. In Ang and Schwarz (1985) the experimental design includes a known period duration of 6 minutes, with warning bells that sound after 5 and 5½ minutes have elapsed since the current period began. It is possible that this knowledge has an important influence on the efficiency of outcomes reported in these and other studies.

In the theoretical literature, Friedman (1984, p.71) concludes that, amongst other features, the knowledge of the preset time at which trade will end is an institutional feature of experimental DA markets that enhances the informational and competitive efficiency of observed outcomes. As the end of trade approaches the opportunities to gain from holding back on transacting decrease, thus traders are more likely to accept or, more importantly, *better* (offer a higher price/ask for a lower price) existing bids and asks. The closer the end of a trading period becomes the more myopic a trader's behaviour must become if they wish to realise any remaining gains from exchange. Indeed, many of the previous studies of experimental DA markets indicate an increase in the rate of trade in the closing stages of trading periods. For a graphic example see Plott and Sunder's (1982, p.680) Figure 4 which shows the time series of transaction prices in their Market 3.

Friedman, Harrison and Salmon (1984) and Friedman (1991) develop models of DA markets that predict bid, ask and acceptance behaviour. Both studies adopt the assumption that trade is permissible over a finite interval time [0, T]. Friedman's (1991, p.52) BGAN3 assumption allows for the random generation of new bid and ask prices at random times. The exact distribution of such prices is unknown, however, it is assumed that traders have sufficient knowledge of the distribution of times to compute the expected number of new prices available to them before the end of the trading period. To achieve this traders require information regarding the time at which trade ceases in the period, thus there is implied knowledge of the trading period duration. It seems that this is a fundamental assumption if the model is to predict convergence of prices and allocations to almost Pareto optimal outcomes (see Proposition 3, op cit p.58).

Thus there is limited theoretical and indirect experimental evidence that the certain knowledge of when a trading period will end actually influences a market's trading behaviour, with respect to overall efficiency and the timing of transactions. Participants may delay transacting because they are waiting to see if additional information concerning the prevailing state of nature is forthcoming. Such behaviour would consequently impact upon the speed at which transaction prices converge to theoretically predicted equilibrium values. Thus the results reported in previous experimental studies may in fact have been biased towards, or away from, the rapid attainment of a FRE equilibrium. Given the high level of informational and allocational efficiency reported in the literature it is more likely to be the former.

The pilot paper by Duxbury (1997) is the only study of the impact of trading period duration on market performance, to date. Drawing extensively on Duxbury (1997), the following section develops a number of testable hypotheses. The subsequent section provides a detailed review of the results reported in Duxbury (1997).

5.3 Development of Hypotheses

The trading performance reported in previous experimental asset markets may potentially be a result of the artificial trading period deadline. In an attempt to overcome this potential bias, period duration is introduced into the experimental design as a treatment variable. Markets are conducted with variable and known (VK) durations and variable and unknown (VU) durations. In the former markets individuals still know when the trading period will end, whilst in the latter markets individuals' knowledge of exactly when a trading period will end is removed. The outcomes observed from a market under the regime of constant and known (CK) period duration form a control against which the trading behaviour witnessed in VK and VU markets can be compared. Comparison of market behaviour observed in VK and VU markets permits the impact of knowledge of period duration to be isolated and investigated.

The issue raised is of substantive theoretical and practical interest. The few theoretical models of bid, ask and transaction price behaviour in experimental DA markets developed to date rely on assumptions concerning the time remaining until the end of trade. Indication of the importance of these assumptions for the convergence behaviour advocated by these theoretical models is necessary for future theoretical development. This study can be viewed as a 'boundary' experiment designed to determine the importance of the period duration on the efficacy of theoretical models and so provide guidance with respect to those areas or variables requiring theoretical refinement. The results may also shed light on the disparate results reported by the empirical (low level of efficiency) and experimental (high level of efficiency) literature investigating the informational efficiency of financial markets and associated trading institutions. The experimental results to date may be an artefact, due to the known trading period duration.

The remainder of this section details the development of a set of null (H_O) and alternative (H_a) hypotheses, concerning the impact of period duration on the volume of trade, informational efficiency and allocative efficiency observed in the experimental markets. Due to the lack of theoretical literature concerning the DA market institution the hypotheses offered are exploratory in nature and are intended to motivate the development of relevant theoretical models.

Early trading volume: The uncertain period duration in VU markets may well result in a reduction in the length of time taken over bartering and thus an increase in the volume of trade early in the period as traders attempt to realise potential gains from trade before the trading period closes. Alternatively there may be no impact (see $1H_O$ below). A priori, it is not clear in which direction VK period duration will impact on the volume of trade. Therefore, for reasons of consistency, the alternative hypothesis will be two-sided for all comparisons.

Informational efficiency: Following Friedman's (1984) line of reasoning, the introduction of uncertain period duration (VU) may result in a decrease in the informational efficiency of the experimental markets with respect to the convergence of transaction prices to theoretically predicted equilibrium values. Non-convergence of prices could plausibly occur if the predicted higher volume of trade early in a period meant that, in their haste to trade, individuals imperfectly infer the underlying state of nature from the publicly available information. Alternatively, a priori, the predicted higher volume of trade may result in an increase in the speed of convergence to equilibrium values if the bids, asks and transaction prices correctly reveal the underlying state of nature. For the VK markets there is no a priori predicted directional change in volume and so consequently it is difficult to conjecture in what direction varying the period duration will impact on the informational efficiency of such markets.

Allocative efficiency: Similarly, Friedman's (1984) line of reasoning, suggests that the introduction of uncertain period duration (VU) may result in a decrease in the allocative efficiency of the experimental financial asset market with respect to the convergence of asset allocations to theoretically predicted equilibrium allocations. The result would be a reduction in the percentage of potential gains from exchange to be exploited. Once more, non-convergence could plausibly occur if the predicted higher volume of trade early in a period meant that, in their haste to trade, individuals imperfectly infer the underlying state of nature. Alternatively the percentage of potential gains from exchange to be exploited may be increased if, a priori, the predicted higher volume of trade resulted in the underlying state of nature being revealed earlier in a period. Thus, more time is available for traders to position their portfolios efficiently. Once again, for the VK markets there is no a priori predicted directional change in volume and so consequently it is difficult to conjecture in what direction varying the period duration will impact on the allocational efficiency of such markets.

Premised on the above line of reasoning, a set of null and alternative hypotheses can be tentatively formulated. The hypotheses are worded generally so as to be equally valid for both VK and VU markets. All alternative hypotheses are two sided and are not explicitly stated.

1H_0: The treatment period duration does not impact on the volume of trade early in a given period, as compared to that observed under a control market.

2.1H_0: The mean deviation of transaction prices from theoretically predicted values in the treatment period duration market does not differ from those observed in a control market.

2.2H_0: There is no correlation between the difference in the volume of trade, across the experimental markets, and the difference in the mean deviations from

predicted transaction values, across the experimental markets, 'early' in trading period.

3.1H_0: The percentage of gains from trade to be exhausted in the treatment period duration market does not differ from those observed in a control market.

3.2H_0: There is no correlation between the difference in the volume of trade, across the experimental markets, and the difference in the percentage of gains from trade to be exhausted, across the experimental markets.

Evaluation of 1H_0 determines whether period duration impacts upon the volume of trade in a trading period. An ability to reject 2.1H_0 for the VU markets provides evidence in support of Friedman's (1984) suggestion of an enhancement of efficiency as a result of predetermined, known period duration. Taken together, an analysis of 2.1 and 2.2 H_0 determines the impact on price convergence (*informational efficiency*) of a change in the volume of trade as a result of the treatment period duration. An analysis of 3.1 and 3.2 H_0 permits an evaluation of a change in the volume of trade (as a result of the treatment period duration) on the percentage of gains from exchange exhausted (*allocational efficiency*).

5.4 A Review of Pilot Study Results

The pilot study of Duxbury (1997) conducts two experimental markets; one (CONPERIOD) is equivalent to the CK markets conducted here, whilst the other (RANPERIOD) is equivalent to the VU markets. The experimental design of these markets is essentially the same as the markets conducted here. Both markets included 12 traders, subdivided into 3 trader type groups. Three states of nature were in existence and 6 insiders received costless perfect information. The major exception is that both markets comprised only 10 trading periods, rather than the 15 adopted here. The paper defines three measures of 'early' in a trading period (45, 60 and 90 seconds) to be used in the analysis. A review of the results follows.

Firstly, the volume of trade per period was compared across markets to determine whether random period duration actually had an impact on overall volume. So as to control for the disparate period durations experienced across CONPERIOD and RANPERIOD, the absolute volume of trade each period was normalised by dividing the volume by the duration in seconds for each period in question. This procedure created a volume/duration (V/D) ratio that could be compared across markets, without being biased by the duration of trade each period. Figure 5.1 illustrates the normalised volume of trade per period. The V/D ratio of RANPERIOD is greater than that for CONPERIOD in 8 out of 10 periods with mean V/D ratios for CONPERIOD and RANPERIOD of 0.051 and 0.060 respectively.

The preliminary analysis indicated that random period duration does influence the timing of transactions in experimental financial markets. Preliminary consideration was then given to the prices at which assets trade in the two markets and the deviation of these from theoretically predicted values. Figure 5.2 shows the root mean squared deviation (RMSD) of transaction prices per period graphed against period number. Over the entire market the RMSD per period shows a declining nature for both CONPERIOD and RANPERIOD. However, without exception, in all ten periods the deviations in RANPERIOD were in excess of those observed for CONPERIOD, suggesting that the average transaction price in CONPERIOD was closer to the predicted FRE value.

Duxbury (1997) also conducts a preliminary analysis of the allocative efficiency of the markets. The actual gains from trade realised were expressed as a percentage of the theoretical gains from exchange to define the measure %GAIN. Neither market ever achieved 100% of the theoretical gains from trade per period. CONPERIOD's average efficiency level was 45.49%, with a maximum of 73.81%

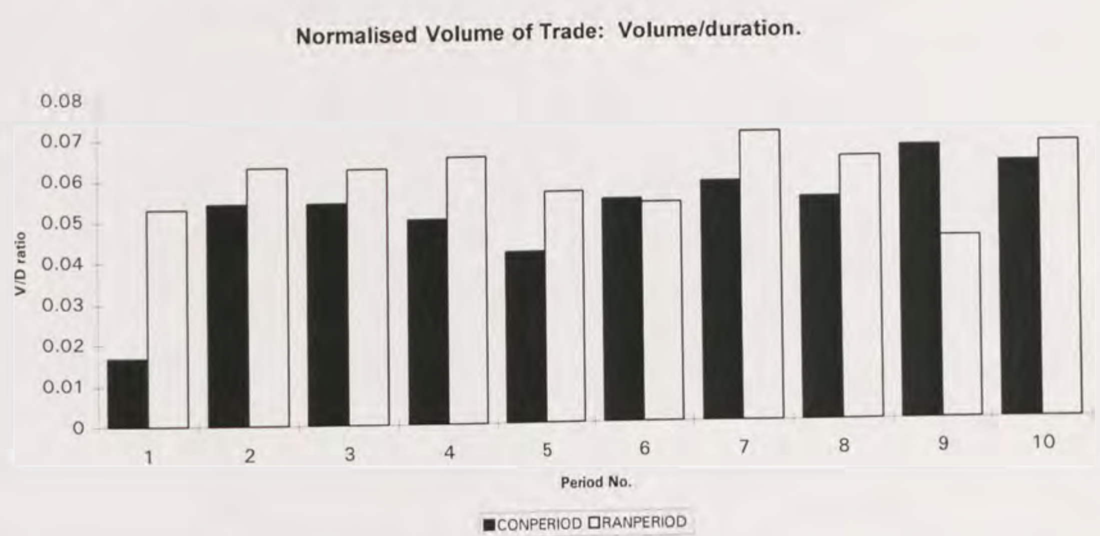

Figure 5.1 Normalised Volume of Trade per Period

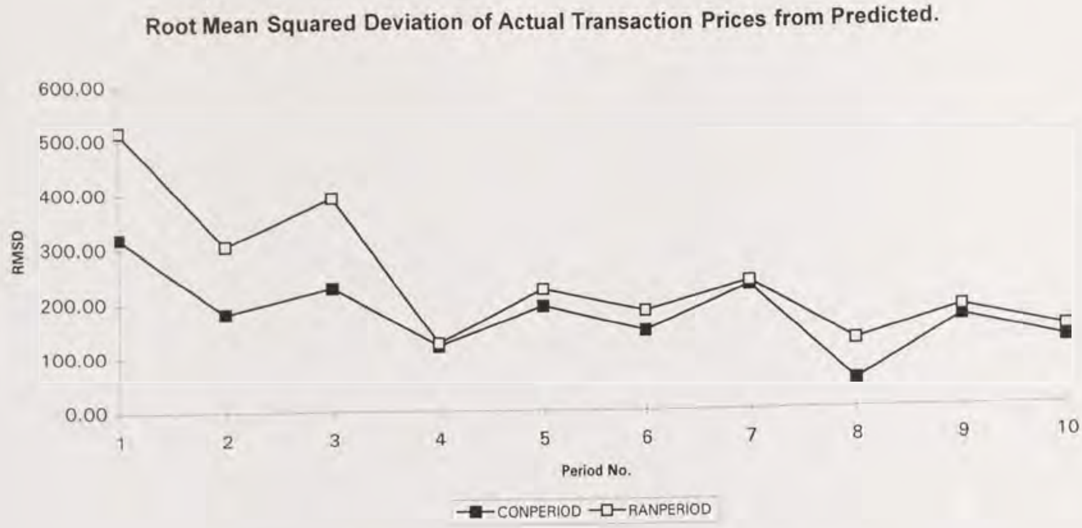

Figure 5.2 RMSD of Transaction Prices per Period

and a minimum of 12.50% (standard deviation = 18.21). The corresponding figures for RANPERIOD where a mean of 45.89%, maximum of 69.53% and a minimum of 17.89% (standard deviation = 17.89). Efficiency losses incurred in both markets were predominantly the result of missed trades (intra-marginal efficiency losses), indicating there may have been insufficient time per period to trade all the predicted assets (especially relevant for RANPERIOD). Direct comparison of the %GAIN values across the two markets was not possible due to the disparate period durations, thus Duxbury (1997), compared normalised %GAIN figures per period. The level of normalised %GAIN is greater in RANPERIOD than in CONPERIOD in 6 out of the 10 periods. It appears, therefore, that random period duration did not impact upon the final allocation of assets in any systematic manner in the two markets investigated.

In order to more directly address the predictions of $1H_0$, $2.1H_0$ and $2.2H_0$ three measures of 'early' in a trading period were defined; the first 45, 60 and 90 seconds of trade in a period. The volume of trade (VOL45, VOL60 and VOL90) and the associated root mean squared deviation of transaction prices from theoretically predicted equilibrium values (RMSD45, RMSD60 and RMSD90) over these three time intervals were compared for CONPERIOD and RANPERIOD.

Volume of trade: RANPERIOD exhibited significantly higher volumes of trade for the three measures of early in a trading period, providing support for the rejection of $1H_0$. The significance levels for 45, 60 and 90 seconds were $\alpha=0.01$, $\alpha=0.02$ and $\alpha=0.005$, respectively. Duxbury (1997) concluded that the uncertainty introduced by random period duration caused individuals to adopt more aggressive trading strategies, with respect to speed of trade.

Informational Efficiency: Analysis of the RMSD of transaction prices over all three measures of early indicated that the mean RMSD for RANPERIOD was statistically greater than for CONPERIOD ($\alpha<0.04$ for all three measures). This evidence allowed the null hypothesis of no statistical difference ($2.1H_0$) to be rejected for all three measures of early. Duxbury (1997) then related the higher volume of trade early in a period with the degree of convergence of asset prices to equilibrium prices, by examining the degree of correlation between the two variables. To this end the correlation coefficients between the change in volume and the change in RMSD across the two markets were computed. The correlation coefficients for the first 45 and 60 seconds of trade in a period were high and positive (0.705 and 0.741 respectively, $\alpha=0.05\%$). Duxbury (1997) interpreted these results as providing evidence of a positive relationship between the volume of trade and the deviation of prices from predicted values early in a period, sub 60 seconds. As the *difference* in the volume of trade increases across markets, so does the *difference* in the deviation of prices from predicted values. Thus the higher volume for RANPERIOD relative to CONPERIOD was positively correlated with a greater RMSD of transaction prices from equilibrium levels in RANPERIOD relative to CONPERIOD. This was interpreted as indicating a reduced level of informational efficiency early in a period. No such correlation was found for 90 seconds into a trading period. Duxbury (1997) provided an ex post rationalisation premised on the 90 second measure not strictly being 'early' in many of the periods, particularly for RANPERIOD.

For the root mean squared deviation of prices over the entire duration of a given period, Duxbury (1997) reports a mean RMSD of 243.743 emus for RANPERIOD which is greater than the value of 176.091 for CONPERIOD ($\alpha=0.05$). Thus the higher volume of trade early in a period for RANPERIOD caused such highly inefficient trades, compared to CONPERIOD, that these price inefficiencies are not reversed by the close of trade in any given period. Evidence that random period duration greatly affects the transaction price behaviour observed in experimental financial asset markets. The ability to reject $2.1H_0$ ($\alpha=0.05$) for RMSD, offers evidence in favour of Friedman's (1984) view that a predetermined, known trading period duration is one of a number of features which enhances the informational efficiency of experimental markets.

Allocational Efficiency: Duxbury (1997) was unable to reject the null hypothesis ($3.1H_O$, $\alpha>0.05$) of no statistical difference between the mean %GAIN for CONPERIOD and RANPERIOD. Thus random period duration did not impact on the allocational efficiency of experimental asset markets, despite the differences in volume of trade and informational efficiency across the two markets.

The results above indicate that random period duration should indeed be considered an important treatment variable in experimental asset markets. The current thesis, therefore, offers a full scale study of its impact on market trading behaviour and efficiency. As discussed earlier, the additional feature offered here is to include markets with variable and known (VK) period durations to provide a stricter comparison (control) for random (VU) period duration markets. The following section considers some relevant experimental design features not introduced in the discussion of design in Chapter Four.

5.5 Experimental Design Considerations

5.5.1 Period Durations

Two markets were conducted with CK period durations (CKPN1, CKPN2), two with VK durations (VKPN1, VKPN2) and two with VU durations (VUPN1, VUPN2). As discussed previously (Chapter Four subsection 4.5.2), the trading period durations in both CKPN1 and CKPN2 were held constant, at 240 seconds, across all 15 trading periods, whilst in the other markets the durations varied between 120 and 360 seconds, from period to period. The actual sequence of trading period durations was randomly determined in advance by computer and two different parameter designs were adopted. The VKPN1 and VUPN1 markets both used the sequence of period durations from parameter set one, whilst VKPN2 and VUPN2 used the sequence from parameter set two (see Chapter Four Table 4.3)[18]. All six market sessions were conducted between the 11th November 1996 and the 5th March 1997, inclusive.

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[18] The use of only two parameter designs was not known by any participant. Participants knew only that the sequence was determined randomly in advance by computer, thus, for all they knew the sequence differed from market to market. The same is true of the sequence of states of nature.

5.5.2 State Contingent Dividends

The state contingent dividend distributions across trader types were the same across all six markets, parameter set A (see Chapter Four Table 4.1, Panel A). The sequence of states of nature did differ between the markets. CKPN1, VKPN1 and VUPN1 used the sequence in parameter set one, whilst CKPN2, VKPN2 and VUPN2 used the sequence in parameter set two (see Chapter Four Table 4.3). Participants were drawn from the population of both undergraduate and postgraduate students. Thus there was minimal contact and interaction between participants within a given market session, let alone across different sessions conducted some months apart. Thus there was no possibility that participants could have known the sequence of states of nature in advance.

5.5.3 Information Structure

The information structure adopted here is identical to that in Plott and Sunder (1982), as amended by Banks (1985). Insiders receive their private information via the distribution of clue cards that perfectly identify the state of nature that will exist throughout the period in question. For example, if the state is X then the clue card will simply contain an 'X'. Those individuals not so privileged (uninformed) only learn the identity of the state of nature with certainty at the end of the trading period. So as to conceal the identity of the insiders from the uninformed clue cards are distributed to all traders. The clue cards distributed to the uninformed contain the word 'blank', thus offering them no information. This design incorporates a very simple informational structure. This facet of the design was chosen, despite the unrealistic simplicity and availability of more complex structures (see Plott and Sunder, 1988), so as not to cloud the impact of VK and VU period duration on market trading behaviour.

The number of insiders each period was 6 in all markets. Two participants are chosen from each trader type group, but their identity is determined randomly within trader types (once more determined prior to the experimental session by computer). Randomly determining the identity of insiders within trader types should diminish the potential for the uninformed to guess the identity of the informed. This is a valid criticism levied at Plott and Sunder (1982) by Banks (1985). Random insider identity is necessary to ensure that the only public information utilised by uninformed traders to determine their trading behaviour are the bids, asks and transaction prices observed in the market. It is the role of prices as disseminators of private information that the series of experimental markets is designed to capture, not the ability to identify an insider.

Two traders from each of the three trader type groups were chosen to be insiders to ensure that the trader type group with the highest dividend payment given the state of nature is represented amongst the insiders. Such a design feature is necessary to provide the possibility for the asset price to be bid up to the highest dividend value, as is predicted by the FRE model. The number and random determination of insiders each period was common knowledge in all markets. Also common knowledge was the fact that all traders would receive clue cards, even if they were 'blank', so as to conceal the identity of insiders in all periods. However, the exact identity of insiders each period was not common knowledge.

All other details of the experimental design are general to the thesis as a whole and were discussed in Chapter Four. The subsequent section reports the results of the investigation of market performance for the six experimental markets in this group. The section begins with the discussion of a number of data issues arising from the influence of outliers, the determination of observations and the problem of dependence, and the choice of statistical test. The section then reports the results of a *comparative* evaluation of the performance of the FRE and PI models and concludes with the *relative* evaluation of the impact of period duration on market performance.

5.6 Results and Analyses

5.6.1 Data Considerations

The main sources of data used in this study are the sequence of transaction prices generated each period, the volume of assets traded within a period, individual trader's profits each period and the end of period allocation of assets[19]. All the data sources are analysed both in their raw form and as various measures of performance (such measures of price convergence, gains from exchange realised, etc.)[20].

The use of the sequence of transaction prices to compute a measure of price convergence requires particular consideration because of the influence of outliers on

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[19] In those markets where an information auction is included in the design, the cost of information provides an additional source of data.

[20] The discussion in this subsection is equally valid for all four groups of experimental markets, and not solely of concern for the six markets investigated in this chapter. To eliminate repetition, future chapters will refer back to the discussion contained here.

the measure adopted. The measure of convergence used in this study, and indeed most other experimental asset markets, is the root mean squared deviation (RMSD) of transaction prices in a period from the predicted equilibrium values of the FRE and PI models. The mean is regularly used as a measure of central tendency or location, however, it can be excessively influenced by the existence of outliers. One very large or small value can dramatically change the value of the mean of a distribution. Figures 5.3-5.8 display the sequence of transaction prices per period for each of the six markets investigated in this chapter. Analysis of the transaction prices will follow in the following subsections, of concern here is the identification of a number of obvious outliers. Casual observation of these charts readily identifies a number of observations that can clearly be classified as outliers. In period 1 of VKPN1 the second observation is a price of 5,000 emus, whilst the first observation in period 2 is a price of 15,000 emus. Similar observations appear in periods 4 and 5 of VUPN1. These observations deviate from the predicted values by orders of magnitude far higher than all other observations in the same period. Clearly these observations will dramatically increase the RMSD of prices for the periods in which they occur.

However, identifying and dealing with outliers is problematic in market settings such as these. Whilst the observations identified above can safely be classed as outliers simply by casual observation, identification may not always be so simple. One solution may be to adopt statistical tests to determine whether an observation should be classed an outlier or not. Such methods include classifying as outliers any observations that lie outside three standard deviations from the mean of the distribution. This procedure would identify certain observations as outliers within a given period. For example, period 14 of VUPN2 includes one observation that is much lower than all others. However, can such an observation safely be classed as an outlier? Specifically, for period 14 of VUPN2, it looks to be an outlier, but many such observations occur in other periods in other markets, for example VKPN1 and VKPN2. Is it correct to class all these observations as outliers, or do they in fact contain valuable information?

Leaving aside the problematic issue of identification, a related problem concerns the treatment of those observations classed as outliers. The deletion of the outliers in periods 1 and 2 of VKPN1 and periods 4 and 5 of VUPN1 could be justified ex post, along the lines: Despite participants having to confirm the price of their bids/asks, the observations are the result of typing errors, with one (or more) too many zeros pressed. A similar justification, along the line of 'too few zeros', could be given if an observation was 'inexplicably' low. Thus, one option would be to delete all those observations statistically identified as outliers. However, for the following reason, this is not the solution adopted here. The investigation here concerns the role of prices as public signals of the underlying state of nature. That is, the ability of prices to disseminate private information and thus perfectly reveal the state of nature. The only publicly available information to traders are bids, asks and prices, consequently, to simply delete any observation may not be sound practice. All prices (observations) form part of traders' information sets.

Instead, what is required is a more robust estimator than the simple mean, one that is not dramatically influenced by occasional outliers. One alternative would be the use of the median in place of the mean and the calculation of the root median squared deviation from predicted equilibrium values. This is not ideal, however, because the median is ultimately derived from only a single data point and ignores information inherent in the other observations. A better robust estimator, and the technique adopted, is to compute an M-estimator, which allocates weights to observations. The weights are assigned so that they decrease as the distance from the centre of the distribution increases.

$$\overline{X} = \frac{\sum w_i x_i}{\sum w_i} \qquad 5.1$$

Where:

$\overline{X}$ = the weighted mean,

w_i = the weight applied to observation i,

x_i = observation i.

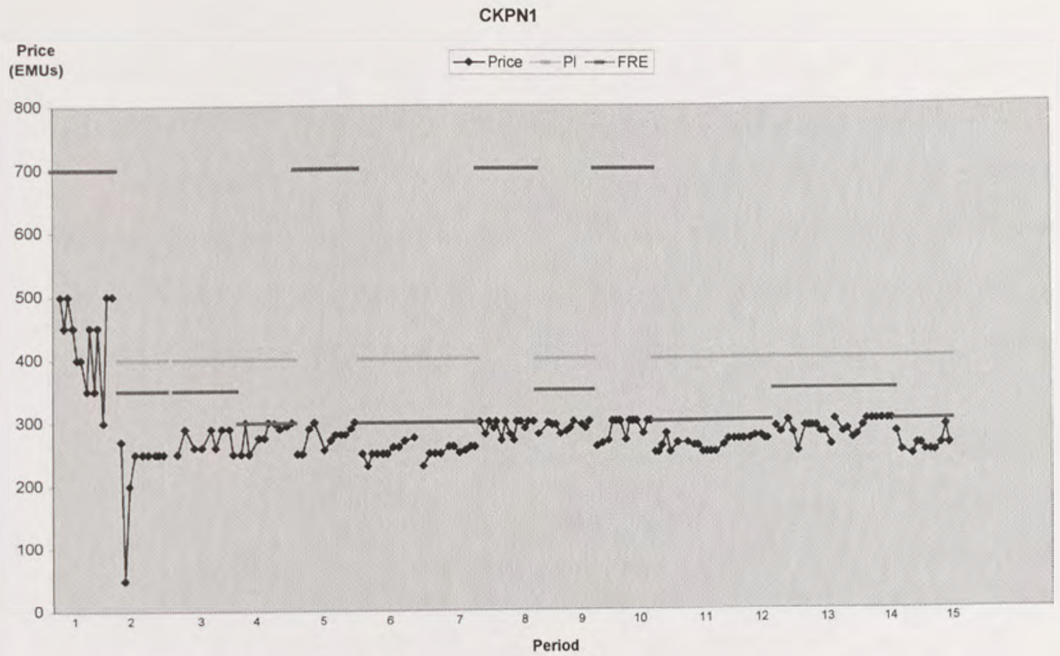

Figure 5.3 Sequence of Transaction Prices per Period – CKPN1

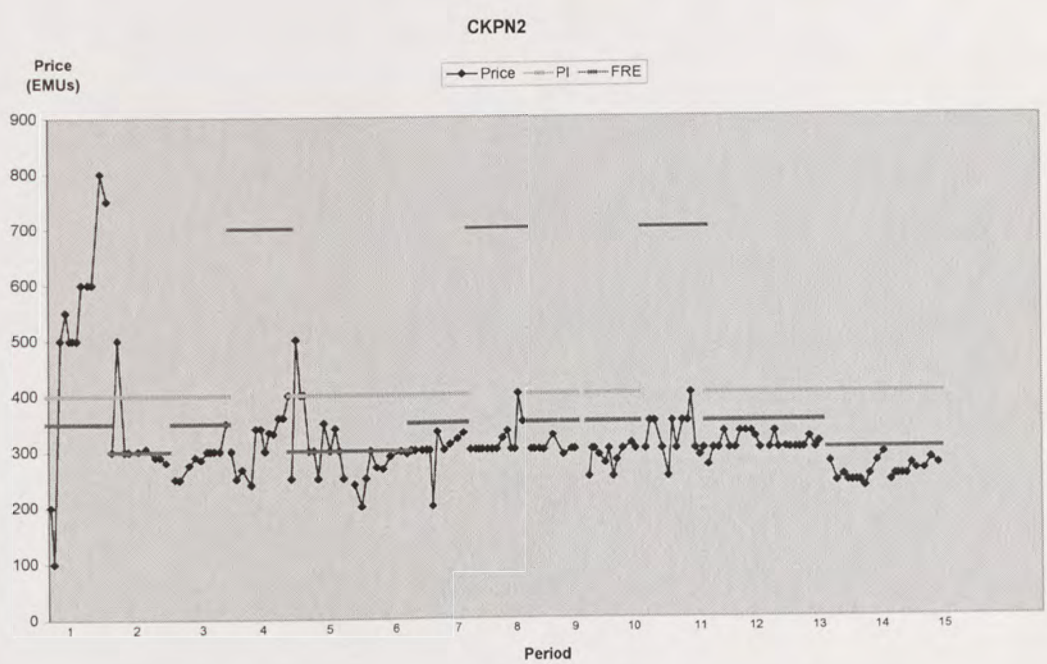

Figure 5.4 Sequence of Transaction Prices per Period – CKPN2

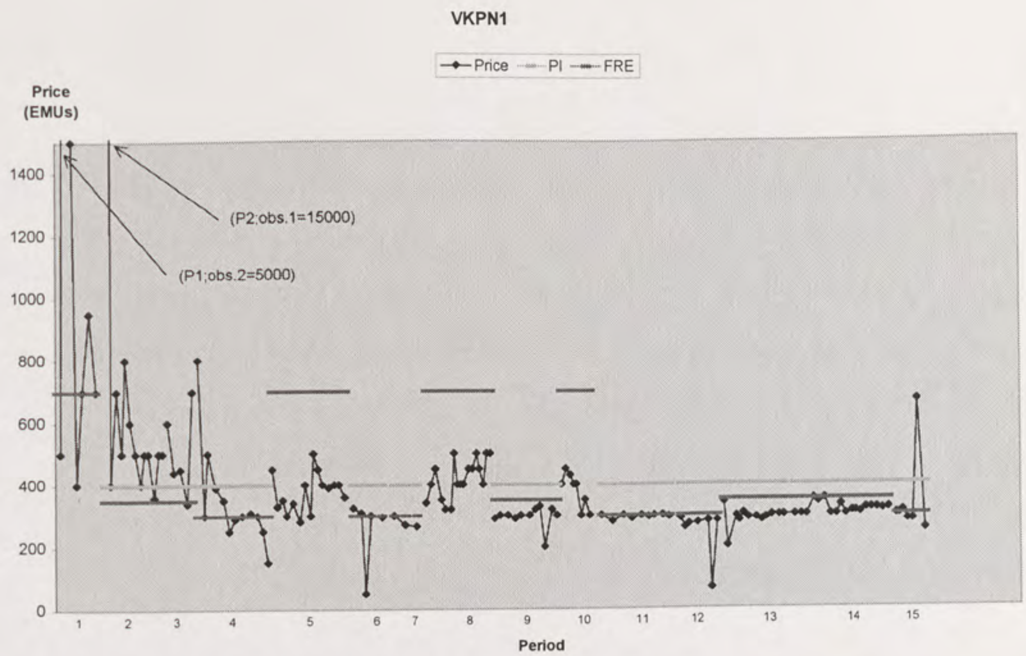

Figure 5.5 Sequence of Transaction Prices per Period – VKPN1

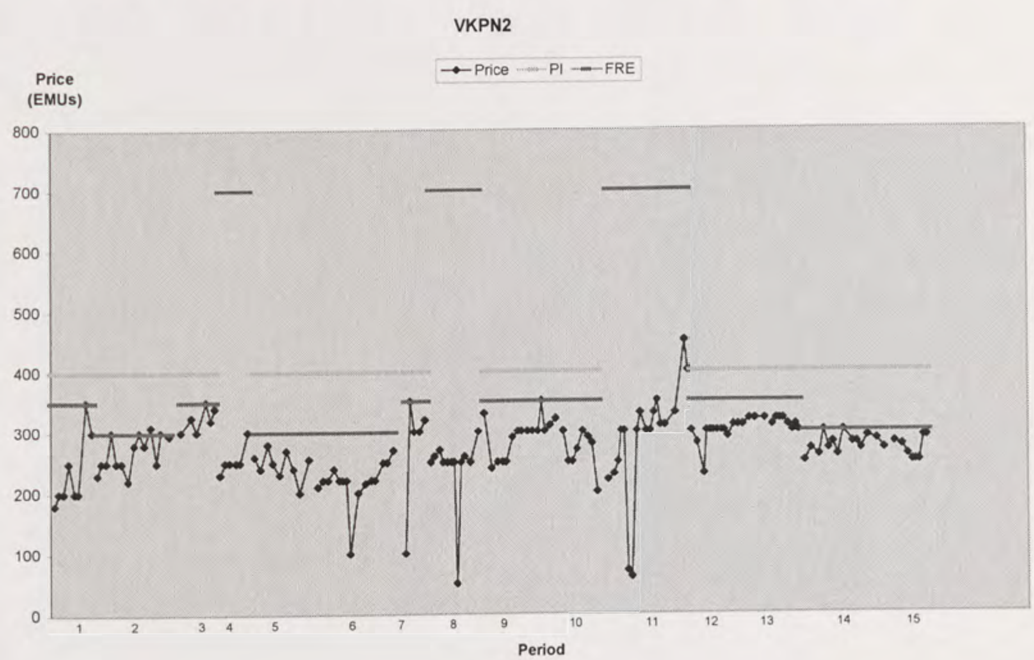

Figure 5.6 Sequence of Transaction Prices per Period – VKPN2

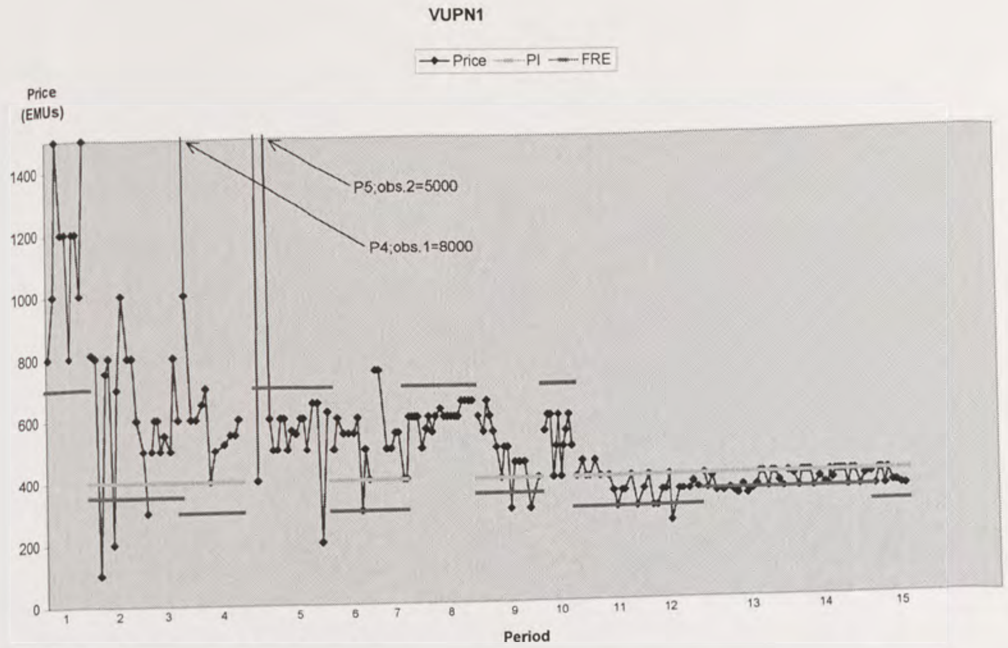

Figure 5.7 Sequence of Transaction Prices per Period – VUPN1

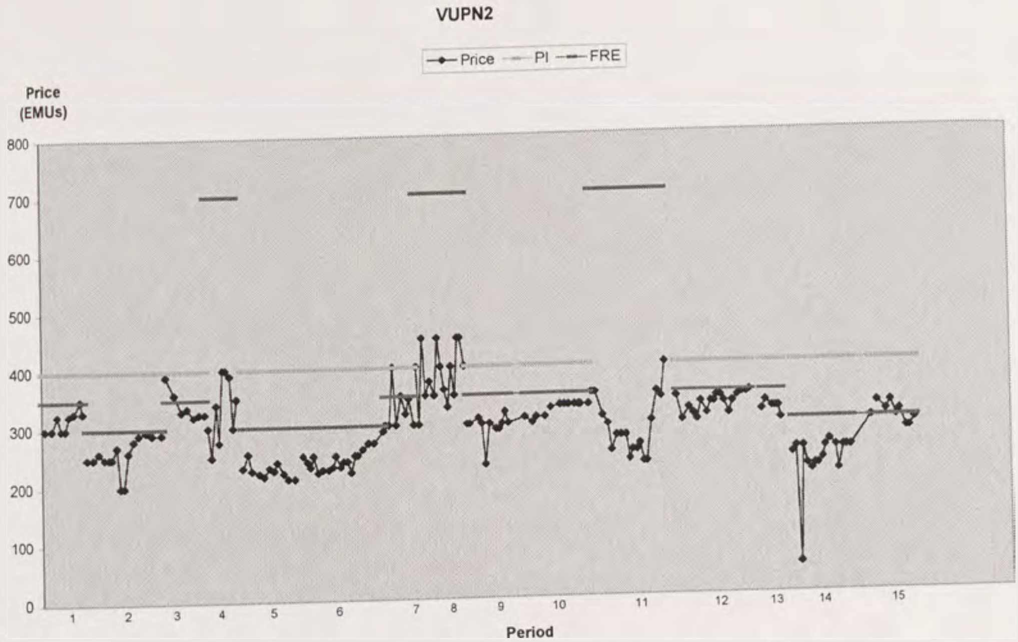

Figure 5.8 Sequence of Transaction Prices per Period – VUPN2

The method by which weights are assigned to cases can vary and there exist many different M-estimators. Four commonly used M-estimators were considered; Huber's, Hampel's, Andrew's, and Tukey's (see Hoaglin, Mosteller and Tukey, 1983, for a detailed discussion). The Huber M-estimator assigns a weight of one to all cases up to a critical point *k* (tuning constant), beyond this point the weights decline as the standardised distance from the estimate of location increases. The Hampel M-estimator uses a more complicated method for allocating weights, based on four different schemes. Like the Huber, the Hampel also assigns a weight of one to all cases up to a critical point, after which the value of the weight declines rapidly as the standardised distance from the estimate of location increases. Both the Andrew and the Tukey M-estimators do not include the abrupt changes in the value of the weighting scheme from an initial value of one. Instead the schemes begin by declining steadily, but with the rate of change in the weights increasing as the standardised distance from the estimate of location increases.

The choice of which M-estimator to use is a difficult one to make. The Huber M-estimator is efficient if the distribution is approximately normal, but does not perform well in the presence of extreme values. Thus, despite its computational simplicity this method may not be viewed as ideal. The Hampel M-estimator does allow a great deal of flexibility given the four different weighting schemes employed, however, the abrupt change in the weight from an initial value of one could be deemed undesirable. The choice between the Andrew and the Tukey M-estimators would seem to be an arbitrary one[21, 22].

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[21] To guarantee that the results were not specific to the choice of M-estimator, the analysis to follow was conducted using all four alternatives, plus the original root mean squared deviations without any adjustment for outliers. The values used for the parameters governing the weighting schemes for each of the four M-estimators were the default values in the SPSS statistical software package and are given in parentheses after the name of the M-estimator; Huber (1.339), Hampel (1.700, 3.400, 8.500), Andrew (1.340π) and Tukey (4.6850). In the ensuing discussion of the results the values as computed using the Andrew M-estimator will be the only ones reported, however, the results are robust to the choice of, or even use of, M-estimator. That is, the conclusions drawn would not change if the results from any of the M-estimators were reported or if the analysis was conducted without any adjustment for outliers. Throughout the discussion the use of the acronym RMSD can be taken to mean the root mean squared deviation from predicted value where the 'mean' has been computed using the Andrew M-estimator. The discussion will make clear when this is not the case.

[22] On a few occasions the M-estimators could not be computed because of the highly

Other data issues require consideration, it is to the definition of an observation for the use in statistical tests that the discussion now turns. This study deviates from the method of analysis adopted in earlier experimental asset market studies in that it analyses the data on a period by period basis, as opposed to aggregating period data into one single market observation. A problem for studies adopting this standard technique is the potential loss of a clean experimental design. This results if data is pooled into a single market observation and then compared across markets that differ with respect to more than one treatment variable. The impact upon trading behaviour of any one treatment variable is then difficult to infer individually. The experimental design in this study is a very clean one in the sense that it allows comparison of markets where only a single treatment differs or comparison across markets where the effect of other treatments is blocked. The analysis to follow is carried out on a period by period basis. The reason for the adoption of a period as an observation stems from the impact of aggregating data and the resultant loss of information this entails. In the context of the present study an analysis of the data period by period is of far more interest and provides greater insight into the impact of period duration than could possibly be gained from an analysis of data aggregated to the market level.

Unfortunately period by period data introduces a bias into the analysis because the results for different periods within the same market are not independent observations. This does not provide a problem for the descriptive statistics reported below in the comparative evaluation of competing models, however, it would bias any statistical significance levels reported for the evaluation of the impact of period duration as a treatment variable. The transaction price data per period generated in each market obviously exhibits strong dependence as the public information incorporated in previous bids, asks and transaction prices is used to determine values for future bids and asks. However, in the analysis to follow this type of dependence is removed as the root mean (M-estimator) squared deviation (RMSD) of transaction prices per period from theoretically predicted equilibrium values is utilised in the comparison across markets. Some dependence will still remain however. The data in a particular market is generated by the same set of participants and so may possibly be

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centralised distribution of observations around the median. On these occasions the mean was substituted in place of the M-estimator. This could be accomplished with out bias because the highly centralised distribution indicated the absence of outliers in the data series.

participant specific. However, the possibility of the results reported being participant specific is remote in this case due to the random assignment of participants to a market. The only dependence to remain in the data is therefore the result of a 'learning effect'. To aggregate away such an effect by analysing market level data would seem to be folly.

However, any dependence remaining in the data biases any statistical significance levels reported. In the presence of data dependence problems many previous studies have calculated significance levels regardless. Such studies (for example Forsythe et al, 1984, p.963) include a comment on the interpretation of the reported significance levels to the effect that, they 'should be regarded more as descriptive statistics than as classical hypothesis tests.' This situation is clearly not ideal.

The present study attempts to remove the dependence by adopting the covariate adjustment technique first introduced to the experimental asset market literature by Duxbury (1997). The technique (discussed in Boniface, 1995, chapter 7) uses one measurement (the covariate) to adjust another measurement (the dependent variable) in order to remove the influence of the covariate upon the dependent variable. In the current context, the dependent variables are the RMSD, volume, %GAIN, allocation and profit per period and the influence that requires removal is the 'learning effect' resulting from increased experience. The period number is used as a proxy for the experience gained by trading. The higher the period number, the higher the experience. The equation used to adjust the dependent variable is given below.

$$AdjDV = DV - [\beta(ActCov - StCov)] \qquad 5.2$$

Where:

DV = Unadjusted dependent variable (RMSD, Volume, etc.),

$AdjDV$ = Adjusted dependent variable,

β = Slope coefficient from the linear regression of the dependent variable against the covariate,

$ActCov$ = Actual value of the covariate measure corresponding to the DV,

$StCov$ = Standardised value of the covariate measure.

In order to estimate the slope coefficient (β) a linear relationship is required between the dependent variable and the covariate. Graphical analysis of the relationships of the various dependent variables (RMSD, etc.) with the period number suggested that the relationship may in fact be nonlinear. Transformation of the variables was required to provide a functional form for the relationship, which then permitted the use of linear regression. Two possible transformations of the independent variable (period number) that more accurately described the data were; a) log period number and b) inverted period number. Three regression models were estimated for all dependent variables, across all time periods. The first model was a simple linear regression against the period number and the other two were regressions using the transformed log period and inverted period number[23]. In order to choose between the three models their R^2 values were computed. The model with the highest mean R^2 would be the preferred model. However, the linear, log and inverted models had mean R^2 values of 0.0825, 0.0819 and 0.0850, respectively. Whilst the mean R^2 value for the inverted model is the highest, all three are very low. As they stand the models have very low explanatory power. To adjust the dependent variables based on β slope coefficients from these models would not be satisfactory. Observation of the Figures 5.3-5.8 suggests the poor mean R^2 values were the result of the differing market performance across the three states of nature, X, Y and Z. Therefore, to improve the three models, two dummy variables were included in the regression models to capture the effect of the three states of nature. The resultant mean R^2 values were vast improvements on the previous ones (0.7283, 0.7324, 0.7337 for linear, log and inverted models, respectively). The inverted model still offered the highest mean R^2 value, however, the performance of the three models is difficult to differentiate based on the mean R^2 values alone. This is because the two dummy variables are very highly significant in the majority of cases and account for much of the higher mean R^2 values. Thus the dummy variables swamp the impact of the three models. To better distinguish between the three models the average statistical significance levels of the β slope coefficients were compared. This measures a model's impact on the dependent variable, the lower the significance level, the higher

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[23] Across the 18 experimental markets, the three regression models were estimated for each of the dependent variables; RMSD(45, 60, 90, entire period) using the mean and all four M-estimators, VOL(45, 60, 90, Normalised), %GAIN, allocations, and PROFIT of the informed and uninformed (both net and gross of information costs where applicable). Thus, the total number of regression equations estimated was 1,620 (3 models for each of 30 dependent variables across each of the 18 markets).

the impact. The model with the lowest significance level would be deemed the better model. The average β values were 0.4363, 0.3950 and 0.3794 for the linear, log and inverted models, respectively. Thus, the inverted period number model was used to transform all the data to give a linear relationship between the dependent variables and the independent variable, inverted period number. These adjusted values are the ones used subsequently in the evaluation of the stated hypotheses, and the calculation of the associated significance levels for the rejection of the null hypotheses of no statistical difference in mean values.

This brings the discussion to a final issue, the choice of statistical test. The statistical test used to compare mean values was the nonparametric Wilcoxon signed-rank test for matched pairs (subsequently referred to as the WSR test). The adjusted data was paired period by period across two markets at a time, with the explicit intention of controlling for any dependence remaining in the data. The comparing of market performance across CK and VU markets permits a joint comparison of both varying period duration and knowledge of period duration. However, this joint comparison can be broken down to isolate the two component parts. Comparison of CK with VK markets isolates the impact of simply varying the period duration. More interestingly, comparison of market performance across VK and VU markets provides a strict evaluation of the knowledge of period duration to be isolated.

A word of caution is required here. The analysis is undertaken using three paired tests across a treatment variable that has three levels. On initial consideration the analysis seems to fall foul of Siegel and Castellan's (1988, p.168) warning concerning the testing of paired samples, one at a time, when there are $k \geq 3$ related samples. Due to the influence of chance, the significance levels reported from such a comparison would be biased and so an overall test for differences in the means should be used. Due to the different levels of the treatment variable investigated in this study, the potential bias is not an issue. Period duration, the treatment variable, takes three different levels, however, as can be seen from the above discussion of joint effects, the levels do not differ in a given direction with respect to a given parameter. For example, in the evaluation of the performance of a new drug, trials may be conducted for the drug at three different dosage levels (5 milligrams, 10 milligrams and 20 milligrams). Thus there can be seen to be a definitive increase in the 'level' of the dosage. The same can not be said for the level of the treatment variable period duration. Strictly speaking, the treatment variable period duration could be broken down into two distinct treatments, each with two levels; constant durations that were known and unknown (CK and CU) and varying durations that were known and unknown (VK and VU). Thus giving a two factor, with two levels design. However, to conduct the cell of the design that corresponds to the constant and unknown (CU) treatment would be nonsensical because participants would learn the duration after very few repetitions. It is for this reason that this cell of the design is omitted and period duration is regarded as a treatment variable with three levels. Paired comparisons are necessary to isolate the effect of varying the period duration and the effect of knowing the period duration. No bias in the significance levels is introduced as a result.

On a final note of clarification, in all graphical representation of the data, in the reporting of all preliminary descriptive statistics and in all comparative evaluations of the FRE and PI models, the unadjusted values are the figures utilised. It is only when statistical significance levels are reported that the adjusted data are used, to control for dependence.

5.6.2 FRE v PI: Comparative Performance Evaluation

The intention in this subsection is to compare the predictive accuracy of the FRE and PI models, to determine which model best explains the observed experimental data. The comparative evaluation will test the models' predictions concerning transaction prices, allocations and profits, using the raw data sources without any adjustment for outliers or dependence in the data. The intention is to keep the data free from transformations whenever it is possible to conduct valid comparisons[24], therefore, in this subsection the RMSD figures were calculated using the mean rather than the Andrew M-estimator and no adjustment to correct for dependence in the data is undertaken. Comparison of the two models is undertaken within a period within a market, not across periods across markets. Thus, outliers and dependence of the data are not an issue.

The two competing models of FRE and PI predict that traders use different information sets in the determination of their expectations of transaction prices. Experimental parameters can be chosen so that the two models predict disparate equilibrium prices. The observed experimental data can then be compared to these

[24] The same is true of all comparative evaluations contained in forthcoming chapters.

disparate predictions to determine which model best explains the data. Given the state contingent dividends governing these six market[25], the FRE model predicts equilibrium prices of 350, 300 and 700 for states of nature X, Y and Z, respectively. The corresponding predicted prices for the PI model are 400, 400 and 700[26]. Note that for state Z the two models make the same price prediction and so occurrences of this state can not be used to make comparative evaluations of the RMSD of prices from the equilibrium price of the two models.

The FRE and PI equilibrium predictions are included in Figures 5.3-5.8 as horizontal lines, towards which the convergence of transaction prices can be compared. In both CKPN markets the transaction prices are quite volatile in the first few periods, after which they settle down. In most periods, prices trade close to the FRE price or tend to show convergence towards the FRE price. The notable exception to this is the occurrence of state of nature Z (where the FRE and PI prices are equal). The markets do not seem to react to state Z and only show convergence on a couple of occasions. In the VKPN markets the volatility of prices in early periods is far higher and takes longer to settle down, particularly in VKPN2. In general, prices exhibit convergence to the FRE price more so than the PI price, particularly in the VKPN1 market. Again, periods when the state of nature was Z do not exhibit convergence to the FRE=PI price. Prices in VUPN2 do not exhibit the same degree of volatility as other markets and generally trade close to, or show convergence towards, the FRE price more so than the PI price. As with the other markets the state Z prices do not exhibit convergence to the FRE=PI price. The volatility of prices in VUPN1 is far higher than the other markets and does not reduce until half way through the market. In the final four trading periods prices bounce between the FRE and PI prices and do not exhibit any clear trend towards the FRE price. Despite this, prices converged closer to the FRE=PI price in the state Z periods than in any other market.

To directly evaluate the FRE and PI models' predictions the RMSD of prices each period were computed for both and compared within a market on a period by period basis. Comparisons were made for the first 45, 60 and 90 seconds of trade in a period and over the entire trading period duration (RMSD45,60,90 and RMSD, respectively). Table 5.1 contains the outcomes of these comparisons, aggregated over

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[25] See Table 4.1, Chapter Four.

[26] See Appendix Three for an explanation of the FRE and PI equilibrium prices.

the two parameter designs. Note that because of identical equilibrium predictions for the FRE and PI models when the state is Z, those periods where the state is Z are omitted from the comparisons. It is apparent from Table 5.1 that the predictive accuracy of the price predictions of the FRE model is far higher than that of the PI model. Across the CKPN and VKPN markets the RMSD of the FRE model is less then that of the PI model in at least 86.96% of the periods for all comparisons. The percentages are not so high in the VUPN markets, however, when trade is taken over the entire period the FRE model beats the PI model in 60.87% of periods. The lower percentages in the first 45 and 60 seconds of trade for the VUPN markets indicate that the FRE model improves over time. In the six markets as a whole, the FRE model's predictions are superior to the those of the PI model in 82.61% of periods over entire trading period durations.

		Percentage Comparison (%)			
Market	***Performance***	***RMSD45***	***RMSD60***	***RMSD90***	***RMSD***
CKPN	FRE < PI	91.30	91.30	91.30	95.65
	FRE > PI	8.70	8.70	4.35	4.35
	FRE = PI	0.00	0.00	4.35	0.00
VKPN	FRE < PI	86.96	86.96	86.96	91.30
	FRE > PI	13.04	13.04	13.04	8.70
	FRE = PI	0.00	0.00	0.00	0.00
VUPN	FRE < PI	52.17	52.17	60.87	60.87
	FRE > PI	47.83	43.48	39.13	39.13
	FRE = PI	0.00	4.35	0.00	0.00
Overall	FRE < PI	76.81	76.81	79.71	82.61
	FRE > PI	23.19	21.74	18.84	17.39
	FRE = PI	0.00	1.45	1.45	0.00

Table 5.1 Comparison of RMSD of Price Predictions for FRE and PI

The different assumptions concerning the information sets individuals use in the determination of their expectations concerning asset prices also mean that the FRE and PI models make divergent predictions concerning the end period allocation of assets. For the six markets investigated here the FRE model predicts that both the informed and uninformed traders in trader type 1, 2 and 3 will hold the assets when the state of nature is X, Y and Z, respectively. In contrast, the PI model predicts that the uninformed type 3 traders will hold the assets in states X and Y, and the informed type 3 traders will hold the assets in state Z[27]. The two models can, therefore, be

[27] See Appendix Three for an explanation of the FRE and PI end-period equilibrium

evaluated based on a comparison of the number of assets misallocated when compared to their equilibrium predictions. It must be recognised, however, that the PI equilibrium requires a greater number of trades than the FRE equilibrium. If no trade took place in a given period then the number of assets misallocated according to the FRE model would be 16 whereas the corresponding figure for the PI model would be 20. Thus, caution must be exercised when comparing misallocations so as not to succumb to the bias that his would introduce. The number of assets, in a given period, misallocated under the two models are compared by subtracting the number of PI misallocations from the number of FRE misallocation, to give the measure ∂. If ∂<0 in a given period then this taken as an observation in support of the PI model (FRE>PI). If ∂>4 in a given period then this is taken as an observation in support of the FRE model (FRE<PI). If $0 \leq \partial \leq 4$ then the measure is deemed to fall within an indiscriminate region and the two models are deemed to have tied (FRE=PI). As displayed in Table 5.2, on average, the percentage of periods (number of observations equals 90) where the FRE model is superior to the PI model is 70.00%, and in no comparison at all can the predictions of the FRE model be classed as inferior to the PI model. The evidence in favour of the FRE model is further strengthened by the fact that 27.78% of the time (25 out of the 90 periods) the ∂ measure is in double figures (obtaining a maximum of ∂=15 in period 12 of CKPN2).

To summarise thus far, the six markets all exhibit, to a greater or lesser extent, transaction price convergence towards the FRE equilibrium price. In addition the RMSD of prices is higher for the PI model than the FRE model in 82.61% of occasions over an entire trading period. The RMSD45 is lower for FRE than PI in 76.81% of periods, indicating that convergence to FRE prices improves over time within a period. Comparison of the number of assets misallocated offers conclusive evidence in support of the predictive accuracy of the FRE model at the expense of the PI model. There is no occasion where the number of assets misallocated by the FRE model is greater than that of the PI model. Taken together these two comparisons provide strong evidence in favour of the superior predictive ability of the FRE model. Two further measures of performance readily adopted in the experimental asset market literature will now be considered.

The first of these is a measure of trading efficiency that utilises the %GAIN

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allocations.

measure introduced as Equation 2.2 in Chapter Two[28]. Recall that, given the definition, the initial allocation of assets each period produces a %GAIN of 0% whereas the end period equilibrium allocation of the FRE model produces a %GAIN of 100%. Table 5.3 illustrates that the level of %GAIN exhibits a large degree of variability across the six markets, from a maximum of 95.83%, through 0% to a minimum of –66.67%. The average %GAIN observed in the CKPN, VKPN and VUPN markets are 43.33%, 38.89% and 36.88%, respectively.

Market	*Performance*	*Percentage Comparison (%)*
CKPN	FRE < PI	86.67
	FRE > PI	0.00
	FRE = PI	13.33
VKPN	FRE < PI	70.00
	FRE > PI	0.00
	FRE = PI	30.00
VUPN	FRE < PI	53.33
	FRE > PI	0.00
	FRE = PI	46.67
Overall	FRE < PI	70.00
	FRE > PI	0.00
	FRE = PI	30.00

Table 5.2 Comparison of Misallocation of Assets for FRE and PI

On the face of it, these low mean %GAIN figures could be interpreted as being more in favour of the PI model, because there are only a few periods where the %GAIN approaches close to the 100% prediction of the FRE model. However, consideration must also be given to the gains from trade to be exploited under the PI model, relative to the zero trade gains. These gains depend on the end of period equilibrium allocations of the PI model. Thus the PI gains from trade are state contingent and take the values of 1,600, 1,200 and –1,600 emus under the states X, Y and Z, respectively. In 41% of periods (37 out of 90) the realised gains from trade are in excess (considerably so in many periods) of the predicted PI gains from trade. This is construed as weak evidence in favour of the FRE model, because the predicted FRE gains from trade are always in excess of the predicted PI gains. However, the fact that

[28] For reference, $\%Gain = \dfrac{(TSA - TSI)}{(TSE - TSI)}$.

the PI model predicts a negative gain from trade under state Z can be exploited to provide excellent differentiation between the two models, because the FRE model predicts positive gains from trade under all three states of nature. For the 21 occurrences of the state Z across the six markets[29] there was only 1 occasion where the realised gains from trade were negative. This simple test provides strong evidence in favour of the FRE model over the PI model. In fact, the occurrence of the state Z coincides with relatively high levels of %GAIN, as can be observed in Table 5.3.

Period	*CKPN1*	*VKPN1*	*VUPN1*	*CKPN2*	*VKPN2*	*VUPN2*
1	62.5000	6.2500	-6.2500	-66.6667	45.8333	39.5833
2	52.0833	64.5833	12.5000	25.0000	18.7500	43.7500
3	60.4167	8.3333	10.4167	37.5000	39.5833	39.5833
4	18.7500	-25.0000	12.5000	56.2500	31.2500	43.7500
5	56.2500	81.2500	31.2500	18.7500	31.2500	43.7500
6	12.5000	0.0000	0.0000	18.7500	68.7500	68.7500
7	31.2500	6.2500	12.5000	45.8333	20.8333	60.4167
8	75.0000	93.7500	56.2500	43.7500	68.7500	93.7500
9	54.1667	72.9167	8.3333	56.2500	66.6667	72.9167
10	62.5000	43.7500	43.7500	39.5833	31.2500	66.6667
11	25.0000	-6.2500	25.0000	75.0000	87.5000	93.7500
12	31.2500	6.2500	6.2500	56.2500	50.0000	95.8333
13	52.0833	43.7500	37.5000	83.3333	60.4167	33.3333
14	72.9167	75.0000	29.1667	50.0000	43.7500	68.7500
15	50.0000	-6.2500	0.0000	43.7500	37.5000	-37.5000
Mean	47.7778	30.9722	18.6111	38.8889	46.8056	55.1389

Table 5.3 Percentage of Gains from Trade Exhausted per Period

A final measure of the comparative performance of the FRE and PI models is provided by comparing the profit of the informed to that of the uninformed on a period by period basis. In the strongest interpretation of the FRE model the underlying state of nature is revealed instantaneously and the value of private information is zero, consequently there should be no difference between the profit of the informed and the uninformed. In contrast, private information retains value under the PI model and so a positive difference between the informed and uninformed traders' profits would be predicted. Table 5.4 contains the average profit of the informed and the uninformed, in emus, for all six markets. Across the six markets the mean informed profit figure of 833.42 emus is convincingly higher

[29] Periods 1, 5, 8 and 10 plus periods 4, 8 11 for parameter sets one and two respectively.

than the mean uninformed profit figure of 617.43 emus, providing evidence more in line with the PI model than the FRE model. This is the result of transactions between informed and uninformed traders that occur early in a period for prices below the FRE equilibrium price. These transaction take place before the information is disseminated and price signal reveals the state of nature, allowing informed traders to make high profits. It is for this reason that this weak evidence against the FRE model is not construed as fatally condemning.

Market	*Informed*	*Uninformed*
CKPN1	826.7444	606.5889
CKPN2	813.8444	591.4911
VKPN1	836.2000	728.8000
VKPN2	748.5556	607.4222
VUPN1	961.2778	565.9444
VUPN2	813.9000	604.3444
Mean	833.4204	617.4319

Table 5.4 Average Profit of Informed and Uninformed Traders

In conclusion, the majority of evidence from this comparative analysis supports the superior predictive abilities of the FRE model. The model is only really susceptible to criticisms of it in its strictest sense, where prices instantaneously reveal the underlying state of nature. The evidence tends to support the progressive convergence of outcomes towards FRE predictions. Having established the superiority of the FRE model the subsequent analysis of the treatment variable period duration across the CKPN, VKPN and VUPN markets will be conducted with reference to the equilibrium predictions of the FRE model only[30].

5.6.3 Impact of Period Duration on Market Behaviour

This subsection begins with a preliminary investigation of observed market performance by way of graphical representation, thus making use of the unadjusted data. The discussion concludes with a direct evaluation of the stated hypotheses and incorporates the data adjusted to remove dependence. The evaluation of the impact of

[30] Indeed, the evaluation of the treatment variable with reference to PI equilibrium predictions is redundant. The comparison is undertaken across markets on a period by period basis. The FRE and PI predictions are benchmarks against which to compare observed outcomes. The choice of which benchmark is irrelevant so long as the same benchmark is adopted for all periods of all markets. Thus, the use of only the FRE model to investigate the impact of period duration does not present a problem.

period duration on the market behaviour observed in experimental asset markets requires a comparison of relative performances across markets where the period duration differs. The influence of extreme observations in some markets but not in others now becomes important. The use of the acronym RMSD in the discussion to follow will, therefore, always refer to the root mean squared deviation of transaction prices where the mean is in fact replaced by Andrew's M-estimator.

First, the volume of trade per period was compared across markets to determine whether period duration would influence the overall volume of trade. So as to control for the disparate period durations across the six markets the absolute volume of trade each period was normalised by dividing the observed volume by the duration in seconds for each period in question. This procedure created the measure NORMVOL that could be compared across the markets, without being biased by the duration of trade in each period[31]. Figures 5.9 and 5.10 graph the normalised volume of trade per period for the markets grouped by parameter design. Comparison of the NORMVOL measure for the CKPN markets with either the VKPN or VUPN markets does not provide any clear interpretation. The NORMVOL measure for CKPN markets is fairly erratic, sometimes higher and sometimes lower than the measure for the other two market types, with a mean of 0.0528. However, comparison of the VKPN and VUPN markets is more informative. The NORMVOL measure for VUPN exceeds that for VKPN in 23 of 30 periods, the reverse is true in only one period. The mean NORMVOL of 0.0538 for VUPN markets convincingly exceeds that of 0.0431 for VKPN markets. Preliminary analysis indicates that knowledge of the period duration, when isolated from the effect of varying period durations, may be an important factor in the timing of transactions. Preliminary consideration is now given to the prices at which assets trade and the deviation of these from the FRE predicted values.

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[31] The period durations are the same across the VKPN and VUPN markets and so the NORMVOL measure is not actually required to compare the volume of trade across these two market types. However, because comparisons between these two markets and the CKPN markets require the NORMVOL measure, it will be used throughout the analysis.

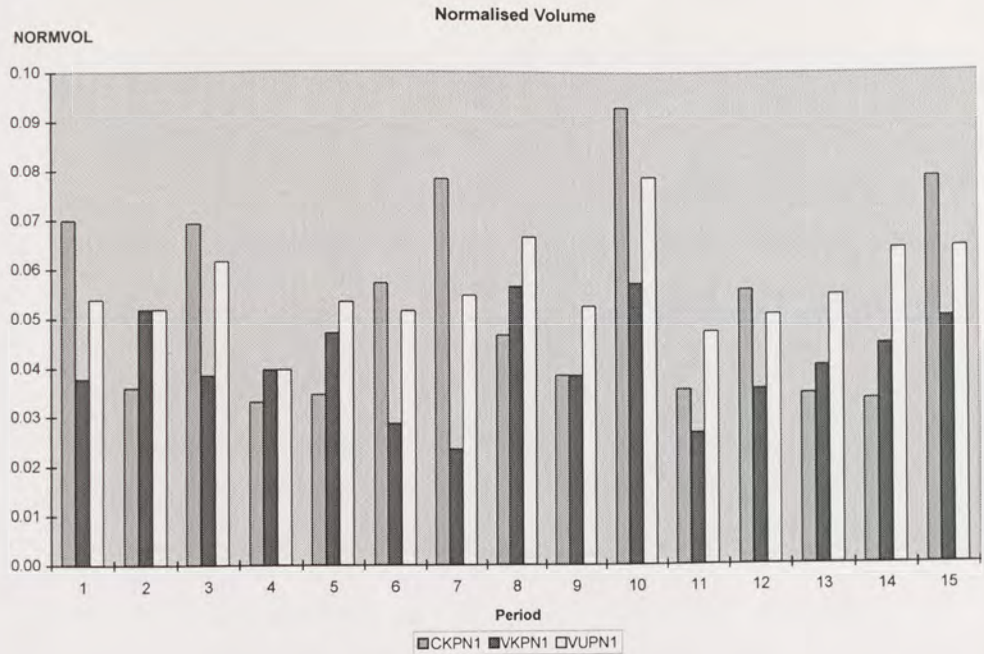

Figure 5.9 Normalised Volume of Trade per Period – PN1 Markets

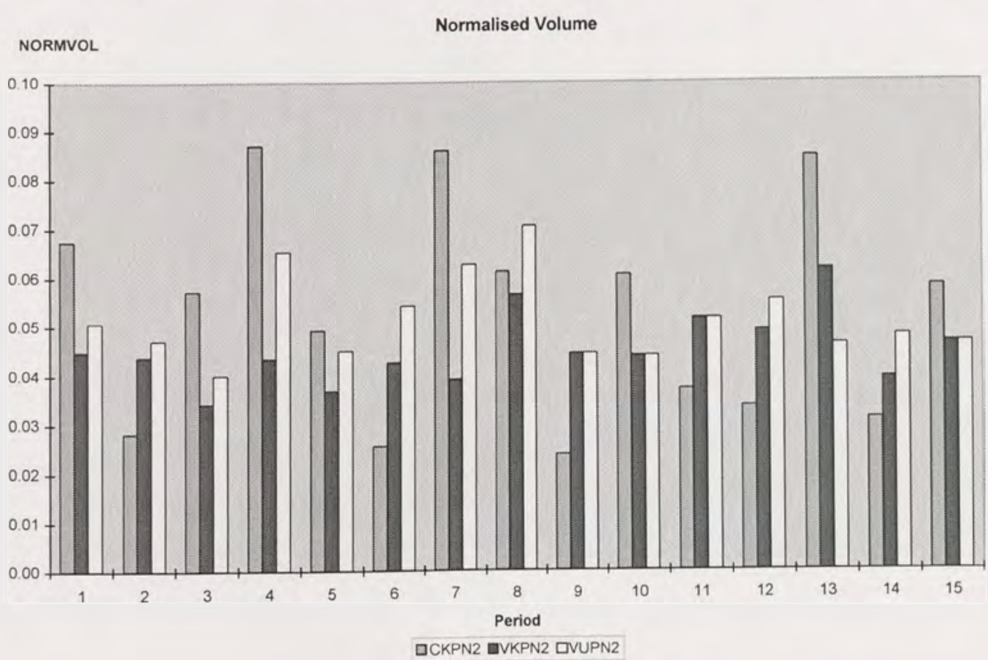

Figure 5.10 Normalised Volume of Trade per Period – PN2 Markets

Figures 5.3-5.8 graph the transaction price sequences per period for each of the six markets. Evidence of the convergence of prices to the FRE price is far from apparent in the early periods of any of the markets. The prices in the CKPN markets, however, appear far less volatile and settle at prices close to the FRE price sooner than in the other two market types. Comparison of the VKPN and VUPN markets indicates a higher volatility of prices in the latter than the former, particularly in earlier periods. In later periods the VUPN prices tend to bounce between the FRE and the PI prices, while the VKPN prices do not generally exceed the FRE price. The VKPN prices appear to converge more closely to the FRE price in later periods than is evident in the VUPN markets. To better see the convergence of prices to FRE prices the Figures 5.11 and 5.12 illustrate the RMSD of prices per period, computed using the Andrew M-estimator, for the three markets in the two different parameter designs. For the CKPN and VKPN markets the RMSD is relatively low in all periods with the exception of those periods when the state of nature was Z. The same can be said of VUPN2, however, VUPN1 exhibits a generally declining RMSD over time and is not unduly influenced by the occurrence of state Z. The RMSD in earlier periods of VUPN1 exceed those in later periods and the market exhibits a high degree of learning. The high degree of variability displayed in these figures make it difficult to draw any conclusive inferences concerning the impact of period duration on the convergence of prices to theoretically predicted FRE values. A more comprehensive investigation by way of statistical testing is required to determine if any effect is present. The results of such an evaluation are reported after the preliminary investigation is concluded.

The trading efficiency across the three market types is also compared to examine the impact of period duration. The %GAIN measure is once more used, however, because of the disparate period durations across the markets the measure requires normalising along the lines of the NORMVOL measure. Thus the NORM%GAIN measure is simply the %GAIN per period divided by the duration in seconds for the given period. The Figures 5.13-5.14 contain the NORM%GAIN per period for each of the three markets in the two parameter designs. For parameter set one the CKPN1 market generates a superior NORM%GAIN in 11 out of the 15 periods, with a mean value of 0.1991, which exceeds the values of 0.1172 and 0.0771 for VKPN1 and VUPN1, respectively. This is not repeated, and is in fact reversed, for the markets using parameter set two, with mean values of 0.1620, 0.2104 and

0.2377 for CKPN2, VKPN2 an VUPN2, respectively. The mean value of the NORM%GAIN for the VUPN1 and VUPN2 are markedly different, with the VUPN2 value being far higher. There is no obvious explanation as to why this is the case. The VKPN markets give a similar but less pronounced change. Aggregating across markets from the two parameter sets results in values of the NORM%GAIN measure that are highest for CKPN markets and lowest for VUPN markets. Whilst it is not possible to draw any decisive conclusions from this analysis, it seems that varying the period duration reduces trading efficiency and that removing knowledge of the period duration reduces the level of efficiency attained still further.

The mean %GAIN values of 43.33, 38.89 and 36.88 for CKPN, VKPN and VUPN markets, respectively, can be investigated more closely to separate the efficiency loss between either intra- or extra-marginal trades (Rust, Miller and Palmer, 1993). The efficiency loss can be associated with either a *missed trade* or an *error trade*. A missed trade (intra- marginal) occurs when an individual does not sell the assets in a given period as predicted by the FRE model. An error trade (extra-marginal) occurs when an individual trades in the wrong direction as predicted by the FRE model (buys when predicted to sell and vice versa). In line with previous DA market results (Rust et al, 1993) both missed and error trades coexisted within many periods. The mean percentage efficiency loss associated with missed and error trades are reported in Table 5.5. The efficiency losses incurred in all markets are mainly the result of missed trades, however, for all markets there were a significant number of periods where the efficiency loss associated with error trades was higher than that associated with missed trades. These conclusions are equally applicable to CKPN, VKPN and VUPN markets, therefore, period duration does not appear to directly impact upon the manner in which the efficiency loss arises.

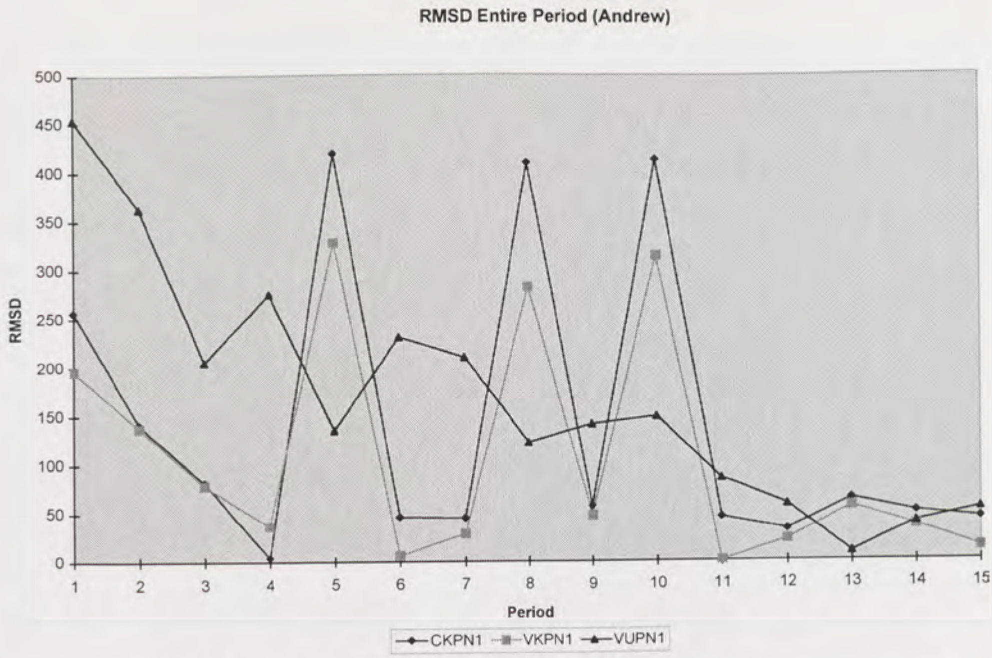

Figure 5.11 Root Mean (Andrew) Squared Deviation of Transaction Prices per Period – PN1 Markets

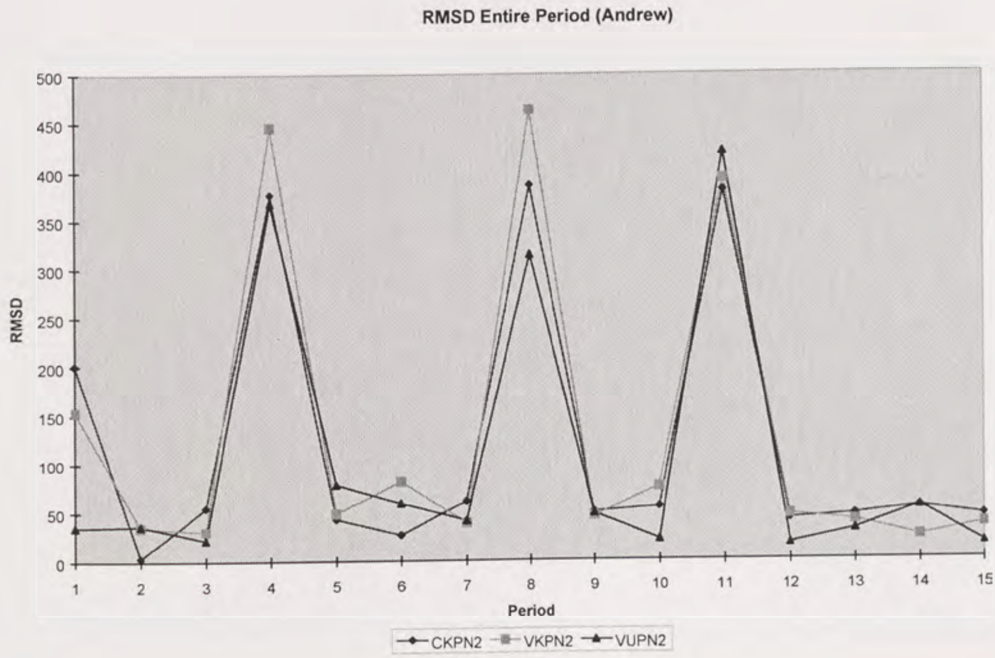

Figure 5.12 Root Mean (Andrew) Squared Deviation of Transaction Prices per Period – PN2 Markets

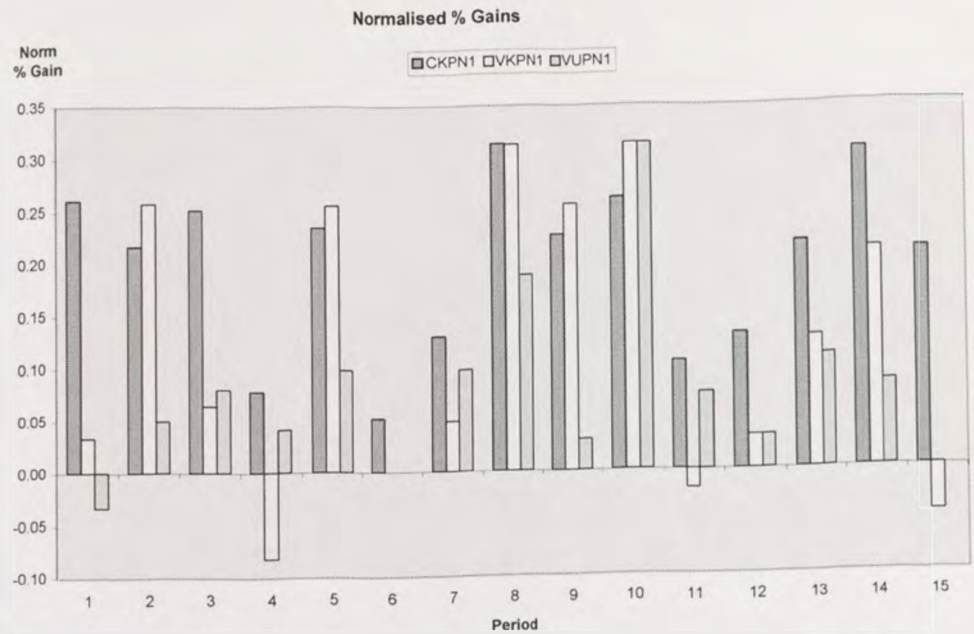

Figure 5.13 Normalised Percentage Gains from Trade – PN1 Markets

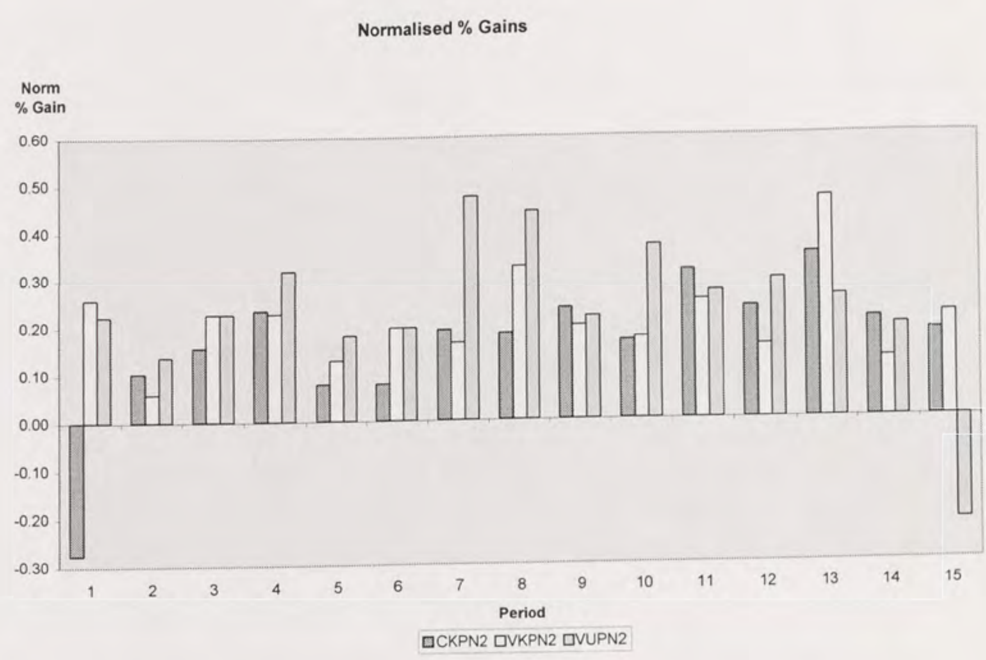

Figure 5.14 Normalised Percentage Gains from Trade – PN2 Markets

Market	*Percentage of Efficiency Loss*	
	Missed Trades	*Error Trades*
CKPN1	59.57%	40.43%
CKPN2	52.35%	47.65%
VKPN1	58.29%	41.71%
VKPN2	72.10%	27.90%
VUPN1	50.53%	49.47%
VUPN2	62.87%	37.13%

Table 5.5 Mean Percentage of Efficiency Losses due to Missed and Error Trades

A final preliminary analysis of trading behaviour can be carried out by comparing the profits earned each period by informed (Inf) and uninformed (UInf) traders. As suggested previously, there should be no difference between the profit of the informed and the uninformed traders if the price signal reveals the underlying state of nature instantaneously, as is the case in the strictest interpretation of the FRE model. In Figures 5.15-5.16 the data series for each market are constructed by subtracting the average profit earned in a period by the uninformed traders from the average profit that period earned by the informed traders, net of any information costs[32]. This difference in average profit is graphed against period number for all six markets. A positive value indicates that the average profit of the informed exceeded the average profit of the uninformed traders in that period, with a negative figure conveying the opposite interpretation. The Figures 5.15-5.16 group the markets by parameter design. For the PN1 markets there is very little difference between CKPN1 and VKPN1, however, VUPN1 exhibits a far larger difference in average profit in earlier periods and the measure exceeds that for the other two markets in 11 of the 15 periods. This can be interpreted as indicating a reduced level of trading efficiency in VUPN1 relative to CKPN1 and VKPN1. Unfortunately the results from the PN2 markets are far less conclusive due to the erratic nature of the data series for all three market types.

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[32] Note that for those markets in which no information auction is conducted, as is the case for these six markets, the information cost is zero and there is no difference between the gross and net profit earned by informed traders. The distinction between the gross and net profit of informed traders is more important in later chapters, where the results of markets with information auctions are investigated.

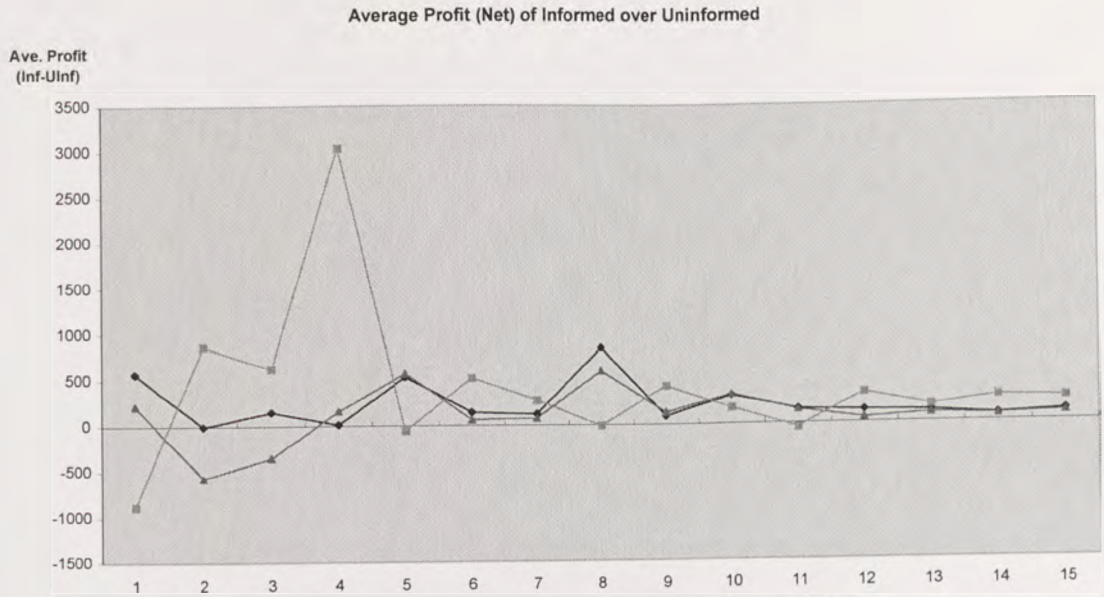

Figure 5.15 Difference between the Average Net Profit of Informed and Uninformed Traders per Period – PN1 Markets

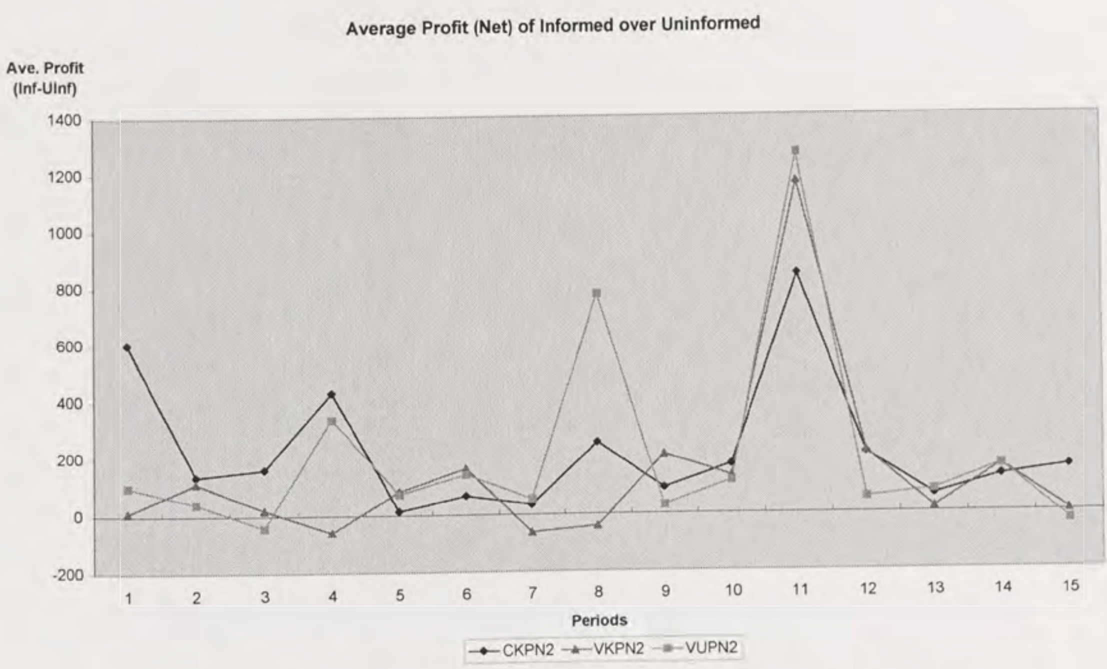

Figure 5.16 Difference between the Average Net Profit of Informed and Uninformed Traders per Period – PN2 Markets

In summary, the analysis thus far indicates that knowledge of when a trading period will end impacts on the volume of trade observed in a period. Specifically, removal of such knowledge results in an increased normalised volume of trade in VUPN markets, relative to VKPN markets. However, from the analysis so far it is not clear exactly how this impacts on observed market behaviour with respect to the prices at which transactions take place, the allocation of assets and the percentage of gains from trade realised. Thus the analysis will continue with a direct evaluation of the hypotheses introduced previously. Note that because the statistical tests performed, generally the Wilcoxon-signed ranks test, require independent observations, the data used has been adjusted to remove any intra-market dependence of observations. This is not so for the preliminary analysis reported above, which was conducted using the unadjusted data.

To directly address the predictions of $1H_O$, $2.1H_O$ and $2.2H_O$ three measures of 'early' in a trading period were defined; the first 45, 60 and 90 seconds of trade in a period. The volume of trade (VOL45, VOL60 and VOL90) and the associated root mean (Andrew M-estimator) squared deviation of transaction prices from theoretically predicted FRE values (RMSD45, RMSD60 and RMSD90) over these three time intervals were compared across the three market types. Figures 5.17-5.18 and 5.19-5.20 provide graphical interpretations of the VOL and RMSD data. The analysis of the stated hypotheses begins with a brief commentary on these figures and concludes with the reporting of statistical significance levels for the rejection of the null hypotheses ($1H_O$, $2.1H_O$, $2.2H_O$, $3.1H_O$ and $3.2H_O$).

Figures 5.17-5.18 show the volume of trade in the first 45 seconds, 60 seconds and 90 seconds for all 15 trading periods of the six markets. The figures, once more, group the markets by parameter set. For all three measures of 'early', in many of the periods the volume of trade is highest, or joint highest, in the VUPN markets. For VOL45, the volume of trade in the VUPN markets is highest, or joint highest, in 25 of the 30 periods. The corresponding figures for CKPN and VKPN are 14 and 12, respectively. For VOL60, the volume of trade in the VUPN markets is highest, or joint highest, in 23 periods, with corresponding figures for CKPN and VKPN of 11 and 7, respectively. For VOL90, the volume of trade in the VUPN markets is highest, or joint highest, in 22 periods, with corresponding figures for CKPN and VKPN of 10 and 7, respectively. Thus, for all three measures of early in a period the volume of trade in the VUPN markets is rarely below that in the CKPN and VKPN markets. Indeed, aggregated across the three measures, the volume of trade in the VUPN markets is the highest volume (excluding ties) in 42 of the 90 periods, almost 50% of the time. The corresponding values for the CKPN and VKPN markets are only 9 and 6, respectively. A graphical analysis of the data clearly supports the belief that the volume of trade, early in a period, is dramatically influenced by the removal of knowledge of the trading period duration.

Figures 5.19-5.20 show the RMSD for the first 45, 60 and 90 seconds of trade for all 15 trading periods of the six markets. The figures are once more grouped according to the parameter set adopted. VKPN1 and VUPN1 each have one period (periods 2 and 5, respectively) in which their RMSD45 and RMSD60 values are exceptionally high. VKPN2 also has an exceptionally high observation for RMSD90 in period 8. This is despite the use of the Andrew M-estimator to limit the impact of outliers. The low number of observations (transactions) mean that any 'outliers' will have a strong influence even on the M-estimator. Excluding these exceptional observations, the RMSD45, RMSD60 and RMSD 90 values for all six markets are below 500. The RMSD values for all markets are fairly erratic and exhibit very little trend other than higher RMSD values when the state of nature is Z. The exception is RMSD90 for VUPN1, which declines erratically as the period number increases. It is difficult to draw any firm conclusions concerning the impact of period duration early in a period from a graphical interpretation of the RMSD data [33].

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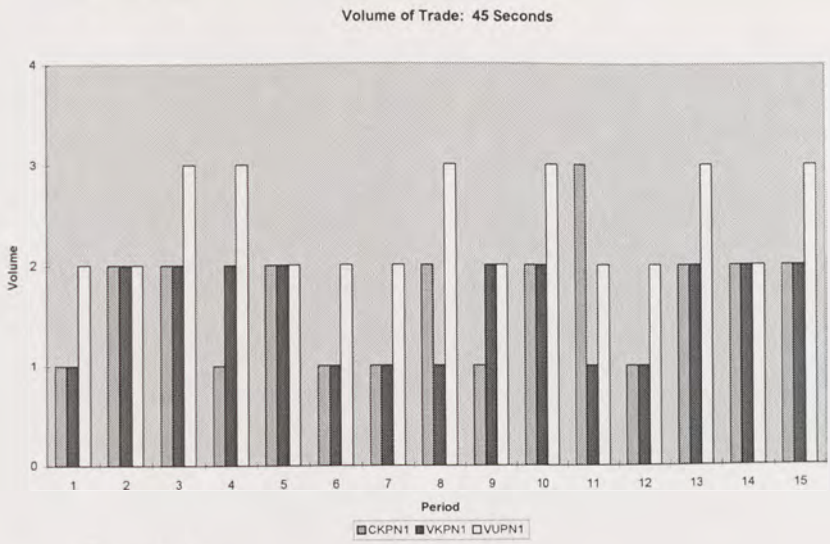
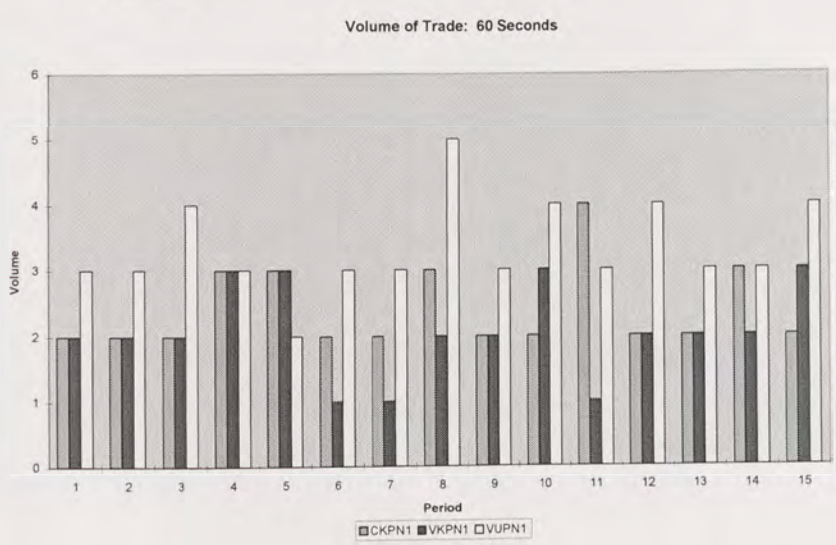
[33] Note that applying the three measures of early to the measure NORM%GAIN is neither possible nor desirable. Any allocation of assets prior to the end of a given trading period may be merely a temporary allocation. The FRE model makes no prediction about intra-period allocations, only end-period allocations. Nor would it make sense to compare the profit of informed and uninformed traders prior to the end of a period, because if a trader buys and holds an asset the profit from this trade is not recognised until the end of the period when it is redeemed for the associated dividend.

Panel A



Panel B



Panel C

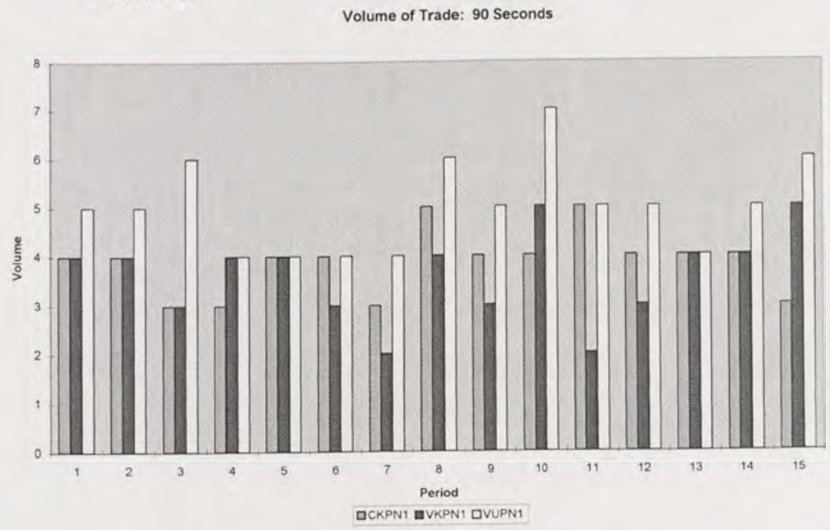
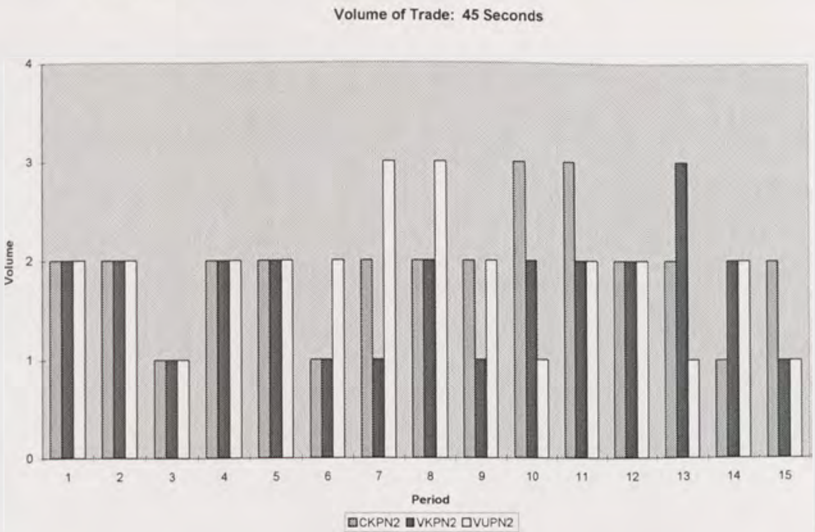


Figure 5.17 Volume of Trade in the First 45, 60 and 90 Seconds of Trade – PN1 Markets

Panel A



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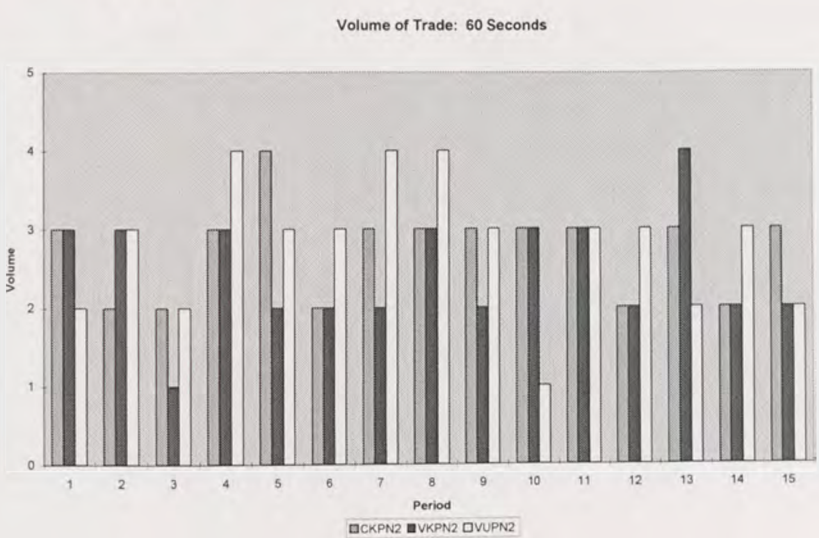

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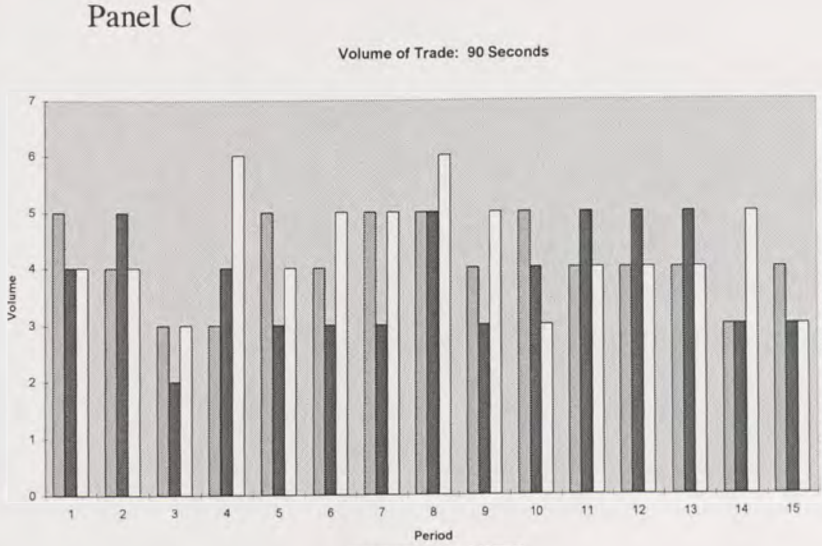


Figure 5.18 Volume of Trade in the First 45, 60 and 90 Seconds of Trade – PN2 Markets

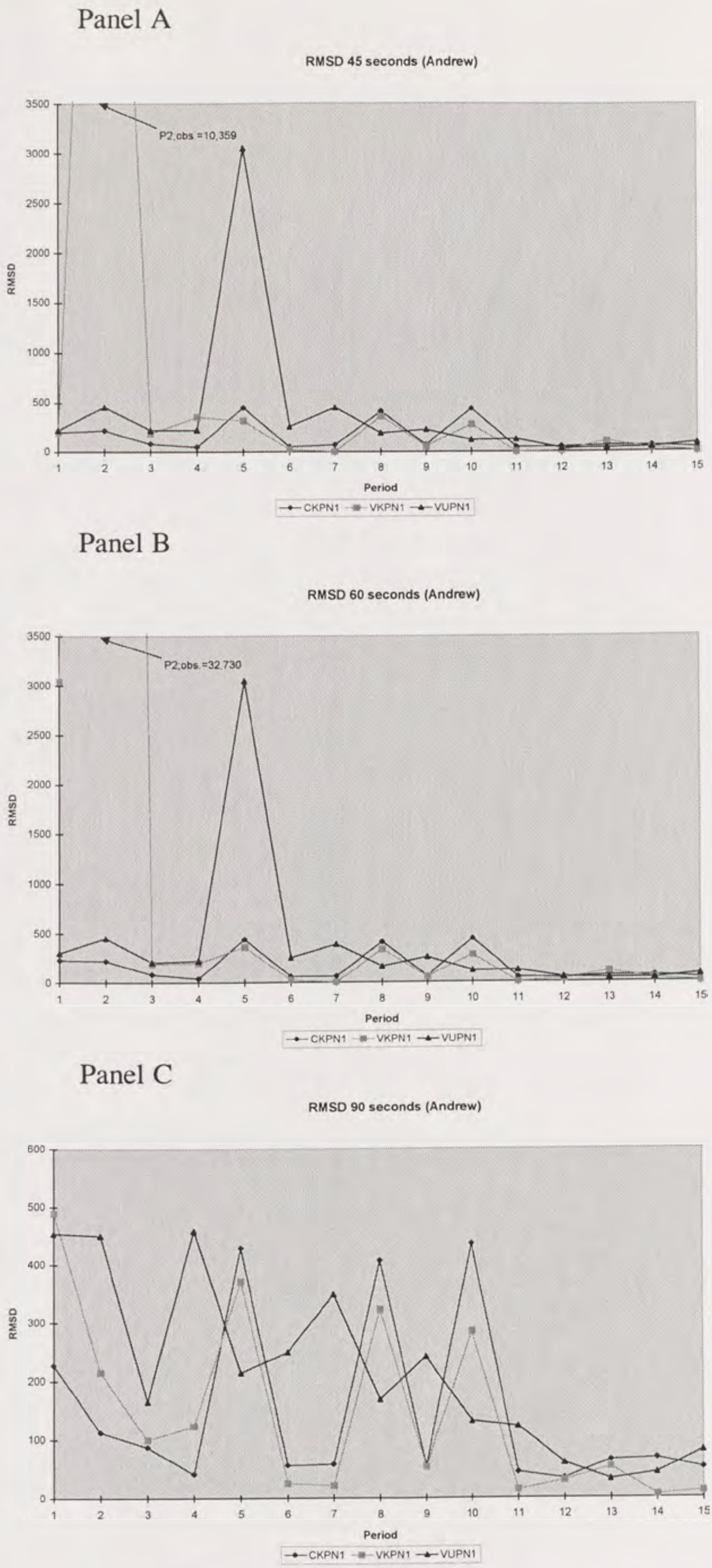
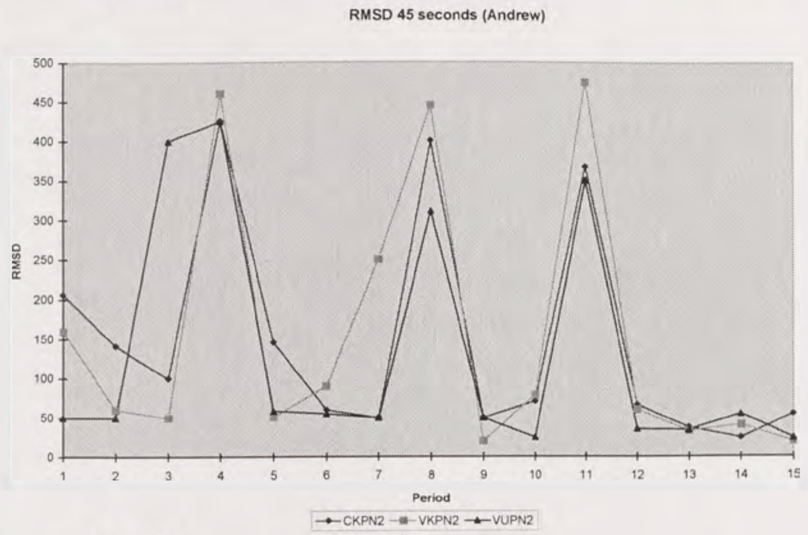
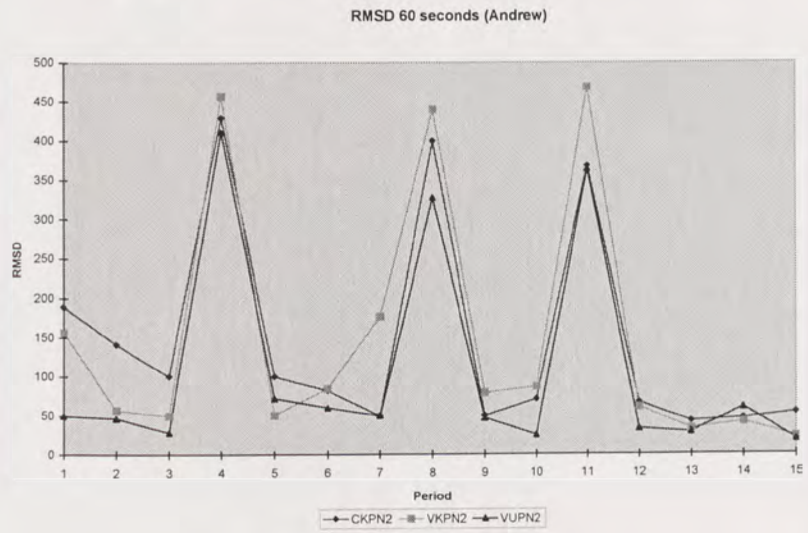


Figure 5.19 RMSD of Prices in the First 45, 60 and 90 Seconds of Trade – PN1 Markets

Panel A



Panel B



Panel C

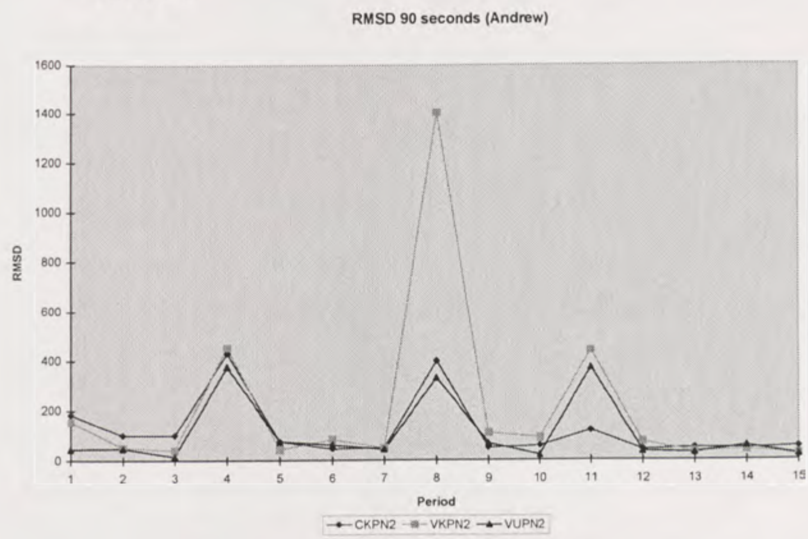


Figure 5.20 RMSD of Prices in the First 45, 60 and 90 Seconds of Trade – PN2 Markets

Table 5.6 reports the level of statistical significance for which the null hypotheses, of no statistical difference in mean values across the two paired markets can be rejected. Attention is once more drawn to the fact that the data used in the following statistical tests has been adjusted in order to remove the intra-market dependence of observations across periods. For the RMSD, VOL, NORMVOL and NORM%GAIN variables, the figures reported are the means of the unadjusted values, across all trading periods. For each variable, the figure in parentheses reports the mean of the adjusted values. The number of paired observations utilised in each of the statistical tests is 30[34]. The Wilcoxon signed ranks test (WSR) was used to compute two-tail significance levels for the comparisons between the three market types. Whilst it is reported for completeness of the analysis, the CKPN:VUPN comparison confounds the effects of both varying period durations and uncertainty over when a trading period will end. These joint effects can be isolated from one another via CKPN:VKPN and VKPN:VUPN comparisons. The results of the CKPN:VUPN comparisons will not, therefore, generally be discussed directly. The remainder of this section will consider separately the impact of period duration on the volume of trade early in a period, the informational efficiency and the overall allocational efficiency of the experimental markets CKPN, VKPN and VUPN.

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[34] The statistical tests paired observations period by period, across two market types at a time. For example, comparing the market performance across VKPN and VUPN, the observation from VKPN1 period 1 is paired with the observation from VUPN1 period 1 and so on until period 15. Then, the observation from VKPN2 period 1 is paired with the observation from VUPN2 period 1 and so on until period 15. Thus the total number of paired observations utilised in each statistical test is 30.

Variable	*Market Means (Adjusted Means)*			*WSR Two-tail α-values*		
	CKPN	***VKPN***	***VUPN***	***CKPN: VKPN***	***CKPN: VUPN***	***VKPN: VUPN***
VOL45	1.8000 (1.8858)	1.6667 (1.6876)	2.1333 (2.1577)	0.0034	0.3876	0.0104
VOL60	2.5667 (2.6225)	2.2667 (2.3456)	3.0667 (3.1468)	0.1499	0.0013	0.0022
VOL90	4.0000 (4.0112)	3.7000 (3.7007)	4.6667 (4.7334)	0.1414	0.0004	0.0001
NORMVOL	0.0528 (0.0514)	0.0431 (0.0445)	0.0539 (0.0551)	0.1254	0.2329	0.0000
RMSD45	150.1291 (146.8936)	486.0485 (174.2116)	257.4541 (281.3040)	0.0368	0.2289	0.1254
RMSD60	149.4388 (145.6553)	1321.64444 (148.7835)	244.8518 (265.8319)	0.0196	0.4779	0.0627
RMSD90	132.3513 (130.9472)	173.8193 (151.2606)	160.8230 (123.4888)	0.1779	0.9099	0.7189
RMSD	130.7098 (129.0361)	117.7417 (-237.9844)	136.2241 (89.1797)	0.0087	0.5170	0.0157
NORM%GAIN	0.1806 (0.2228)	0.1638 (0.1847)	0.1574 (0.1783)	0.0545	0.0495	0.7577

Table 5.6 Summary Table of Market Means (Adjusted Means) and Wilcoxon Signed Ranks Test Two-tail Significance Levels

Volume of Trade

Comparison of the volume of trade between the CKPN and VKPN markets produces a significantly higher mean VOL45 value for the CKPN markets. This would suggest that for the VKPN markets the long durations in some periods may have made traders more cautious. This is despite the average period duration being equal across the two market types. After the first 45 seconds of trade, however, varying period durations no longer impact on the volume of trade, with the other three volume measures resulting in insignificant differences in mean values across the CKPN and VKPN markets. Given that on average the duration per period is equal across the two market types, thus VKPN periods are sometimes longer and sometimes shorter than the 240 second CKPN periods, these results are to be expected. Of greater interest is the comparison of the measures of volume of trade across the VKPN:VUPN comparison. Such a comparison isolates the impact of knowledge of period duration on the volume of trade observed in experimental asset markets. VUPN exhibits a significantly higher volume of trade in all three measures of early in a trading period (α=0.0104, 0.0022 and 0.0001 for VOL45, 60 and 90, respectively), providing support for the rejection of $1H_O$. The volume of trade early in a period is indeed higher in VUPN than in VKPN markets, given the three measures of 'early' utilised in the analysis. It can be concluded, therefore, that the uncertainty introduced by the removal of the knowledge of period duration causes individuals to adopt a more aggressive trading strategy, with respect to the speed of trade. This result is further strengthened by the highly significant difference between the NORMVOL measures for the two market types (α=0.0000). The NORMVOL figures effectively measure the rate of trade across an entire period. Thus the rate of trade per period is, on average, far higher in VUPN markets than in VKPN markets. This is the market's response to the increased uncertainty faced in the VUPN environment.

Informational Efficiency

The issue now requiring consideration is the determination of how the increased rate of trade early in a period, as a result of uncertainty concerning period duration, impacts on the informational efficiency of VUPN markets relative to VKPN markets. It is possible that the rush to trade results in disequilibrium trades, the impact of which is to reduce the informational efficiency of the market by clouding the public price signal. Alternatively the rush of trade may facilitate the convergence of transaction prices to theoretically predicted equilibrium prices. Such a result may be due to a reduction in the length of time over which bartering over bid and ask prices takes place, which in turn may be a result of the uncertainty introduced by the lack of period duration knowledge.

The investigation begins with an evaluation of hypothesis $2.1H_O$ to determine the extent of any difference in transaction prices across the markets VKPN and VUPN. As reported in Table 5.6, for the three measures of early in a trading period, the mean RMSD does not differ statistically across the two market types. For the measures RMSD(45,60,90) the two-tail significance levels are all $\alpha>0.05$ and the null hypothesis of no statistical difference ($2.1H_O$) can not be rejected. Thus, the higher early volume of trade in the VUPN markets does not impact on the level of informational efficiency attained early in a period, relative to the informational efficiency of the VKPN markets over the same time periods. As a result, it would make no sense to formally evaluate hypothesis $2.2H_O$, because no *difference* exists in the RMSD of early prices from the FRE model.

The VKPN and VUPN markets were further compared to see if any difference existed between the RMSD of prices over an entire trading period. As reported in Table 5.6, the unadjusted mean RMSD of 136.2241 emus for the VUPN markets is greater than the value of 117.7417 emus for the VKPN markets (α=0.0157 calculated using a two-tail WSR test on the adjusted data). This result indicates that, over an entire trading period, the level of informational efficiency attained is reduced (relative to VKPN markets) as a result of the uncertainty over period duration. Thus, whilst the early volume of trade in a period does not impact on the early RMSD of prices, it is possible that the faster rate of trade over an entire period may impact on the overall RMSD measure. To this end the degree of correlation between the *difference* in normalised volume of trade across the two market types and the *difference* in RMSD across the markets was computed. A significantly positive correlation would connect the higher rate of trade observed in VUPN markets with the reduced convergence of asset prices to FRE values, relative to VKPN markets. Unfortunately, the correlation coefficient of 0.1684 computed using Spearman's rank correlation test was not statistically significant (α=0.374). It is difficult to conclude decisively, therefore, that the higher rate of trade is the cause of the loss of informational efficiency observed over the entire period in VUPN markets, relative to VKPN markets. However, the ability to reject 2.1H_O for RMSD over the entire period still offers evidence in favour of Friedman's (1984) view that a predetermined, known trading period duration is one of a number of features that enhances the informational efficiency of experimental markets.

The comparison of the VKPN and VUPN markets provided the strictest test of the impact of uncertainty concerning period duration on market behaviour. A further comparison between the CKPN and VKPN markets offers insight into the influence of varying the period duration on the RMSD observed early in a trading period. The mean RMSD45 and RMSD60 measures for the VKPN markets are statistically greater than the corresponding measures for the CKPN markets (α=0.0368 and α=0.0196, respectively). By the time 90 seconds of trade has elapsed there is no longer any statistically significant difference in the mean RMSD90 figures for the two market types. In fact, by the end of the period the trend has reversed with the mean RMSD of the CKPN markets statistically exceeding the mean RMSD for the VKPN markets (α=0.0087). These results can be interpreted as providing initial detrimental evidence against the relative level of informational efficiency early in VKPN markets. Over time, however, as the period proceeds the VKPN markets are able to correct themselves and end with a higher level of informational efficiency, relative to the CKPN markets. This phenomenon is not due to any difference in early trading volume or overall rate of trade across the two market types. With respect to the adopted measures of volume, the only significant difference between the two market types occurs for VOL45, however, the correlation coefficient between the *difference* in VOL45 and the *difference* in RMSD45 across the markets is insignificant (α=0.566). It seems, therefore, that whilst varying the period duration does not have any major impact on the timing of transactions, it does impact, in opposite directions, on the relative informational efficiency attained both early in a period and over the entire trading period.

Allocational Efficiency

Having established that both varying period duration and knowledge of the period duration influence the level of informational efficiency observed in experimental asset markets, but that it is not possible to tie this to resulting differences in the timing of transactions, it remains to determine the impact of the two treatments on the level of allocational efficiency observed. The analysis fails to reject the null hypothesis (3.1H_O, α=0.7577) of no statistical between the mean NORM%GAIN of 0.1638 for the VKPN and 0.1574 VUPN markets. Thus, whilst the increased uncertainty experienced due to the lack of knowledge concerning period duration results in a lower mean NORM%GAIN figure, this reduction is not statistically significant and so it is not possible to claim any impact on the relative level of allocational efficiency. It is, therefore, not necessary to formally evaluate hypothesis 3.2H_O for the VKPN:VUPN comparison. In contrast to this result, however, both the CKPN:VKPN and CKPN:VUPN comparisons provide statistically significant differences between the mean NORM%GAIN figures for the compared markets (α=0.0545 and α=0.0495, respectively). It can be concluded, therefore, that the mean NORM%GAIN figure of 0.1806 for the CKPN markets significantly exceeds the corresponding figures for the VKPN and VUPN markets. Once more it not necessary to formally evaluate hypothesis 3.2H_O for either of these two comparisons, because in this case there is no statistically significant difference between the mean NORMVOL figure for the CKPN markets and the corresponding figures for the other two market types.

From the above analysis it can be concluded that varying the duration each period, with or without uncertainty concerning the actual period duration, has a negative impact on the level of allocational efficiency observed in the experimental asset market investigated, relative to the control provided by the CKPN markets. In isolation, however, uncertainty over the actual period duration to be faced does not influence the level of allocational efficiency observed.

5.7 Discussion and Conclusions

This concluding section will summarise the results provided in this chapter, relating them to other experimental results, including the exploratory study by Duxbury (1997). To begin with a comparative analysis was conducted to determine the superiority of either the FRE model or PI model with respect to their predictive accuracy. The two models were evaluated against a number of different performance measures. First, the RMSD of prices from the disparate theoretically predicted equilibrium prices of the two models were compared. Over all six markets the RMSD of transaction prices from the FRE price, over the entire trading period, was below that for the PI model in 82.61% of periods. Next, the two models were compared using a measure of the misallocation of assets relative to their end-period allocation predictions. The number of misallocations under the FRE model were less than those for the PI model in 70% of periods, with the remaining 30% of periods falling within an indiscriminate region. In no period was the number of assets misallocated under the FRE model in excess of the number misallocated under the PI model. Thirdly, a measure of the percentage gains from trade exploited was used to discriminate between the competing models. Relative to the initial allocation of assets, the predicted end-period allocations of the FRE and PI models predict positive and negative gains from trade, respectively, when the state of nature is Z. Of the 21 occurrences of the state Z there was only 1 period where the realised gains from trade were negative. These three performance measures all provided strong support for the predictive accuracy of the FRE model over the PI model. The only weakly negative performance measure for the FRE model was the comparison of the average profit earned by informed traders relative to uninformed traders. This was only construed as evidence against the strict interpretation of the FRE model in which the price signal reveals private information instantaneously. The superiority of the FRE model in simple experimental asset markets with perfect information structures is in line with the results of many of the early experimental asset markets, such as Plott and Sunder (1982) and Banks (1985).

The second stage of the investigation was a relative analysis of the impact of period duration on observed market behaviour. The effect was separated between the impact of varying period durations (CKPN:VKPN) and the impact of uncertainty concerning the period durations (VKPN:VUPN). Varying the period durations had little significant effect on the volume or rate of trade observed and had a mixed effect on the deviation of transaction prices from the FRE price. For the two measures of price deviation early in a period, RMSD45 and RMSD60, varying the period duration resulted in a higher deviation. By the end of a trading period this trend had been reversed and varying period durations were associated with lower price deviations and so the VK markets were deemed informationally more efficient. Contrary to this was the finding of a significant reduction in allocational efficiency as a result of varying period duration.

Uncertainty concerning the period durations had a major impact on market behaviour, significantly increasing the early volume of trade and the rate of trade observed in a period. The higher early volume of trade did not feed through to impact on the early RMSD(45,60,90) of prices from FRE values. The RMSD of prices over an entire period, however, did increase significantly as a result of the uncertainty regarding period duration and this was construed as reducing the overall level of informational efficiency attained. This reduction in informational efficiency, however, could not be directly linked to the higher rate of trade that resulted due to the increased uncertainty over period durations. The result provides support for Friedman's (1984) suggestion that a predetermined, known period duration was a feature of experimental asset markets that enhanced the observed level of market efficiency. Despite this loss of informational efficiency the markets with uncertain period durations (VUPN) did not suffer any significant reduction in allocational efficiency relative to the VKPN markets. These final two results, lower informational efficiency but no loss of allocational efficiency, support the exploratory results reported in Duxbury (1997). However, Duxbury (1997) also reports a loss of informational efficiency early in a trading period and is able to relate this directly to the higher early volume of trade observed. The results reported here do not support this conclusion.

It is of worth noting, however, that had each cell of the design not been repeated and thus only the markets CKPN1, VKPN1 andVUPN1 been conducted, the evidence from the relative analysis of market performance (VKPN1:VUPN1) would have been directly in support of the results reported in Duxbury (1997). The early measures of RMSD for VUPN1 were significantly higher than the corresponding measures for VKPN1, with the exception of RMSD90, which was higher but insignificant. The end of period RMSD figure was also significantly higher as were all the volume measures (VOL45,60,90 and NORMVOL). It is difficult to place much emphasis on these results with out falling foul of Roth's (1994) criticism of the selective reporting of experiments, discussed in Chapter Four. For this reason nothing more is made here of these results from the PN1 markets, however, the discussion will return to this issue in the final results chapter in which a holistic approach to the analysis is taken.

In summary, the incorporation of uncertain period durations in DA markets resulted in an increase in the volume of trade both early in a period and across an entire period. The uncertain period duration also resulted in a reduction in the level of informational efficiency generated by the DA markets. These results have implications for the trade across on-line networks, which has developed as a result of the growth in virtual communities. If a vendor wishes to sell a higher volume of a certain commodity the results reported here suggest that they should conduct auctions incorporating uncertain period durations instead of fixed, known durations. Unfortunately, however, uncertain period durations are associated with a reduction in informational efficiency. Assets trade at prices that do not represent their true economic worth. In the context of on-line auctions, whether this represents a benefit to the vendor or the purchaser depends on whether the commodity trades at a price above or below the true economic value.

Finally, the lack of statistically significant results regarding the impact of uncertainty of period duration on the early measures of RMSD may have been the result of noise generated in the data (particularly in market VUPN2 in light of the above discussion). The evidence can not be regarded as conclusive one way or another. The experimental methodology lesson to be learned from the experience in this chapter is that repeated cell designs are essential if the results of an investigation are to be regarded as conclusive. If only the PN1 markets of this experimental design had been conducted the whole flavour of the results would have been fundamentally altered. Fortunately, the strength of the experimental method lies in the ability to replicate previous experiments. With this in mind the next chapter reports the results of six more experimental asset markets that essentially replicate the six studied in this chapter. The only difference stems from the introduction of an imperfect information structure to the experimental design of all six markets. This change in the information structure is constant and controlled across all six markets, therefore, the treatment variable period duration (varying durations and uncertainty of durations) can once more be investigated without any confounding factors present.

Chapter Six

6 IMPACT OF PERIOD DURATION ON EXPERIMENTAL ASSET MARKETS WITH IMPERFECT INFORMATION STRUCTURES

6.1 Introduction

The previous chapter investigated the impact of period duration, as a treatment variable, on the market behaviour observed in experimental financial asset markets. The markets conducted adopted an intentionally simplistic information structure, providing perfect private information to six out of the twelve traders. This chapter also investigates the impact of period duration on observed market behaviour, however, the markets conducted are more complex and provide only *imperfect* private information to six out of the twelve traders.

The investigation of market performance in the presence of imperfect information is of substantive practical interest, because it more closely mirrors the situation in which individuals find themselves when conducting trade in real world markets. It is highly unlikely that a trader on any of the world's financial markets would know with certainty the true fundamental value at which a particular company's shares should be priced. The introduction of imperfect information to the experimental design increases the degree of uncertainty faced by traders and so offers a more demanding test of market performance. In comparison to the markets in the previous chapter, the markets investigated here are required not only to disseminate private information, but also to collect and aggregate the information first. This is a much more complex task to perform.

Once more two markets are conducted for each of the three levels of the treatment variable, CK, VK and VU markets. The only difference between this second group of markets and the first group studied in Chapter Five is with respect to the information structure. Thus, this second group of markets adds another layer to the overall experimental design (see Table 4.4, Chapter Four). As the intention in this chapter is to once more investigate the impact of period duration on market behaviour, the hypotheses developed and tested in Chapter Five are equally relevant and applicable for the analysis of market behaviour observed in this second group of experimental sessions. A comparison of market efficiency across the two different information structures, perfect versus imperfect, is left until the holistic analysis conducted in Chapter Eight.

The following section reviews the relevant experimental literature in which asset markets with imperfect information structures have been studied. Section 6.3 details the specifics of the design, not included in the earlier general experimental design chapter, for this second group of markets, highlighting both how the markets differ to those in the previous chapter and how the similarities provide the necessary control for subsequent comparisons. Section 6.4 reports the results from the analysis of the experimental markets. As with Chapter Five, a comparative (within market) evaluation of the FRE and PI models is performed first, to determine whether the FRE model is still able to provide superior predictions in a more complex trading environment, where traders face greater uncertainty. This comparative analysis is followed by a relative (across market) evaluation of the treatment variable, period duration, focusing on its impact in markets where information aggregation is required in addition to dissemination. The final section contains a summary and discussion of the results.

6.2 Review of Relevant Literature

The FRE model predicts that in equilibrium prices fully reveal all private information. When private information concerning the state of nature (and consequently dividend value) is asymmetrically distributed between fully informed and uninformed traders the FRE model predicts that the private information will be disseminated throughout the market, permitting the uninformed to infer the state of nature. The issue of information dissemination was the focus of the previous chapter, along with many of the early experimental asset market studies (for example, Plott and Sunder, 1982). In addition to the dissemination of private information the FRE model also predicts that markets are able to first aggregate diverse private information and then disseminate it throughout the market. Price acts as the signal for information aggregation and dissemination, without requiring any direct communication between traders.

This dual role of markets as aggregators and disseminators of diverse, asymmetrically distributed private information via publicly available price signals was the focus of Plott and Sunder (1988). Eleven markets were conducted in which traders were given diverse, imperfect information concerning the state of nature. The information structure was such that no trader knew the state of nature with certainty, but if the market pooled the diverse information then this would reveal the state of nature. The information structure, therefore, incorporated aggregate certainty. For example, if the state of nature was X, then half the traders would receive the message 'Not Y' and the other half would receive the message 'Not Z'. Plott and Sunder

(1988) conducted three groups of markets. Series A markets traded a single asset between traders with diverse dividend distributions. Series B markets included a complete set of state contingent claims, while series C markets traded a single asset between traders with uniform dividend distributions. Plott and Sunder (1988) were able to conclude that information aggregation, and so convergence to FRE equilibrium, was poor unless a complete set of state contingent claims markets and homogenous trader types were present in the design. Thus, their series A markets did not converge to FRE predictions.

Forsythe and Lundholm (1990) also conducted experimental markets that included imperfect information but with aggregate certainty. However, their experimental design differed to Plott and Sunder's (1988) in, amongst others, two key respects. First, all markets parameters were common knowledge, therefore, participants had complete information about all traders' payoffs. Second, traders participated in markets in two consecutive sessions over which the market parameters were not altered, but the trader type (of which there were only two) was rotated. The importance of these design changes were confirmed by Forsythe and Lundholm's (1990) results, which supported the conclusion that common knowledge of dividend payoffs and similar prior experience were sufficient to achieve a FRE equilibrium, but that rotating trader types was not necessary.

That convergence to a FRE equilibrium requires common knowledge of all traders' dividend payoffs indicates that reduced uncertainty concerning other participants' incentives to trade facilitates market efficiency. Lundholm (1991) pursued this point further, building on the previous experimental design by including an information structure in which insiders receive imperfect information but in aggregate this information does not reveal the state of nature, that is aggregate uncertainty. In the presence of aggregate uncertainty the equilibrium price will be contingent on traders' risk preferences. Such preferences are unobservable and thus the ability of participants to identify other traders' incentives to trade is removed. Lundholm (1991) compared the performance of aggregate uncertainty (AU) markets with the performance achieved in aggregate certainty (AC) markets. To achieve this the experimental design required four states of nature with either two or three clues depending on whether the market was AU or AC, respectively. The design was, therefore, more complex than those in the other two studies discussed above, in which three states and two clues were present. In an attempt to compensate for this

Lundholm (1991) incorporated a number of other design features aimed at facilitating the convergence to a FRE equilibrium, including common knowledge of all parameters and additional experience. Despite the inclusion of these aids to convergence Lundholm (1991) reports AC markets that exhibited lower convergence to the FRE equilibrium than equivalent markets reported in Plott and Sunder (1988), thus the increased complexity hindered convergence. The AU markets exhibited considerably worse convergence and thus less efficiency than the AC markets.

Relative to the markets investigated in the literature above, the experimental markets (VU) conducted in this research already include uncertainty concerning trading period duration. Rather than introduce a high degree of uncertainty concerning the state of nature, as would be the case with an imperfect information structure with aggregate uncertainty, the information structure introduced in these six markets will be of the aggregate certainty type. It was felt that the VU markets were already required to conduct a complex trading task and that the level of state uncertainty connected with aggregate uncertainty markets would be asking too much of these markets. Furthermore, the next logical step in the experimental design, in terms of slowly increasing the complexity and uncertainty of the trading environment, is to move from markets with perfect information to markets with imperfect information but aggregate certainty. Details of the specifics of the experimental design governing this second group of markets are given in the following section.

6.3 Experimental Design Considerations

6.3.1 Markets and Period Durations

As with the first group of experimental markets reported in Chapter Five, two markets were conducted for each of the three levels of the treatment variable, period duration. The CK markets are identified CKIN1 and CKIN2, the VK markets are identified VKIN1 and VKIN2 and the VU markets are identified VUIN1 and VUIN2. As expected the trading period durations in the CK markets were held constant, at 240 seconds, across all 15 trading periods. In the VK and VU markets the durations varied between 120 and 360 seconds, from period to period. As previously, the actual sequence of trading period durations was randomly determined in advance by computer and two different parameter designs were adopted. Once again, for all three market types, the identifiers 1 and 2 refer to the parameter sets used in the particular market (see Chapter Four Table 4.3)[35]. The six markets comprising this second group were conducted during the period 13th November 1996 to the 12th February 1997, inclusive.

6.3.2 State Contingent Dividends

The state contingent dividend distributions across trader types were the same across all six markets. Parameter set A was used for all markets (see Chapter Four Table 4.1, Panel A). The sequence of states of nature did differ between the markets. CKIN1, VKIN1 and VUIN1 used the sequence in parameter set one, whilst CKIN2, VKIN2 and VUIN2 used the sequence in parameter set two (see Chapter Four Table 4.3). As previously, the participants' diverse backgrounds plus the minimal contact and interaction between them across different market sessions conducted some months apart, serves to ensure no participant could have been aware of the sequence of states of nature in advance.

6.3.3 Information Structure

The information structure prevalent throughout these six markets is imperfect (I) in that insiders are given information that no longer identifies with certainty the state of nature for a given trading period. Instead, insiders receive information that allows them to eliminate one of the possible states of nature, thus reducing the degree of state uncertainty that they face. The procedures are similar to Plott and Sunder (1988) with one slight modification. In Plott and Sunder's (1988) markets all 12 traders received imperfect information concerning the state of nature. There were, therefore, no uninformed traders (with 'Blank' clue cards) in their markets. In order to maintain strict experimental control and thus permit comparative evaluations across markets, across chapters, the experimental design utilised here maintains the convention from Chapter Five of including six uninformed traders ('Blank' clue card) in the design of the experimental markets[36].

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[35] Again, the use of only two parameter designs was not known by any participant. Participants knew only that the sequence was determined randomly in advance by computer, thus, for all they knew the sequence differed from market to market. The same is true of the sequence of states of nature.

[36] Maintaining both the number of insiders and uninformed equal to six in all periods is not strictly necessary for the purpose of this chapter, namely an investigation of the impact of period duration on market behaviour in the presence of imperfect information. Adequate experimental control would have been achieved simply by holding the number of insiders constant, at any level, across the

The six randomly chosen insiders receive clue cards prior to the commencement of trade, which inform them of one of the three states of nature that will *not* occur in the coming trading period. For example, if the state of nature for the coming period was X then three insiders would receive the clue 'Not Y' and the other three insiders would receive the clue 'Not Z'. The information structure, therefore, provides for aggregate certainty. If the market is able to aggregate and disseminate the two different clues, via the price signal, the underlying state of nature will be revealed with certainty.

As with the markets studied in Chapter Five, two participants were chosen from each trader type group, with their identity determined randomly within trader types (once more determined prior to the experimental session by computer). Randomly determining the identity of insiders within trader types diminishes the potential for the uninformed to guess the identity of the informed. This will ensure that the only public information utilised by uninformed traders to determine their trading behaviour are the bids, asks and transaction prices observed in the market. The two traders, within a trader type group, chosen to be insiders were never given the same clue. For example, assuming the sate of nature is X, if traders 1 and 2 are randomly chosen to be insiders from trader type 1 and trader 1 receives the clue 'Not Y' then trader 2 will receive the clue 'Not Z'. This feature ensures that the trader type group with the highest dividend payment given the state of nature receives both of the clues, permitting them to identify the state of nature in aggregate. This feature of the design provides for asset prices to be bid up to the FRE price.

As with the experimental asset markets of Chapter Five, the number and random determination of insiders each period was common knowledge in all markets. Participants knew the nature of information insiders would receive, thus that it would allow them to eliminate one of the three possible states of nature. Also common knowledge was the fact that all traders would receive clue cards, even if they were 'Blank', so as to conceal the identity of insiders in all periods. The exact identity of insiders each period was not common knowledge.

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six markets studied in this chapter. However, holding the number constant at six is essential to provide the control necessary for a comparative analysis of the perfect versus imperfect information structures that is performed in the holistic analysis of Chapter Eight. So as to provide for strict experimental control, all eighteen experimental markets conducted in this research programme adopt this convention.

The six experimental markets studied in this chapter differ in design to the six markets of Chapter Five only with respect to the imperfect nature of the information structure. All other details of the experimental design are general to the thesis as a whole and were discussed in Chapter Four. The subsequent section reports the results of the investigation of market performance for the six experimental markets in this second group. The section reports the results of a *comparative* evaluation of the performance of the FRE and PI models and concludes with a *relative* evaluation of the impact of period duration on market performance.

6.4 Results and Analyses

6.4.1 Data Considerations

There are no concerns over the data generated in the six markets conducted in this chapter that are specific to these markets and require comment. It should be noted, however, that the three data issues raised in Chapter Five (section 5.6.1) are all equally applicable here. The concerns expressed in Chapter Five regarding the existence of outliers, data dependence and the use of statistical tests are all equally valid for the markets conducted in this chapter. The same is true of the methods for dealing with these concerns and the justifications provided for the adoption of such methods.

6.4.2 FRE v PI: Comparative Performance Evaluation

The discussion within this subsection is centred around a comparative evaluation of the predictive accuracy of the FRE and PI models. The comparison is performed on the raw data generated by the experimental markets, including transaction prices, allocations and profits. For this period-by-period, within market comparative analysis the transformations to the data required to deal with outliers and dependence are not necessary.

As seen previously, the two competing models of FRE and PI predict that traders use different information sets in the determination of their expectations of transaction prices. The two models, therefore, make disparate predictions concerning equilibrium prices. Given the state contingent dividends governing these six market[37], the FRE models predicts equilibrium prices of 350, 300 and 700 for states of nature X, Y and Z, respectively. These are the same equilibrium prices as were

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[37] See Table 4.1, Chapter Four, parameter set A.

predicted by the FRE model for the first group of experimental markets for which the information structure was perfect. This is because the state contingent dividend distributions used in the experimental design are the same for the first two groups of markets. The fact that the information structure is now imperfect does not influence the FRE equilibrium prices, because in aggregate the market is fully informed and in equilibrium the price signal fully reveals the underlying state of nature. The same is not true of the price predictions of the PI model, as these will change as a result of moving from a perfect to imperfect information structure. Under the assumptions of the PI model traders condition their price expectations on private information only, thus the PI equilibrium price is contingent upon the accuracy of the private information received. The PI model predicts equilibrium prices of 500, 450 and 500 for states of nature X, Y and Z, respectively[38].

[38] See Appendix 3 for an explanation of the FRE and PI equilibrium price calculations.

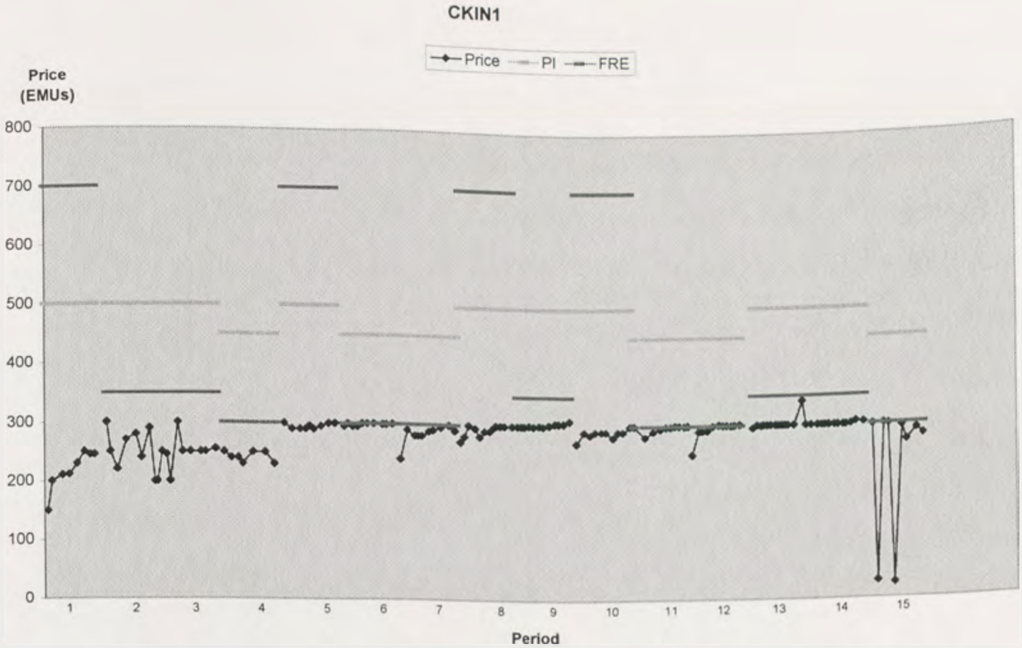


Figure 6.1 Sequence of Transaction Prices per Period – CKIN1

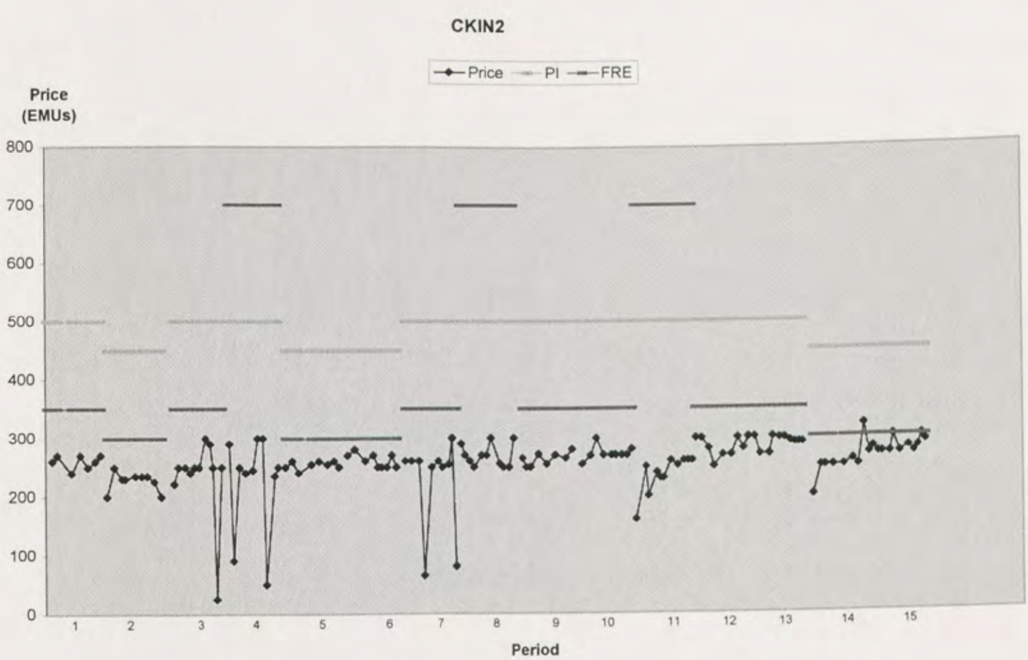


Figure 6.2 Sequence of Transaction Prices per Period – CKIN2

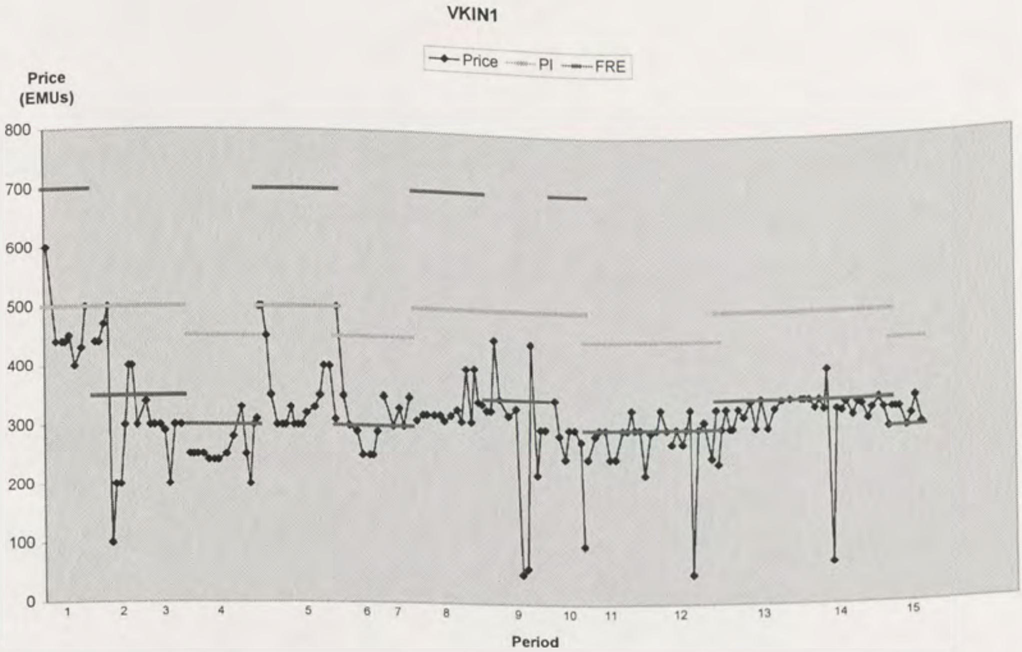


Figure 6.3 Sequence of Transaction Prices per Period – VKIN1

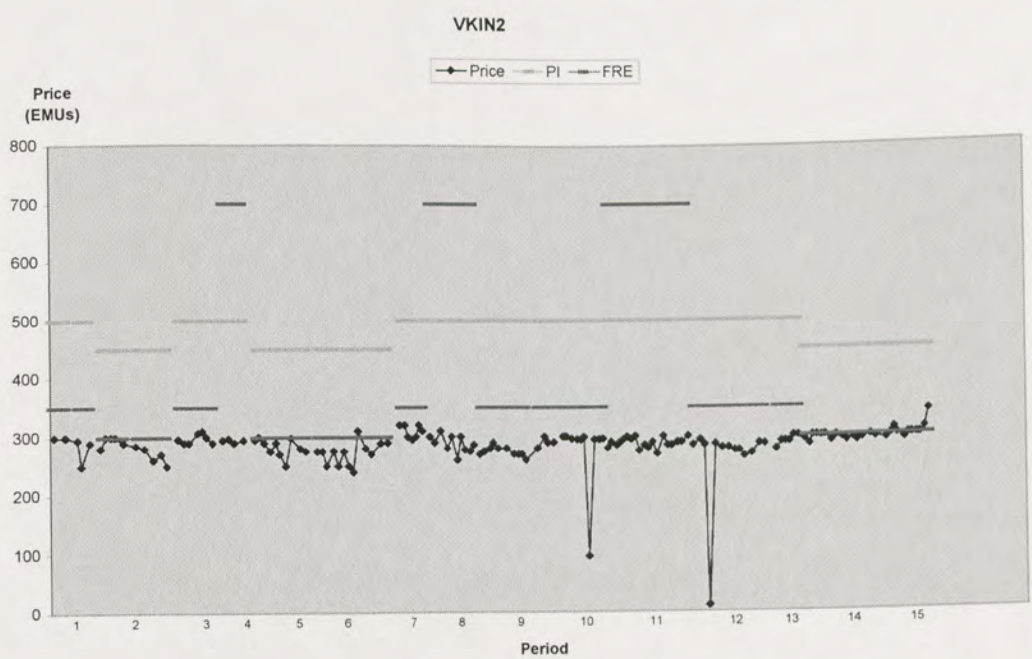


Figure 6.4 Sequence of Transaction Prices per Period – VKIN2

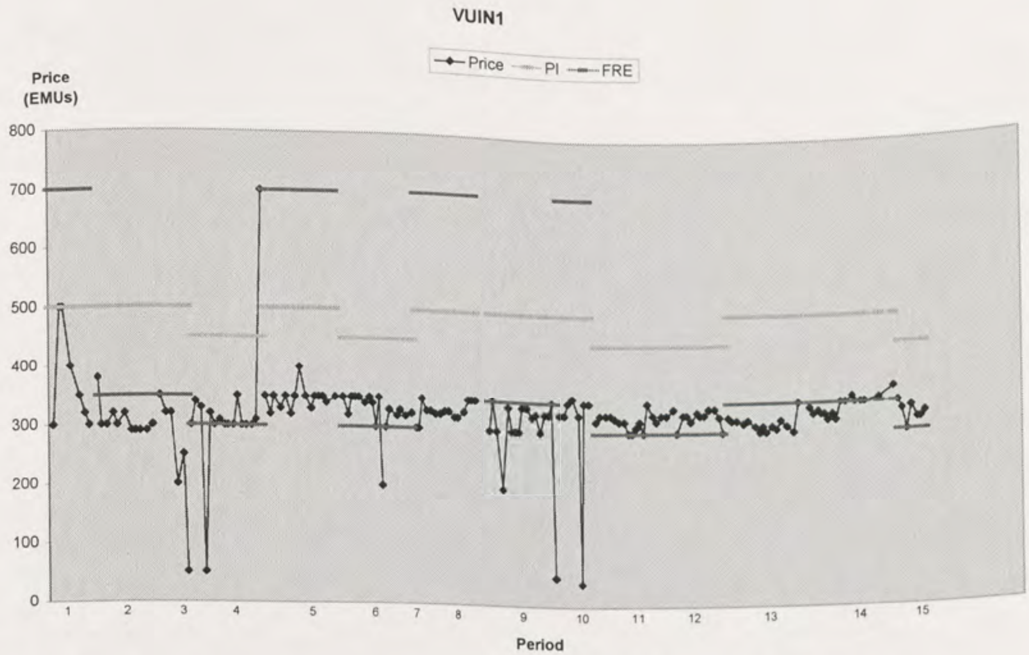


Figure 6.5 Sequence of Transaction Prices per Period – VUIN1

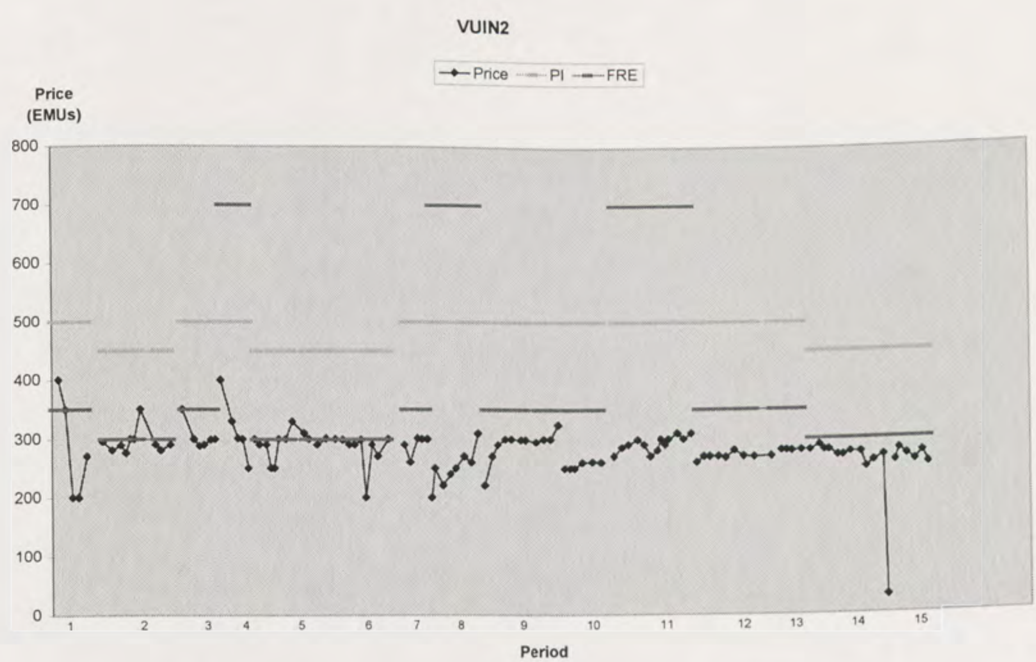


Figure 6.6 Sequence of Transaction Prices per Period – VUIN2

The FRE and PI equilibrium price predictions are included in Figures 6.1-6.6 as horizontal lines, towards which the convergence of transaction prices can be compared. In both CKIN markets the transaction prices are reasonably stable even in early trading periods. There are a few periods, more noticeably in CKIN2, where a few transactions occur at very low prices that deviate from most of the other transaction prices within the same period. Across the 15 trading periods of both markets assets trade, on the whole, at prices within a narrow band between 250 and 300 emus. As with the first group of markets, prices do not appear to be very responsive to the state of nature Z. For states X and Y the assets trade at prices much closer to the FRE price than the PI price. This is not so for those periods where the state was Z. In this second group of markets, in contrast to the first group, the two models predict disparate equilibrium prices under state Z and so these periods can be used to distinguish between them. The markets do not appear to react to the occurrence of the state of nature Z. The sequences of transaction prices in the VKIN2 market are very similar to those observed in the CKIN markets. However, in marked contrast, the transaction prices observed in VKIN1 are far more volatile. In many of the early periods the opening transactions occur at prices close to the PI price, however, over the period the transaction price converges towards the FRE price. In the later periods the transaction prices are clustered far closer to the FRE price from the beginning of the period onwards. The only differences between these two markets are with respect to the sequence of period durations and the sequence of states of nature. It is offered, by way of conjecture only, that the occurrence of state Z in the first period of VKIN1, but not until period 4 in VKIN2, plays an important role in the observed sequences of transaction prices. Early trades at high transaction prices (for example, 600 emus) in VKIN1 alerted traders to the fact that prices could in fact rise that high. The early trades at prices around 300 emus, close to the FRE price of 350, in VKIN2 did not provide traders with early experience of high (relative) prices. The volatility of prices in the VUIN markets exceed that of VKIN2 but do not exceed the observed volatility in VKIN1. The level of volatility declines as traders become more familiar with the experimental markets. The assets generally trade at prices close to the FRE price with the usual exception when the state is Z.

To directly evaluate the FRE and PI models' predictions the RMSD of prices each period were computed for both and compared within a market on a period by period basis. In this comparative analysis the normal arithmetic mean is used to compute the RMSD, the use of Andrew's M-estimator is not necessary. Comparisons were made for the first 45, 60 and 90 seconds of trade in a period and over the entire trading period duration (RMSD45,60,90 and RMSD, respectively). Table 6.1 contains the outcomes of these comparisons, aggregated over the two parameter designs. The percentages are calculated based on the total number of periods of 30. The predictive accuracy of the price predictions of the FRE model is far higher than that of the PI model. Aggregated across all three market types (Overall) the RMSD of the FRE model is less than that of the PI model in approximately three quarters of all the periods. For the CKIN and VUIN markets the only time that the PI model out predicts the FRE model is when the state of nature is Z. The same is true of the VKIN2 market, however, for VKIN1 the PI model makes superior predictions in 6 of the 15 periods.

		Percentage Comparison (%)			
Market	***Performance***	***RMSD45***	***RMSD60***	***RMSD90***	***RMSD***
CKIN	FRE < PI	76.67	76.67	76.67	76.67
	FRE > PI	23.33	23.33	23.33	23.33
	FRE = PI	0.00	0.00	0.00	0.00
VKIN	FRE < PI	66.67	70.00	76.67	76.67
	FRE > PI	30.00	30.00	23.33	23.33
	FRE = PI	3.33	0.00	0.00	0.00
VUIN	FRE < PI	76.67	76.67	76.67	76.67
	FRE > PI	23.33	23.33	23.33	23.33
	FRE = PI	0.00	0.00	0.00	0.00
Overall	FRE < PI	73.34	74.45	76.67	76.67
	FRE > PI	25.55	25.55	23.33	23.33
	FRE = PI	1.11	0.00	0.00	0.00

Table 6.1 Comparison of RMSD of Price Predictions for FRE and PI

The disparate predictions of the FRE and PI model regarding end-period allocations will now be used to compare their predictive abilities. For this second group of markets the FRE model predicts that both the informed and uninformed traders in trader type 1, 2 and 3 will hold the assets when the state of nature is X, Y and Z, respectively. As with the FRE equilibrium price predictions, the model's end-period allocations are not effected by the move from a perfect to imperfect information structure. In contrast, the PI model's predictions are dependent upon the information structure, because they are dependent upon the private information messages that individual traders receive. For the imperfect information structure utilised in this second group of markets the PI model predicts that informed type 3 traders receiving the 'Not Y' clue will hold the assets in states X and Z, and that informed type 3 traders receiving the 'Not X' clue will hold the assets in state Y. The two models can, therefore, be evaluated based on a comparison of the number of assets misallocated when compared to their equilibrium predictions[39]. It must again be recognised that the PI equilibrium requires a greater number of trades than the FRE equilibrium. If no trade took place in a given period then the number of assets misallocated according to the FRE model would be 16 (as is the case in the first group of markets) whereas the corresponding figure for the PI model would now be 22. Only one type 3 trader will receive the clue card identified above that corresponds to the PI prediction. Again, caution must be exercised when comparing misallocations so as not to succumb to any bias that his would introduce. The ∂ measure introduced in Chapter Five is again used to avoid such bias, with one slight modification. The size of the indiscriminate region is increased to $0 \leq \partial \leq 6$, within which the two models are deemed to have tied. If $\partial < 0$ in a given period then this taken as an observation in support of the PI model (FRE>PI). If $\partial > 6$ in a given period then this is taken as an observation in support of the FRE model (FRE<PI). As displayed in Table 6.2, on average, the percentage of periods (number of observations equals 90) where the FRE model is superior to the PI model is 30.00%, as compared to 21.11% where the reverse is true. This is interpreted as providing weak support in favour of the predictive accuracy of the FRE model over the PI model. The evidence in favour of the FRE model may be further strengthened by the fact that in 8 of the periods the ∂ measure reaches positive double figures (obtaining a maximum of $\partial = 16$ in period 8 of VUIN1), whereas the measure reaches negative double figures in only 1 period (obtaining a minimum of $\partial = -14$ in period 9 of VUIN1).

[39] See Appendix 3 for an explanation of the FRE and PI end-period asset allocations.

Market	*Performance*	*Percentage Comparison (%)*
CKIN	FRE < PI	36.67
	FRE > PI	33.33
	FRE = PI	30.00
VKIN	FRE < PI	33.33
	FRE > PI	10.00
	FRE = PI	56.67
VUIN	FRE < PI	20.00
	FRE > PI	20.00
	FRE = PI	60.00
Overall	FRE < PI	30.00
	FRE > PI	21.11
	FRE = PI	48.89

Table 6.2 Comparison of Misallocation of Assets for FRE and PI

To summarise the results so far, the comparison of the RMSD of prices from the theoretically predicted equilibrium price predictions of the two models offers conclusive support in favour of the superiority of the predictions of the FRE model. Comparison of the number of assets misallocated provides weak support in favour of the FRE model and certainly can not be construed as evidence in favour of the PI model.

Two further measures of performance readily adopted in the experimental asset market literature can also be used to distinguish between the two competing models. The first of these is the measure of trading efficiency, %GAIN. Recall that, given the definition, the initial allocation of assets each period produces a %GAIN of 0% whereas the end period equilibrium allocation of the FRE model produces a %GAIN of 100%. Table 6.3 illustrates that the level of %GAIN exhibits a large degree of variability across the six markets, from a maximum of 100.00%, through 0% to a minimum of –50.00%. The average %GAIN observed in the CKIN, VKIN and VUIN markets are 16.81%, 13.33% and 10.63%, respectively.

Period	*CKIN1*	*VKIN1*	*VUIN1*	*CKIN2*	*VKIN2*	*VUIN2*
1	25.0000	-12.5000	18.7500	20.8333	20.8333	-2.0833
2	45.8333	8.3333	33.3333	-18.7500	-12.5000	6.2500
3	43.7500	37.5000	2.0833	18.7500	35.4167	27.0833
4	-12.5000	-31.2500	-25.0000	25.0000	25.0000	6.2500
5	56.2500	-12.5000	56.2500	0.0000	-25.0000	-6.2500
6	-50.0000	-6.2500	-18.7500	-18.7500	-37.5000	-25.0000
7	-43.7500	-6.2500	-6.2500	45.8333	31.2500	18.7500
8	56.2500	6.2500	68.7500	56.2500	50.0000	6.2500
9	68.7500	50.0000	29.1667	22.9167	62.5000	52.0833
10	50.0000	18.7500	43.7500	6.2500	56.2500	-16.6667
11	-31.2500	-25.0000	-37.5000	50.0000	100.0000	43.7500
12	-50.0000	-18.7500	-37.5000	37.5000	45.8333	-6.2500
13	77.0833	52.0833	52.0833	22.9167	47.9167	6.2500
14	50.0000	33.3333	47.9167	-12.5000	-43.7500	0.0000
15	-12.5000	-18.7500	-18.7500	-25.0000	-31.2500	0.0000
Mean	18.1944	5.0000	13.8889	15.4167	21.6667	7.3611

Table 6.3 Percentage of Gains from Trade Exhausted per Period

The low mean %GAIN figures could be interpreted as being more in favour of the PI model, because there is only one period where the %GAIN achieves the 100% prediction of the FRE model. However, consideration must also be given to the gains from trade to be exploited under the PI model, relative to the zero trade gains. These gains depend on the end-period equilibrium allocations of the PI model. Thus the PI gains from trade are state contingent and take the values of 1,200, -800 and 8,000 emus under the states X, Y and Z, respectively. Before continuing it must be recognised that the gains from trade under the FRE and PI models are equal when the state of nature is Z, because both predict type 3 traders to hold the assets. For this reason those periods where the state of nature is Z can not be used in the following comparative analysis. In 55.07% of periods (38 out of 69) the realised gains from trade are in excess of the predicted PI gains from trade. This is construed as weak evidence in favour of the FRE model, because the predicted FRE gains from trade are in excess of the predicted PI gains for the states X and Y. However, the fact that the PI model predicts a negative gain from trade under state Y can be exploited to provide excellent differentiation between the two models, because the FRE model predicts positive gains from trade under all three states of nature. For the 33 occurrences of the state Y across the six markets there were 29 occasions where the realised gains from trade were negative. Thus contrary to the earlier conclusion in favour of the

FRE model, this simple test provides strong evidence in favour of the PI model over the FRE model.

Finally, the performances of the FRE and PI models are evaluated by comparing the profit of the informed to that of the uninformed on a period by period basis. The FRE model would predict no difference in the average level of profit across the two kinds of traders, whereas the PI model would predict higher average profits of informed traders over uninformed traders. These predictions stem from the value of private information under the two models, which is zero and positive for the FRE and PI models, respectively. Table 6.4 contains the average profit of the informed and the uninformed, in emus, for all six markets. Across the six markets the mean informed profit figure of 654.4074 emus is only a little higher than the mean uninformed profit figure of 570.4578 emus, providing evidence more in line with the PI model than the FRE model. The difference in average profits is only slight, thus this only constitutes weak evidence against the FRE model and so is not construed as fatally condemning.

Market	*Informed*	*Uninformed*
CKIN1	695.1778	609.8222
CKIN2	646.2556	573.0111
VKIN1	587.3333	539.8889
VKIN2	695.0000	584.9267
VUIN1	704.4333	578.3444
VUIN2	598.2444	536.7533
Mean	654.4074	570.4578

Table 6.4 Average Profit of Informed and Uninformed Traders

In conclusion, the evidence from this comparative analysis appears a little mixed. A comparison of the RMSD of prices from the equilibrium price predictions of the two models offers strong support in favour of the superiority of the predictions of the FRE model. Comparison of the number of assets misallocated, however, only provides weak support in favour of the FRE model, but certainly can not be construed as evidence in favour of the PI model. In contrast, a simple test based on sign of the predicted gains from trade when the state of nature was Y, provided fairly condemning evidence against the superiority of the FRE model. In the presence of increased state uncertainty due to imperfect information the FRE model does not dominate the PI model on most comparative measures as it did when the information structure was perfect (see Chapter Five).

6.4.3 Impact of Period Duration on Market Behaviour

The analysis in this subsection is concerned with an evaluation of the impact of VK and VU period duration on the trading behaviour observed in experimental asset markets incorporating an imperfect information structure. As with the investigation in the previous chapter, the analysis will be conducted relative to the benchmark provided by the FRE model. The discussion begins with a preliminary investigation of observed market performance by way of graphical representation, for which the unadjusted raw data is sufficient. The analysis concludes with a direct evaluation of the stated hypotheses (see Chapter Five) and incorporates the data adjusted to remove dependence and the influence of extreme observations. The use of the acronym RMSD in the discussion to follow will always refer to the root mean squared deviation of transaction prices where the mean is in fact replaced by Andrew's M-estimator.

The preliminary analysis begins by comparing the volume of trade per period across markets to observe the influence of period duration. So as to control for the disparate period durations across the six markets the NORMVOL measure defined in Chapter Five is once more used for the comparisons to avoid any bias due to the duration of trade in each period. Figures 6.7-6.8 graph the normalised volume of trade per period for the markets grouped by parameter design. Comparison of the NORMVOL measure for the CKIN markets with either the VKIN or VUIN markets does not provide any clear interpretation. The NORMVOL measure for CKIN markets is fairly erratic, sometimes higher and sometimes lower than the measure for the other two market types, with a mean of 0.04666. Comparison of the VKIN and VUIN markets is equally uninformative. The NORMVOL measure for VKIN exceeds that for VUIN in 15 of the 30 periods, whilst the reverse is true in 9 periods. The mean NORMVOL of 0.0420 for VUIN markets is marginally smaller than the value of 0.0450 for VKIN markets. This preliminary analysis of the influence of period duration on the rate of trade observed does not offer any clear interpretation. The results from a formal statistical test for significant differences in the mean values of the NORMVOL measure across CKIN, VKIN and VUIN markets will be reported shortly, upon the completion of the preliminary analysis. In the meantime preliminary consideration is given to the prices at which assets trade and the deviation of these from the FRE predicted values.

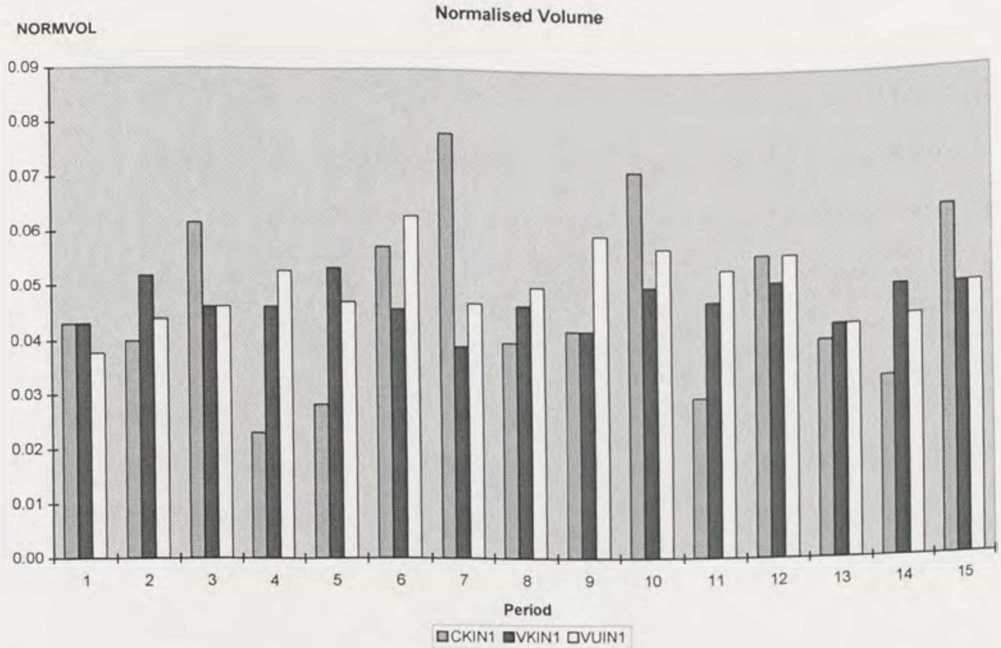


Figure 6.7 Normalised Volume of Trade per Period – IN1 Markets

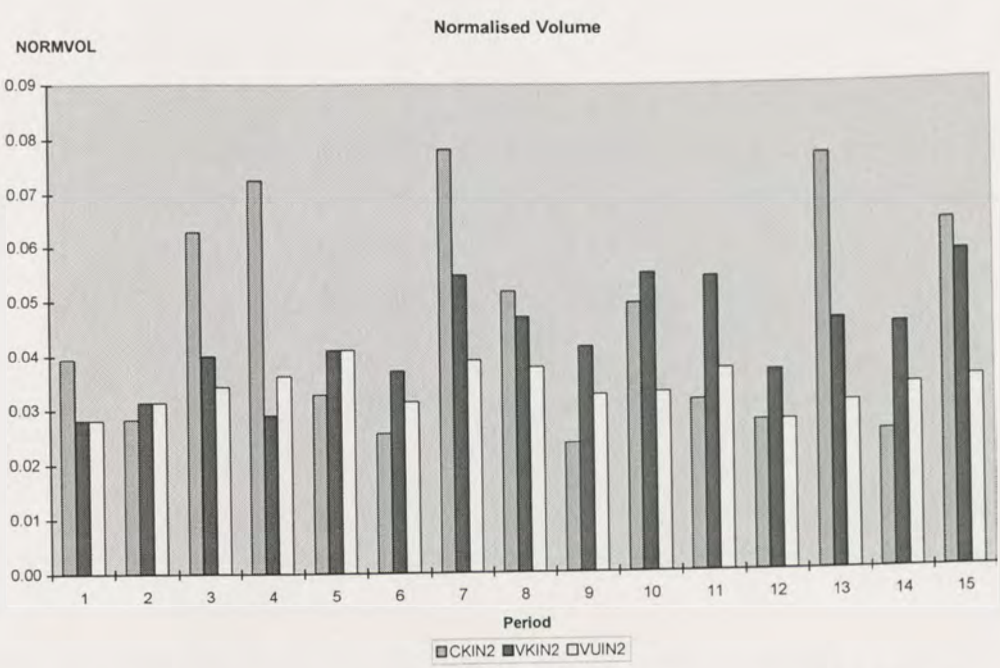


Figure 6.8 Normalised Volume of Trade per Period – IN2 Markets

Figures 6.1-6.6 display the sequence of transaction prices per period for each of the six markets. Evidence of the convergence of prices to the FRE price is marginal at best in the early periods of any of the markets. In fact, in some early periods, particularly for the VKIN and VUIN markets, the sequence of transaction prices exhibit a tendency to diverge from the FRE price. Period 4 of market VUIN2 provides an example of such a tendency. The volatility of prices in the markets are markedly different even across markets from the same period duration type. This is particularly evident for the VKIN markets, with VKIN1 exhibiting a far higher volatility throughout the 15 periods, which shows little sign of abating. In contrast, VKIN2 prices show much less volatility even in early periods, with only the occasional price deviating significantly from other prices in the same period. A similar, though not as marked, difference in observed volatility is apparent for the CKIN markets. The VUIN markets, however, both generate similar levels of volatility that are only exceeded by VKIN1 and that are present in most of the early trading periods. There is a slightly improved tendency towards the FRE price in the later periods of some markets, particularly CKIN2 and VKIN1. No market, however, could be said to exhibit a high degree of convergence to the FRE price. In all markets, with the exception of VKIN1, the assets trade within a fairly narrow range of prices and show little sign of responding to the state of nature. CKIN1 provides the best example of this failure to recognise changes in the state. Despite this there are many periods where the sequence of transaction prices tend to cluster around the FRE price and on most occasions where this is not the case the transactions cluster around prices that are closer to the FRE equilibrium than the PI equilibrium (state of nature Z is the exception).

In an attempt to better see the convergence of transactions to FRE prices the Figures 6.9-6.10 illustrate the RMSD of prices per period, computed using the Andrew M-estimator, for the three markets grouped by parameter sets. Unfortunately these functions are fairly erratic with the market type with the highest/lowest RMSD changing on a regular basis from period to period. It is very difficult, therefore, to draw any conclusions concerning the impact of period duration on the informational efficiency of the experimental markets simply from a graphical representation of the data. The only striking observation to be drawn concerns the failure of all market types to react to state of nature Z, the occurrence of which corresponds to all the peaks in RMSD displayed in the two figures. A more comprehensive investigation by way of statistical testing is required to determine if any effect of period duration is present. The results of such an evaluation are reported after the preliminary investigation is concluded. Preliminary investigations of the trading efficiency and the profits earned by informed and uninformed traders are now considered.

The %GAIN measure was used to compare the trading efficiency across market types. The measure was normalised to control for disparate period durations, giving the measure NORM%GAIN. The Figures 6.11-6.12 display the NORM%GAIN figures per period for each market, grouped by parameter design. The NORM%GAIN figures for all three market types are very erratic and display no obvious pattern. On 11 occasions out of the 30 periods the CKIN markets generate the highest, or least negative, NORM%GAIN measure. The corresponding figures for the VKIN and VUIN markets are 9 and 5, respectively, with the remaining 5 periods witnessing ties between two markets. The CKIN markets seem to generate a slightly higher level of NORM%GAIN than the VKIN markets and a much higher level compared to the VUIN markets. This is evidenced by the higher mean NORM%GAIN of 0.0700 for the CKIN markets (aggregated across parameter sets) compared to the values of 0.0671 and 0.0394 for the VKIN and VUIN markets, respectively. It appears that on average the level of trading efficiency attained is lowest under the VUIN markets. Whilst it is not possible to draw any decisive conclusions from this analysis, it seems that varying the period duration reduces trading efficiency and that removing knowledge of the period duration reduces the level of efficiency attained still further.

The mean %GAIN values of 16.81, 13.33 and 10.63 for CKPN, VKPN and VUPN markets, respectively, can be investigated more closely to separate the efficiency loss between either a *missed trade* or an *error trade*. The mean percentage efficiency loss associated with missed and error trades are reported in Table 6.5. For four of the markets the mean efficiency loss figures for error trades exceed those for missed trades, indicating that in these markets efficiency losses are predominantly the result of error trades. It is difficult to conclude from this analysis how, if at all, period duration impacts upon the manner in which the efficiency losses arise.

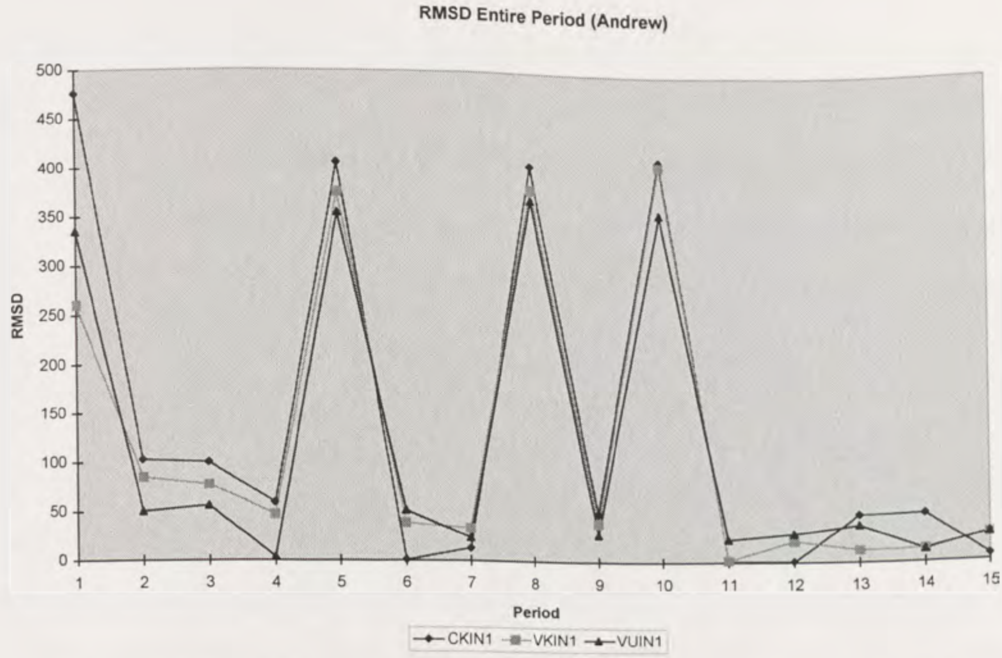


Figure 6.9 Root Mean (Andrew) Squared Deviation of Transaction Prices per Period – IN1 Markets

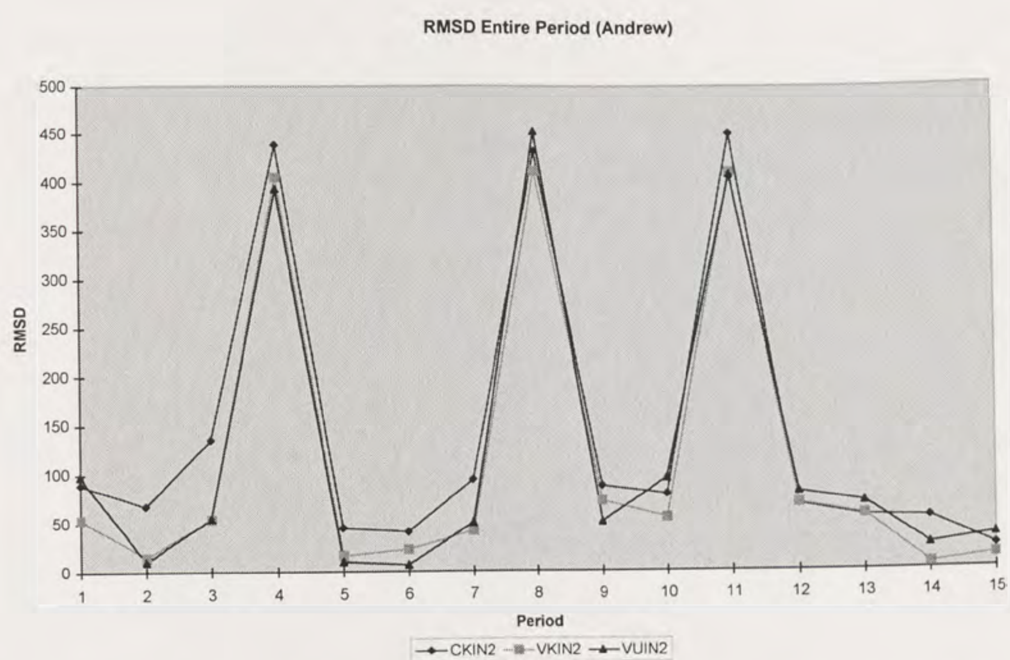


Figure 6.10 Root Mean (Andrew) Squared Deviation of Transaction Prices per Period – IN2 Markets

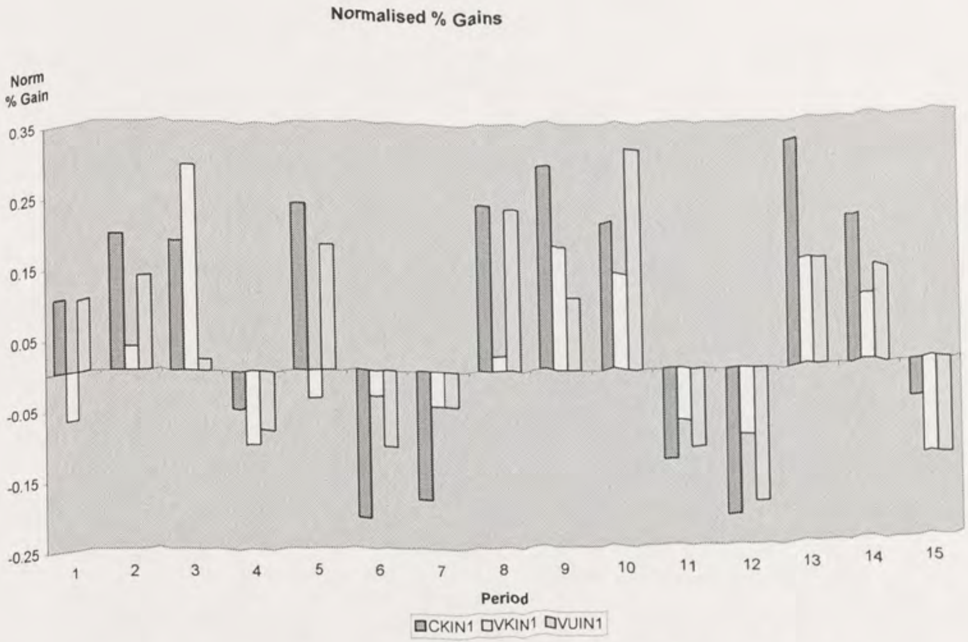


Figure 6.11 Normalised Percentage Gains from Trade – IN1 Markets

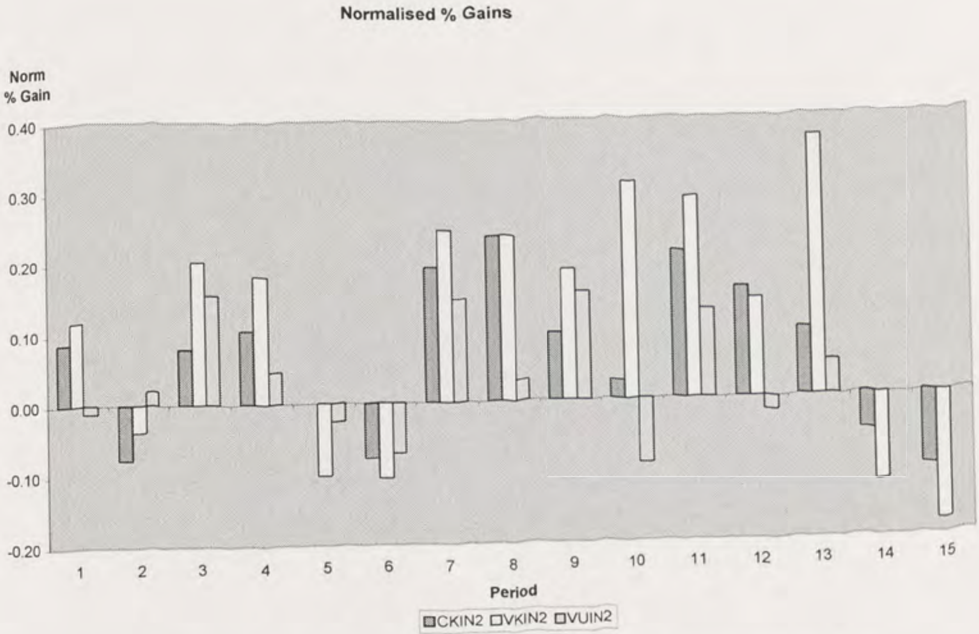


Figure 6.12 Normalised Percentage Gains from Trade – IN2 Markets

Market	Percentage of Efficiency Loss	
	Missed Trades	Error Trades
CKIN1	45.41%	54.59%
CKIN2	51.02%	48.98%
VKIN1	48.17%	51.83%
VKIN2	44.77%	48.56%
VUIN1	41.11%	58.89%
VUIN2	52.83%	47.17%

Table 6.5 Mean Percentage of Efficiency Losses due to Missed and Error Trades

The final preliminary analysis of trading behaviour incorporates a comparison of the average profits earned by informed and uninformed traders on a period by period basis. The FRE model in its strictest interpretation would predict no difference in the average profits of the two groups of traders. Figures 6.13-6.14 display the difference between the average profit of the informed and uninformed traders for each of the markets on a period by period basis. A positive observation indicates excess informed profits and a negative observation indicates excess uninformed profits. The functions from all six markets exhibit very little by way of trend, thus, it is difficult to draw strong inferences from the two figures. A comparison of the number of periods in which a particular market type generates the largest (positive) difference between the average profit of the informed and uninformed reveals values of 6, 9 and 11 for market types CKIN, VKIN and VUIN, respectively. The weak interpretation that can be drawn from this comparison is that the VUIN markets exhibit a slightly lower level of trading efficiency than the other markets. Introducing varying period durations to the experimental design reduces trading efficiency, but incorporating uncertain period durations reduces the level still further.

The results of a more comprehensive investigation of the impact of period duration on market behaviour by way of formal hypotheses testing will now be reported. The analysis of the stated hypotheses begins with a brief commentary of the Figures 6.15-6.16, which display the three measures for the volume of trade early in a period (VOL45,60,90) for the markets grouped by parameter design. This is followed by a commentary of the Figures 6.17-6.18, which graph the three measures of RMSD early in a period (RMSD45,60,90). The analysis concludes by reporting and interpreting the statistical significance levels for the rejection of the null hypotheses ($1H_O$, $2.1H_O$, $2.2H_O$, $3.1H_O$ and $3.2H_O$).

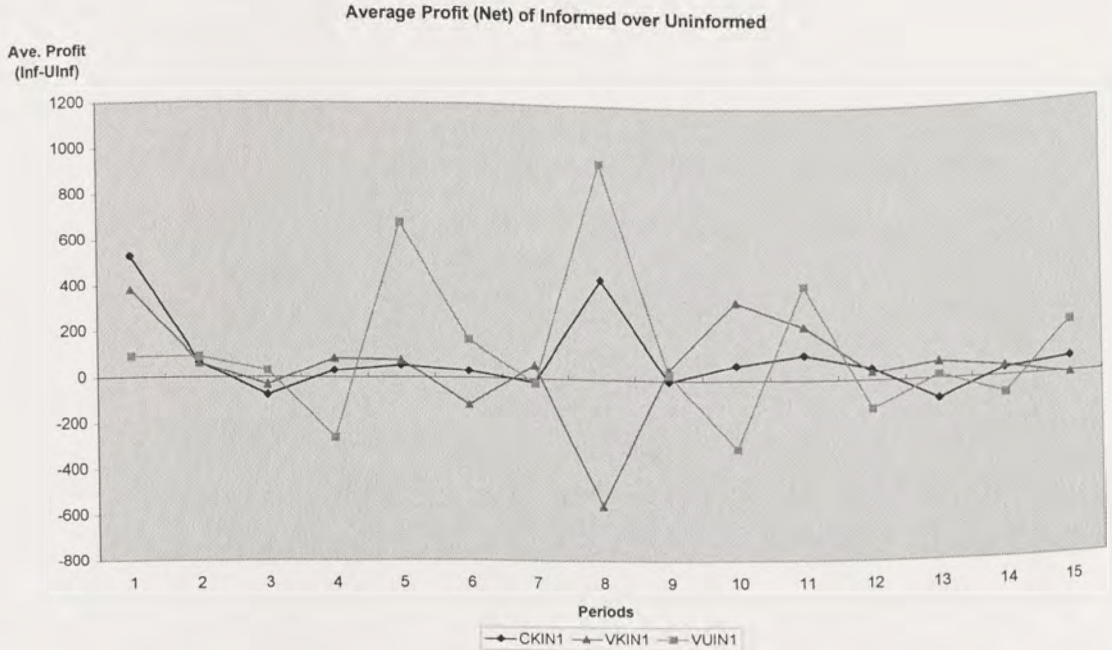


Figure 6.13 Difference between the Average Net Profit of Informed and Uninformed Traders per Period – IN1 Markets

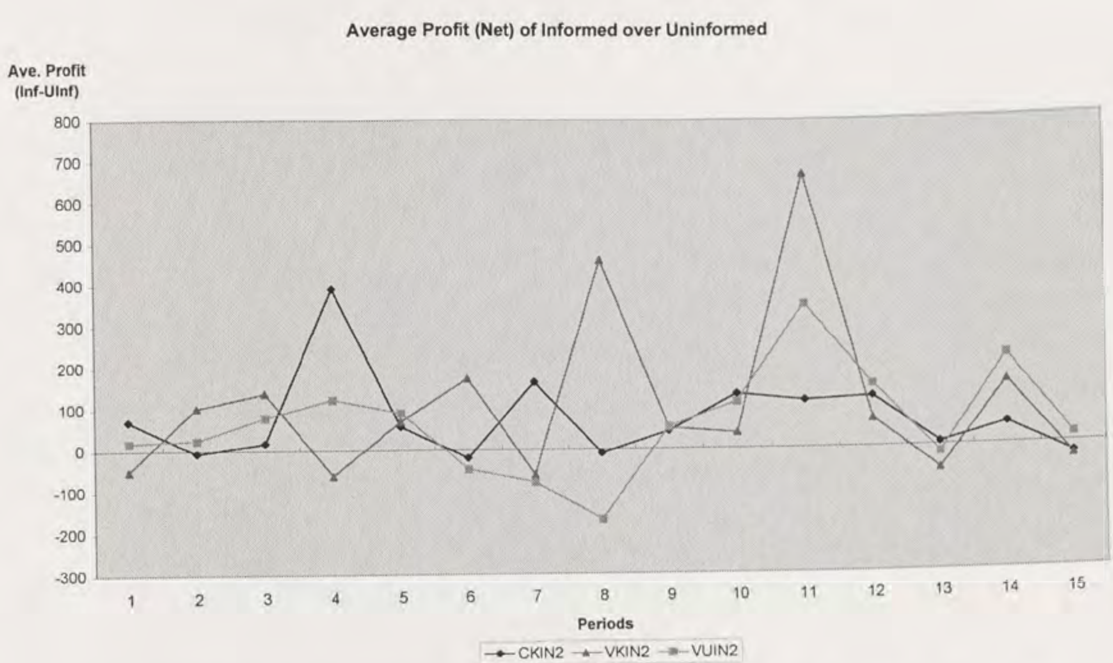
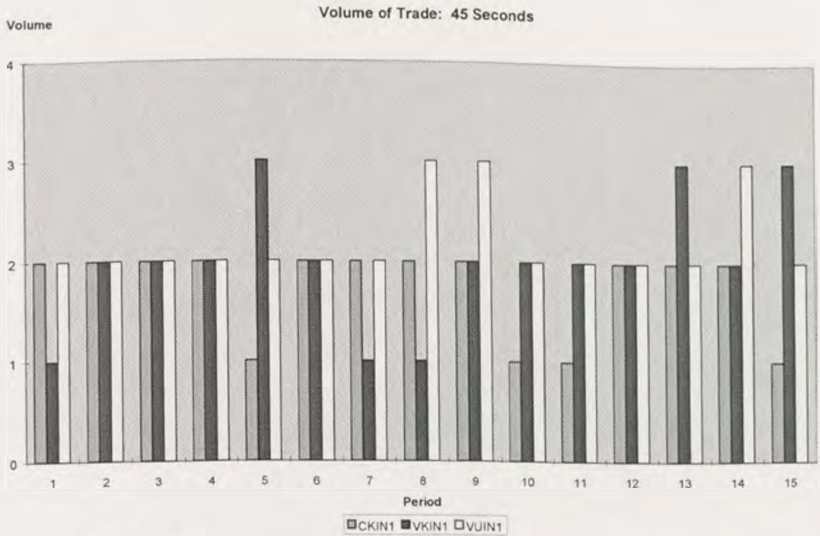


Figure 6.14 Difference between the Average Net Profit of Informed and Uninformed Traders per Period – IN2 Markets

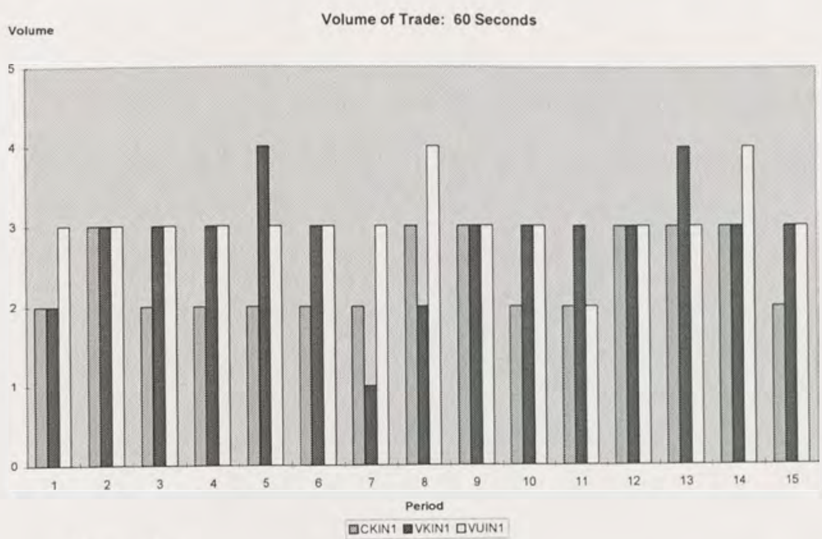
For all three measures of 'early', in most of the periods the volume of trade is highest, or joint highest, in the VKIN and/or VUIN markets. Aggregated across the three measures of early, the volume of trade in the VKIN markets is the highest volume (excluding ties) in 22 of the 90 periods. The corresponding values for the CKIN and VUIN markets are only 5 and 16, respectively. A graphical interpretation of the data supports the belief that the volume of trade, early in a period, is influenced by both varying period durations and uncertain period duration, with both resulting in higher volumes of trade early in a period relative to the control provided by the CKIN markets. Unlike the results in the previous chapter the volume of trade in the VU markets is below that observed in the VK markets. For the VU markets the additional uncertainty surrounding imperfect information, coupled with the uncertainty over period duration, results in a such a high level of uncertainty that trade early in a period is reduced relative to the VK markets, in which the level of uncertainty faced is less.

The erratic nature of the RMSD for all three market types (Figures 6.17-6.18), for all three measures of early in a period make it very difficult to draw any strong conclusions regarding the impact of period duration on the RMSD early in a trading period. The use of the Andrew's M-estimator as a replacement for the simple arithmetic mean suggests that the erratic behaviour of these functions is not due to the influence of outliers. The only obvious interpretation from the data concerns the inability of all six markets to react to the state of nature Z. The failure to draw any strong inferences of the influence of period duration on observed market behaviour from simple graphical representation necessitates a more formal approach. The investigation, therefore, will now turn to an explicit statistical evaluation of the stated hypotheses.

Panel A



Panel B



Panel C

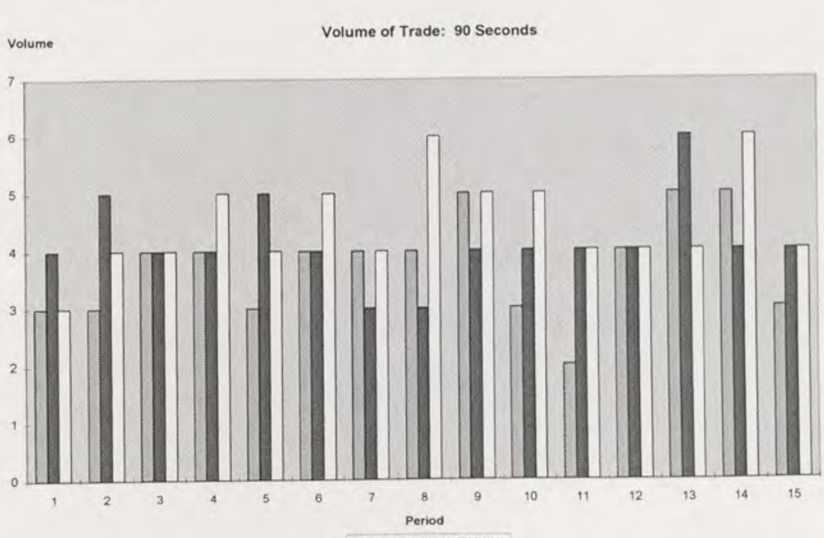
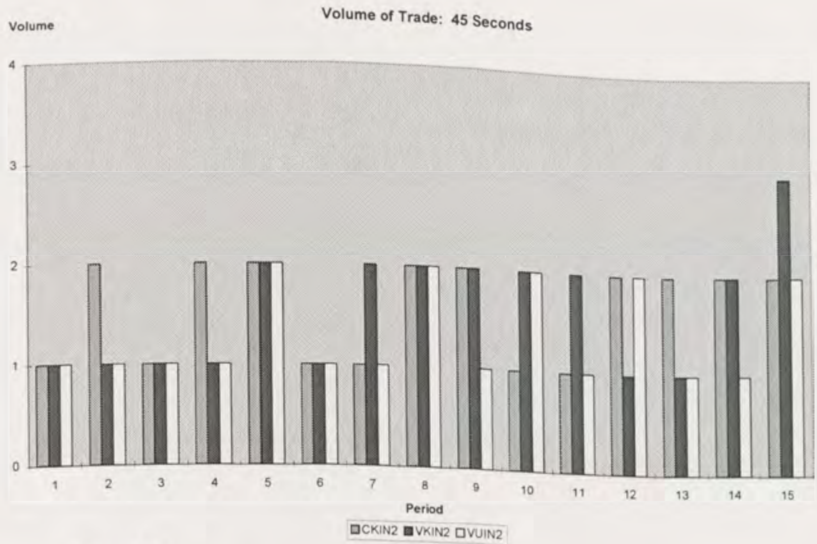


Figure 6.15 Volume of Trade in the First 45, 60 and 90 Seconds of Trade – IN1 Markets

Panel A



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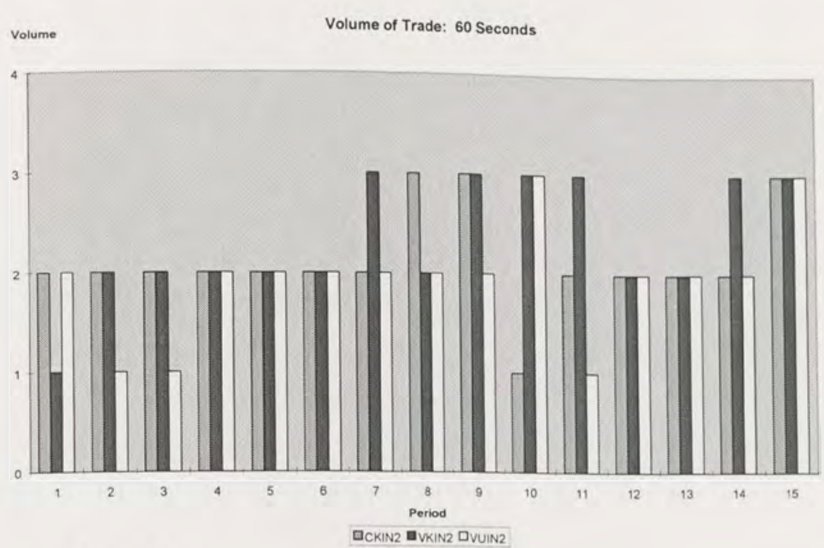

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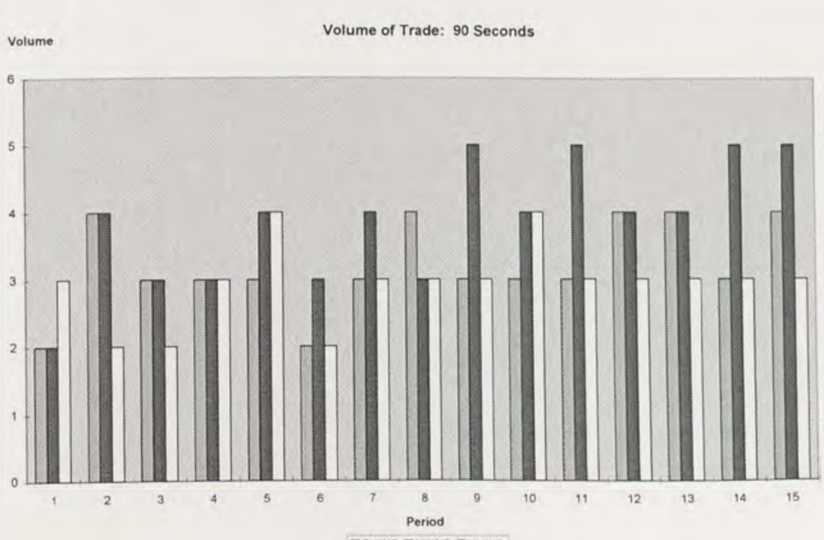
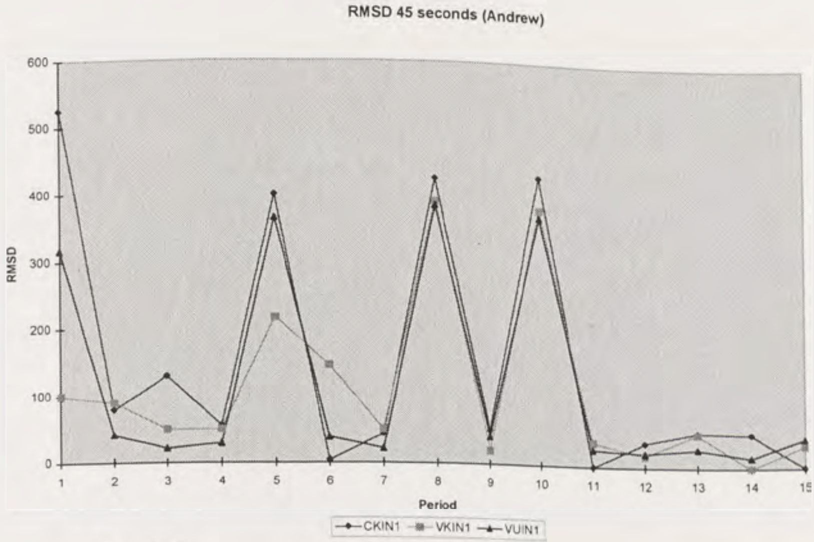
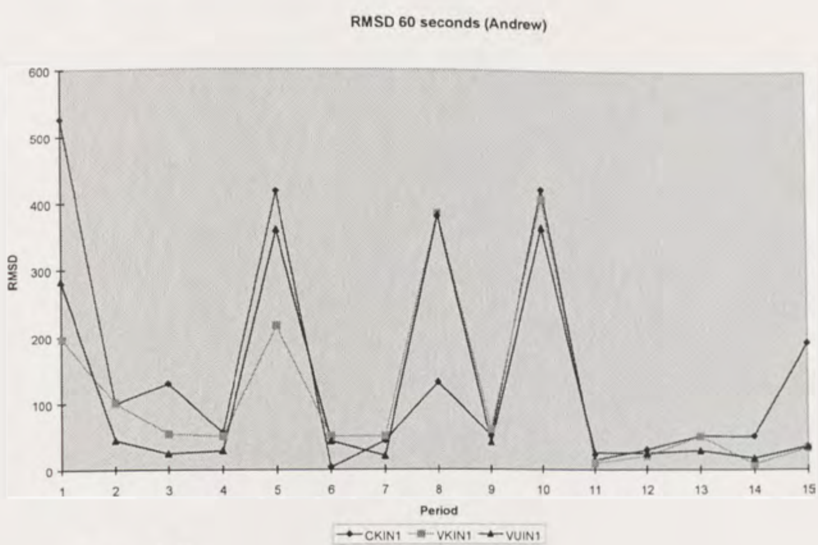


Figure 6.16 Volume of Trade in the First 45, 60 and 90 Seconds of Trade – IN2 Markets

Panel A



Panel B



Panel C

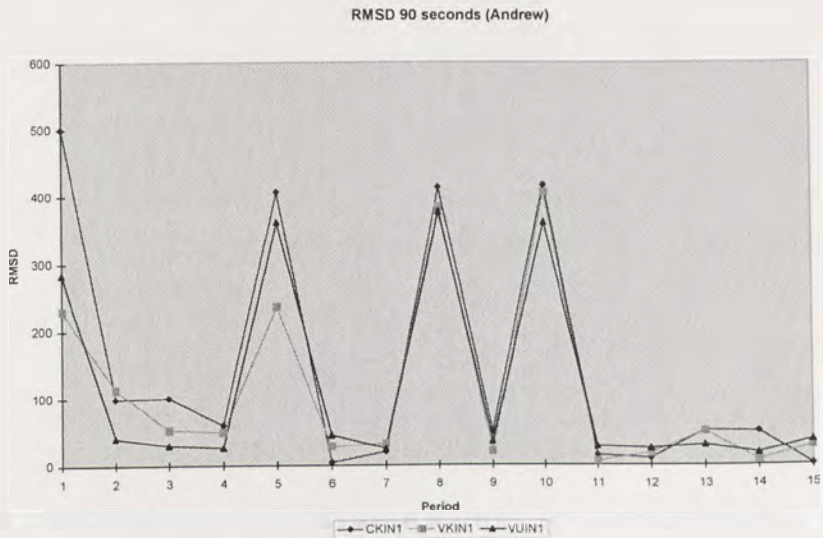
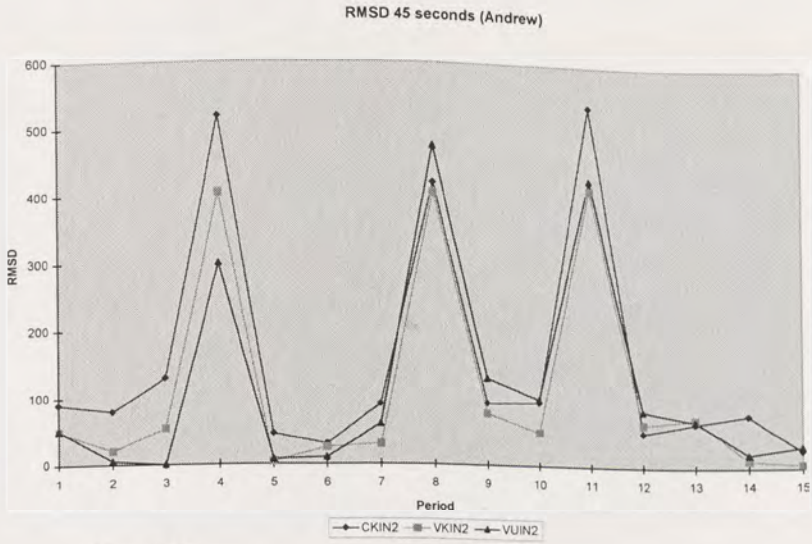


Figure 6.17 RMSD of Prices in the First 45, 60 and 90 Seconds of Trade – IN1 Markets

Panel A



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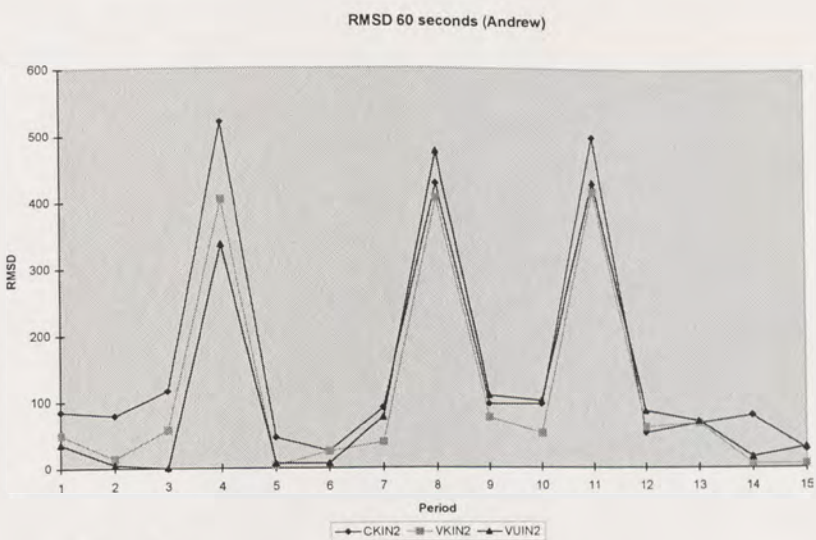

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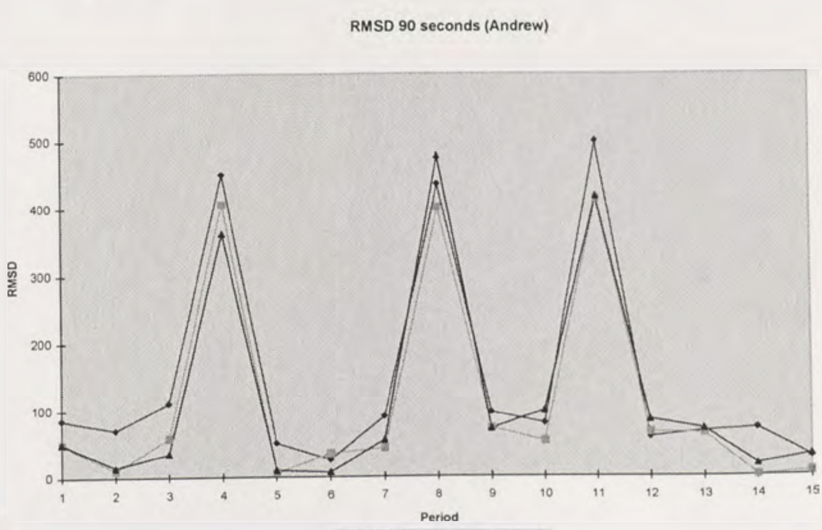

Figure 6.18 RMSD of Prices in the First 45, 60 and 90 Seconds of Trade – IN2 Markets

Table 6.6 reports the level of statistical significance for which the null hypotheses of no statistical difference in mean values across the two paired markets can be rejected. Attention is once more drawn to the fact that the data used in the following statistical tests has been adjusted in order to remove the intra-market dependence of observations across periods. For all the performance measures the figures reported are the means of the unadjusted values, across all trading periods. For each variable, the figure in parentheses reports the mean of the adjusted values. The Wilcoxon signed ranks test (WSR) was used to compute two-tail significance levels, based on 30 paired observations, for the comparisons between the three market types. Recall, from Chapter Five, that the CKIN:VUIN comparison confounds the effects of both varying period durations and uncertain period durations. The two effects can be isolated and analysed separately via the CKIN:VKIN and VKIN:VUIN comparisons. The results of the CKIN:VUIN comparisons will not be discussed directly. The remainder of this section will consider separately the impact of period duration on the volume of trade early in a period, the informational efficiency and the overall allocational efficiency of the experimental markets CKIN, VKIN and VUIN.

Variable	*Market Means (Adjusted Means)*			*WSR Two-tail α-values*		
	CKIN	*VKIN*	*VUIN*	*CKIN: VKIN*	*CKIN: VUIN*	*VKIN: VUIN*
VOL45	1.6667 (1.6511)	1.8000 (1.9715)	1.7667 (1.8664)	0.0117	0.0058	0.0207
VOL60	2.2667 (2.2332)	2.6000 (2.8193)	2.5000 (2.5925)	0.0002	0.0141	0.0062
VOL90	3.4667 (3.4589)	4.0000 (4.1870)	3.7000 (3.9186)	0.0053	0.0098	0.2655
NORMVOL	0.0466 (0.0478)	0.0450 (0.0475)	0.0420 (0.0434)	0.7971	0.4653	0.0645
RMSD45	154.4757 (144.7697)	110.7323 (125.0514)	117.8292 (126.5157)	0.0545	0.2059	0.7189
RMSD60	150.3773 (132.4749)	112.2919 (120.9447)	116.9566 (127.8973)	0.1204	0.5716	0.5038
RMSD90	146.8968 (136.9056)	111.3953 (117.2604)	117.4065 (125.6091)	0.0230	0.0822	0.2452
RMSD	142.7678 (132.6657)	117.3947 (124.8817)	119.9761 (124.7529)	0.1717	0.1156	0.8774
NORM%GAIN	0.0700 (0.0839)	0.0671 (0.0834)	0.0394 (0.0524)	0.9590	0.1180	0.3812

Table 6.6 Summary Table of Market Means (Adjusted Means) and Wilcoxon Signed Ranks Test Two-tail Significance Levels

Volume of Trade

For all three measures of the volume of trade early in a period (VOL45,60,90) the VKIN markets generate a significantly higher mean volume than the CKIN markets (α=0.0117, 0.0002 and 0.0053, respectively). This would suggest that for the VKIN markets the short durations in some trading periods may have made traders more eager to trade early in a period, in order to avoid the disappointment of missing out on profitable trades. The average period duration is equal across the two market types, however, so such an effect would be expected to be cancelled out by the opposite effect in periods where the duration was in excess of the 240 seconds experienced in the CKIN markets. Why this should not be the case is not clear. Taken over an entire trading period though, the mean rate of trade (NORMVOL) does not differ significantly across the two market types, suggesting that, on average, the impact of short and long period durations in VKIN markets cancel out. Of greater interest is the comparison of the measures of volume of trade across the VKIN:VUIN comparison. Such a comparison isolates the impact of uncertainty concerning period duration on the volume of trade observed in experimental asset markets. For VOL45 and VOL60 VUIN exhibits a significantly lower volume of trade than the VKIN markets (α=0.0207 and 0.0062, respectively). Thus, it is possible to reject $1H_0$ for these two measures of early in a trading period. By the time 90 seconds of trade have passed the mean VOL90 value for VUIN markets is still higher than that for the VKIN markets, but there is no longer a significant difference. The same is true for the volume of trade across an entire period, NORMVOL. It is possible that the 90 second measure of early in a trading period does not in fact constitute 'early' in many of the trading periods. For example, the overall duration in some trading periods is as low as 128 seconds (see Chapter Four, Table 4.3) and so 90 seconds constitutes approximately 70% of the total time available to trade. This is clearly not early in such periods. For this reason then, the result of insignificant difference in mean VOL90 values across the two market types is given less emphasis than the other two measures of early. It can be concluded, therefore, that in markets incorporating imperfect information structures the uncertainty regarding period duration results in a reduction in the volume of trade observed early in a period. The market's response to the increased uncertainty faced in the VUIN environment, in the presence of uncertainty regarding the state of nature due to the imperfect information structure, is to become more cautious and so trade less aggressively early in a period, relative to the less uncertain environment of VKIN. Recall that this is the reverse of the findings in the previous chapter where the markets incorporated perfect information structures. This would suggest that in simpler environments (perfect information) the uncertainty surrounding period duration causes more aggressive trading behaviour, whilst in more complex environments (imperfect information) it results in more cautious trading behaviour. This issue will be considered further in the holistic analysis of Chapter Eight.

Informational Efficiency

The issue of interest now is how, if at all, the reduction in the volume of trade early in a period in VUIN markets impacts on the level of informational efficiency attained by these markets. It is conceivable that the reduced volume of trade will slow the convergence of prices to the FRE equilibrium. Alternatively the more cautious approach to trade may mean fewer disequilibrium trades, therefore, less noise in the price signal and so consequently an increase in the informational efficiency of these markets.

The investigation begins with an evaluation of hypothesis $2.1H_O$ to determine the extent of any difference in transaction prices across the markets VKIN and VUIN. As reported in Table 6.6, for the three measures of early in a trading period, the mean RMSD, whilst being higher in the VUIN markets, does not differ statistically across the two market types. For the measures RMSD(45,60,90) the two-tail significance levels are all $\alpha>0.05$ and the null hypothesis of no statistical difference ($2.1H_O$) can not be rejected. Thus, the lower early volume of trade in the VUIN markets does not impact on the level of informational efficiency attained early in a period, relative to the informational efficiency of the VKIN markets over the same time periods. As a result, it would make no sense to formally evaluate hypothesis $2.2H_O$, because no *difference* exists in the RMSD of early prices from the FRE model.

The VKIN and VUIN markets were further compared to see if any difference existed between the RMSD of prices over an entire trading period. Table 6.6 reports an unadjusted mean RMSD of 119.9761 emus for the VUIN markets that is greater than the value of 117.3947 emus for the VKIN markets, but not significantly ($\alpha=0.8774$ calculated using a two-tail WSR test on the adjusted data). This result indicates that, over an entire trading period, the level of informational efficiency observed in the VUIN markets relative to the VKIN markets is not influenced by uncertainty concerning period duration. These results, therefore, offer no support for Friedman's (1984) view that a predetermined, known trading period duration is one of a number of features that enhances the informational efficiency of experimental markets incorporating imperfect information structures.

The comparison of the VKIN and VUIN markets provided the strictest test of the impact of uncertainty concerning period duration on market behaviour. A further comparison between the CKIN and VKIN markets offers insight into the influence of varying the period duration on the RMSD observed early in a trading period. The results are mixed. The mean RMSD45 and RMSD90 measures for the VKIN markets are statistically lower than the corresponding measures for the CKIN markets (α=0.0545 and α=0.0230, respectively). The RMSD60 and RMSD measures, however, do not differ statistically. For some measures, therefore, the level of informational efficiency observed in the VKIN markets is higher relative to the CKIN markets. It remains to be seen whether this can be related to any differences in the volume of trade early in a period.

Recall that the three measures of volume early in a period were all significantly higher under the VKIN markets than the CKIN markets. The correlation coefficient of 0.1804 between the *difference* in VOL45 and the *difference* in RMSD45 across the markets is insignificant (α=0.520). The correlation coefficient of 0.0884 between the *difference* in VOL90 and the *difference* in RMSD90 across the markets is also insignificant (α=0.754). In light of the reported results for the correlation coefficients, it would be impossible to argue that the higher volume early in a period impacts in any comprehensive manner on the RMSD early in a period. It would also be problematic to explain why there is no difference in the RMSD60 measure across the CKIN and VKIN markets.

Allocational Efficiency

In this final analysis it remains to determine the impact of the two treatments (VK and VU) on the level of allocational efficiency observed in the experimental asset markets studied. The analysis fails to reject the null hypothesis (3.1H_0, α=0.3812) of no statistical between the mean NORM%GAIN of 0.0671 for the VKIN markets and 0.0394 for the VUIN markets[40]. Thus, whilst the increased uncertainty experienced due to the lack of knowledge concerning period duration results in a far lower mean NORM%GAIN figure, this reduction is not statistically significant and so it is not possible to claim any impact on the relative level of allocational efficiency. It is, therefore, not necessary to formally evaluate hypothesis $3.2H_0$ for the VKIN:VUIN comparison. Similar insignificant results are reported for the other CKIN:VKIN and CKIN:VUIN comparisons. It can be concluded, therefore, that the treatment effects of varying period duration and uncertain period duration neither separately nor jointly impact on the level of allocational efficiency observed in experimental asset markets with imperfect information structures.

6.5 Discussion and Conclusions

After reviewing the evidence on the effect of imperfect information structures reported in previous experimental studies, the chapter proceeded to explain the specifics of the experimental design utilised for the six markets investigated in this chapter. The discussion then moved on to report and discuss the results of the analysis conducted. It is to a review of these results that the discussion in this final section now turns.

Initially a comparative analysis was conducted to determine if either the FRE or PI models generated superior predictive accuracy. The two models were evaluated against a number of different performance measures. First, the RMSD of prices from the disparate theoretically predicted equilibrium prices of the two models were compared. Over all six markets the RMSD of transaction prices from the FRE price, over the entire trading period, was below that for the PI model in 76.67% of periods. This was interpreted as providing strong support for the superiority of the FRE model. This was followed by a comparison of the number of assets misallocated relative to the two models' predictions regarding end-period allocations. The number of misallocations under the FRE model were less than those for the PI model in 30% of periods, whilst the reverse was true for 21.11% of periods. The difference in the number of assets misallocated for the remaining 48.89% of periods fell within an indiscriminate region, $0 \leq \partial \leq 6$. The evidence weakly supported the FRE model

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[40] Note that the unadjusted means are reported in the discussion, but that it is the adjusted data that is used to compute the statistical significance levels.

over the PI model. Thirdly, a measure of the percentage gains from trade exploited was used to discriminate between the competing models. Relative to the initial allocation of assets, the predicted end-period allocations of the FRE and PI models predict positive and negative gains from trade, respectively, when the state of nature is Y. Of the 33 occurrences of the state Y there were 29 periods where the gains from trade were negative, providing strong support for the predictive accuracy of the PI model over the FRE model. Finally, a comparison of the average profit earned by informed traders relative to uninformed traders was undertaken. On average, there was only a small difference between the two figures. This was construed as weak evidence against the strictest interpretation of the FRE model, in which the price signal reveals private information instantaneously, and so was not considered fatally condemning.

The asset markets conducted in this chapter represent a more complex trading environment than those investigated in Chapter Five. The implication of this increased complexity and uncertainty seems to be a weakening of the superiority of the FRE model over the PI model. The former offers better predictions of equilibrium asset prices, whilst the later predicts observed trading efficiency (%GAIN) more accurately. The weakening of the superiority of the predictive accuracy of the FRE model in markets with imperfect information structures is in line with the findings of earlier experimental studies such as Plott and Sunder (1988) and Forsythe and Lundholm (1990).

The second stage of the investigation was a relative analysis of the impact of period duration on observed market behaviour. The effect was separated between the impact of varying period durations (CKIN:VKIN) and the impact of uncertainty concerning the period durations (VKIN:VUIN). Varying the period durations resulted in a significant increase in the volume of trade early in a period. By the end of the period, however, there was no significant influence on the rate of trade. There were mixed results regarding the effect on the deviation of transaction prices from the FRE price. For two of the measures of price deviation early in a period, RMSD45 and RMSD90, varying the period duration resulted in a lower deviation. No significant effect was found, however, for the measures RMSD60 or RMSD over the entire trading period. It is difficult to conclude decisively, therefore, that the higher volume of trade early in a period impacted in any comprehensive manner on the observed informational efficiency. There was no significant impact of varying the period duration on the overall level of allocational efficiency observed in the experimental markets.

Uncertainty concerning the period durations had a mixed effect on observed market behaviour. There was a significant reduction in the volume of trade for two of the measures of early, VOL45 and VOL60. This is in stark contrast to the evidence to the contrary reported in Chapter Five. The increase in the level of uncertainty faced as a result of imperfect information regarding the state of nature together with uncertainty surrounding the period duration appears to make traders more cautious about trading. There is little impact, however, of this caution on the level of informational or allocational efficiency achieved in the VUIN markets relative to the VKIN markets. The evidence from experimental markets incorporating imperfect information structures fails to provide support for Friedman's (1984) suggestion that a predetermined, known period duration was a feature of experimental asset markets that enhanced the observed level of market efficiency.

In the context of the on-line auctions that have emerged with the growth of virtual communities the evidence reported in this chapter fails to offer any guidance concerning the choice of trading environment to be used to conduct trade across electronic networks. Complex trading environments characterised by imperfect private information appear to render the choice of fixed and known or uncertain period durations irrelevant. This is in contrast to the evidence from the previous chapter in which it was suggested that the presence on uncertain period durations would result in an increase in the volume of trade, but a reduction in the informational efficiency observed in on-line auctions. It seems that further evidence is required to guide the development of new business models for the conduct of trade in virtual communities across electronic networks.

In conclusion, the evidence from this chapter and the previous one regarding the impact of uncertain period durations on observed market behaviour, particularly volume of trade and informational efficiency, is far from conclusive. In particular, the evidence concerning the volume of trade early in a period is actually contradictory. Fortunately, the strength of the experimental method lies in the ability to replicate previous experiments. With this in mind the next chapter reports the results of six more experimental asset markets that essentially replicate the twelve studied so far. The only difference stems from the introduction of costly private information. Prior to trade in each period an information auction is conducted, with the six highest bidders receiving the private information. Three markets, one for each of the three period duration types (CK, VK and VU), are conducted with perfect information structures (group three) and three markets with imperfect information structures (group four). The introduction of an information auction is the only way that the group three markets differ from the group one markets and the group four markets differ from the group two markets. Therefore, these two additional groups of markets provide two more opportunities to investigate the impact of period duration on market behaviour.

Chapter Seven

7 Impact of Period Duration on Experimental Asset Markets with Information Auctions plus Perfect and Imperfect Information Structures

7.1 Introduction

The intention in this chapter is to provide additional evidence concerning the impact of period duration on the observed market performance in experimental asset markets. Collectively the results reported in the previous two chapters do not permit decisive conclusions to be drawn regarding the impact of both varying period durations and uncertain period durations, in isolation or jointly, on observed market performance. To this end six more experimental asset markets are conducted. Rather than simply replicating exactly the experimental design of the previous markets, the trading environment is slightly modified to permit another feature of experimental markets to be investigated. The new design feature incorporated in these markets is the inclusion of a pre-trade information auction. All six markets studied in this chapter include the information auction, therefore, it is still possible to investigate the impact of period duration on the performance of these markets whilst controlling for any confounding effects at the same time. Three markets, one for each of the three period duration types (CK, VK and VU), are conducted with perfect information structures (group three) and three markets with imperfect information structures (group four). With the exception of participants' experience levels, the introduction of an information auction is the only way that the group three markets differ from the group one markets and the group four markets differ from the group two markets. Thus, two additional layers are added to the overall experimental design (see Table 4.4, Chapter Four).

The inclusion of an information auction prior to trade in any period means that the allocation of private information becomes a process endogenous to the experimental markets themselves. This is in contrast to the markets in Chapters Five and Six in which the allocation was determined exogenously in advance by a random procedure. The competing models of theoretical equilibrium (FRE and PI) make disparate predictions regarding the value of private information. These disparate predictions provide another means with which to discriminate between the FRE and PI models and evaluate their predictive accuracy. The FRE model predicts that the value of private information is zero, whilst the PI model predicts that such information retains value. The inclusion of information auctions in the experimental design provides an additional measure of performance on which the predictive accuracy of the two models can be evaluated.

The incorporation of costly information acquisition is an additional facet of the experimental design that brings it more into line with the situation faced by traders in real world markets. The acquisition of private information generally involves some form of cost to the acquirer. Even if there is no financial cost associated with the purchase of information there will be some form of search cost in the form of an individual's time spent obtaining the information. The pre-trade information auctions, therefore, not only provide an additional performance measure for the evaluation of the FRE and PI models, but also bring the experimental design more in line with real world environments.

A break down of the structure of the chapter is now offered. The following section reviews the few experimental asset market studies that incorporate an information auction in their experimental design. Section 7.3 details the specifics of the design, not included in the earlier general experimental design chapter, for the markets, highlighting both how the markets differ to those in earlier chapters and how the similarities provide the necessary control for subsequent comparisons. Section 7.4 reports the results from the analysis of the experimental markets. A comparative (within market) evaluation of the FRE and PI models is performed first and includes the performance measurement based on the value of private information. The comparative analysis is followed by a relative (across market) evaluation of the impact of the treatment variable, both in terms of varying period durations and uncertain period durations. The final section contains a summary and discussion of the results.

7.2 Review of Relevant Literature

The majority of studies of experimental asset markets investigate the aggregation and dissemination of costless, asymmetrically distributed private information. The competing models of theoretical equilibrium make disparate predictions regarding the value of such private information. A small number of experimental studies have conducted markets that allow this method of discrimination to be exploited. The following discussion will review the results of these studies.

Copeland and Friedman (1992) extends on Copeland and Friedman (1987) by incorporating a pre-trade auction for information in which traders bid to receive their news message before each trading period opens. Messages are given anonymously to the three highest bidders, at the fourth highest bid price, in a uniform-price sealed-bid auction. Consequently, the identity of those traders who receive information is determined endogenously, this is in contrast with such studies as Plott and Sunder (1982, 1988) in which the identity is determined exogenously. In Copeland and Friedman's (1992) markets with simple environments, incorporating the simultaneous arrival of homogenous news messages, the market value of information declines and tends to zero over time. However, in the more complex setting of the of markets with heterogeneous news messages, the market value remains positive providing evidence in favour of the PI model.

Sunder (1992) is another study in which a market for information is conducted prior to trade in a period. Two different designs for the information auction were conducted. In Sunder's (1992) series A markets the supply of information is fixed at four traders with the price determined by the market (i.e. fifth highest bid price), whilst in the series B markets the price is fixed and the number of buyers is determined endogenously. Series A results show a decrease in the cross-sectional standard deviation of net profit and thus convergence to the equality of profit across traders over time. These results provide support for the FRE prediction that the price of information in equilibrium is zero and there is no difference between gross and net profit. The results of the series B markets are less supportive. The distribution of profit does not converge to the full revelation (FRE) benchmark even with experience and all market observables point towards the lower informativeness of the series B markets relative to series A. Despite this the net profit of informed and uninformed traders were statistically indistinguishable.

In those studies above that have incorporated information auctions prior to trade the private messages bid for always revealed the payoff state with certainty (perfect information), thus these studies have only addressed the question of information dissemination. It seems probable that the increased complexity introduced by incorporating imperfect signals into the design, via the need for the aggregation of information, will have some bearing on the efficiency of the experimental market and on the convergence of the price of information to zero. Ackert et al (1997) incorporate costly, imperfect information in their experimental design and directly address the value of imperfect information plus the dissemination and aggregation of the imperfect information. They conducted 12 markets each of which consisted of 12 or 11 traders divided among two trade types with disparate state contingent dividends. Half the markets were conducted with inexperienced traders and the other half with experienced traders. The markets were conducted under the rules of oral double auctions, with a single asset traded at a time. Two states of nature were possible, X and Y, drawn randomly from a deck of 50 cards, comprising 30 X and 20 Y. A market for information is conducted prior to trade under the rules of a sealed-bid auction with the four highest bidders acquiring the clues at the fifth highest bid price. Clue accuracy was determined by the draw of a card from a deck of 40, labelled A for accurate and I for inaccurate. Clue accuracy was manipulated to lie between 0.60 and 0.90 to determine the sensitivity of the market to the chosen parameter values. At the end of each trading period the state of nature and clue accuracy (accurate or inaccurate) were revealed to all participants.

In seven out of the twelve markets prices converged to predicted Bayesian prices. Of the remaining five markets, four experienced under-reaction and one market generated prices that over-shot the Bayesian price (over-reaction). Price convergence was found to be affected by clue accuracy with all five cases of failure to converge occurring under clue accuracy of 0.60 and 0.75. Those markets with the least uncertainty (0.90) never failed to converge. The results support at least partial dissemination of information with prices moving away from those predicted by a naive benchmark (reflecting only prior probabilities) in nine out of the twelve markets.

Ackert et al (1997) report that the value of the imperfect information decreases over time and tends to zero in some markets. Information value is lower in experienced markets than inexperienced markets, in one of which prices strangely increased over time. Overall, however, prices converge to a value that is above zero and below a computed upper bound (based on an assumption concerning the number of assets an individual buys). Thus Ackert et al (1997, p.71) conclude, '.... traders perceive imperfect information has value' and this is consistent with imperfect information being slowly disseminated through the market. Like Sunder (1992), the study compares the profit of informed and uninformed traders. Comparing the average *gross* profit of the two, Ackert et al (1997) find that the uninformed outperformed the informed. Though not explicitly reported, this result would have been further exacerbated if the comparison had been on a net of information acquisition cost basis. Ackert et al (1997) relate this difference in average gross profit to the degree of clue accuracy, reporting that informed traders were able to earn a greater profit in those markets with a high degree of clue accuracy than in the low clue accuracy markets in which their ability to trade profitably suffered.

Ackert et al (1997) is the only published study to date in which information auctions are conducted for imperfect information. Independently of this study the current research programme designed and conducted experimental asset markets where pre-trade information auctions for imperfect information were incorporated in the experimental design. The information structure in the markets studied here was not imperfect in the sense adopted in Ackert et al (1997). That is, the information was not imperfect in the sense that its accuracy was some probability parameter less than unity. Instead the information structure utilised in Chapter Six was employed in the imperfect information asset markets investigated in this chapter. Traders bid for clues that did not reveal the state of nature with certainty, but allowed them to eliminate one of the three possible states of nature. Not withstanding the role of replication within experimental economics, the different ways the two studies operationalise the imperfect information structures render them complimentary. Confirmation of the results in Ackert et al (1997) under different imperfect information structures can only strengthen the conclusions regarding the value of imperfect private information. The markets from the two studies also differ in other ways. For example, Ackert et al (1997) conduct information auctions where the four highest bidders receive the private information and asset markets where there are only two possible states of nature. In contrast, with the intention of maintaining strict experimental control across all eighteen markets of this research programme, the six highest bidders in the information auction receive the private information and there are three possible states of nature in the asset markets. Unfortunately, therefore, if the evidence of the current analysis is contradictory to the findings in Ackert et al (1997) it will be difficult to infer exactly why that should be the case.

7.3 Experimental Design Considerations

7.3.1 Information Markets and Information Structures

For all six of the asset markets studied in this chapter every trading period is preceded by an information auction. The information auctions were conducted under the rules of a sealed-bid uniform-price auction, permitting traders to submit bids to purchase information concerning the state of nature that would be in existence in the forthcoming period.

The information auctions proceeded as follows. All participants entered a bid price at which they were willing to buy information. The six participants offering to buy at the six highest prices won the information auction and received the information for that period. The cost of the information was equal to the seventh highest bid price. All six purchasers were charged for the cost of the information at the end of the trading period. The distribution of clue cards that had been the norm in the earlier experimental asset markets was no longer desirable. The identity of the six insiders was determined endogenously and as such was no longer under the control of the experimenter. For this reason it was not possible to pre-order the clue cards in advance of the experimental session, as had been the case in the earlier experimental markets. To wait for the outcome of the information auction each period and then to order the clue cards accordingly would have been extremely time consuming, adding excessively to the overall length of the experiment. This was deemed undesirable and an alternative method for distributing the private information to traders was adopted. After the final bid had been received all participants were informed of the price at which information had been purchased for the coming period. They were then able to press a designated key on the keyboard to reveal their own private information for a fraction of a second on the computer screen. To prevent individuals observing other participants' private information the length of time that the information was displayed for was purposefully short. Should a participant wish to they could redisplay their own private information by repressing the designated key. To further prevent the loss of control of private information the messages were displayed on the computer screens in a dull colour and a small font size.

The six participants that do not purchase information were not charged the information cost. Those individuals received the message 'Blank' via the computer screen when they requested their private information. In the event of tied bids to buy the information the tie was resolved with reference to the time at which the bid was received. The earliest received bid was deemed to be the winner. If an individual did not wish to enter an offer to purchase private information they entered a bid price of zero in the information auction.

Three of the experimental asset markets incorporated the perfect information structure adopted in the design of the markets studied in Chapter Five, one for each of the three levels of the treatment period duration. The private information that participants bid for perfectly revealed the forthcoming state of nature. The three other markets reported here adopt the imperfect information structure utilised in the design of markets studied in Chapter Six. Due to the endogenous determination of insider identity in the three markets studied in this chapter the convention from Chapter Six of never giving traders within the same trader type identical messages could not be adhered to. Instead, the six insiders each randomly received one of the two possible private information messages. However, if for example the state of nature was X, the convention of distributing three messages each of the type 'Not Y' and the type 'Not Z' was maintained. The number of insiders, the manner in which they were determined and their concealed identities, along with the nature of private information available, were all common knowledge.

7.3.2 *Markets and Period Durations*

As with the previous two groups of experimental markets reported in Chapters Five and Six, two markets were conducted for each of the three levels of the treatment variable, period duration. As usual the trading period durations in the CK markets were held constant (240 seconds) across all 15 trading periods. In the VK and VU markets the durations varied between 120 and 360 seconds, from period to period. As previously, the actual sequence of trading period durations was randomly determined in advance by computer. Parameter sets 3a and 3b were used for the perfect and imperfect information structure markets, respectively. Note, however, that the sequences of period durations are the same for the two parameter sets (see Chapter Four Table 4.3). The constant, varying and uncertain markets durations for those governed by perfect information structures are identified CKPM, VKPM and VUPM, respectively. These markets comprise the third group of markets studied. The corresponding acronyms identifying the imperfect information structure markets are CKIM, VKIM and VUIM, respectively. These markets comprise the fourth group of markets studied. The group three and four markets were conducted during the period 13th May to the 28th May 1998, inclusive.

Recall that in an attempt to ease the recruitment problem experienced for the first and second groups of experimental sessions, the participants recruited for groups three and four were experienced. That is, the participants were recruited from the pool of participants that had taken part in one of the asset markets from either group one or two. With the exception of participants' experience levels, the introduction of an information auction is the only way that the group three markets differ from the group one markets and the group four markets differ from the group two markets. The impact of experience on observed market behaviour, and the confounded effect of information markets, will be considered in the holistic analysis of Chapter Eight.

7.3.3 *State Contingent Dividends*

The state contingent dividend distributions across trader types were the same across all six markets. Parameter set B was used for all markets (see Chapter Four Table 4.1, Panel B). Due to participants' prior experience the state contingent dividends for these two groups of markets had to be changed from the ones used in the previous experimental markets. The sequence of states of nature did differ between the markets. CKPM, VKPM and VUPM used the sequence in parameter set 3a, whilst CKIM, VKIM and VUIM used the sequence in parameter set 3b (see Chapter Four Table 4.3). As previously, the participants' diverse backgrounds plus the minimal contact and interaction between them across different market sessions conducted some time apart, serves to ensure no participant could have been aware of the sequence of states of nature in advance.

The group three and group four markets studied in this chapter differ in design to the group one and group two markets, respectively, from the earlier chapters with respect to the incorporation of an information auction and the experience level of participants. All other details of the experimental design are general to the thesis as a whole and were discussed in Chapter Four. The subsequent section reports the results of the investigation of market performance for the two groups of experimental markets. The section reports the results of a *comparative* evaluation of the performance of the FRE and PI models and concludes with a *relative* evaluation of the impact of period duration on market performance. The analyses are conducted separately for each of the two groups of markets.

7.4 Results and Analyses

7.4.1 *Data Considerations*

The concerns expressed in Chapter Five (section 5.6.1) regarding the existence of outliers, data dependence and the use of statistical tests are all equally valid for the markets conducted in this chapter. The same is true of the methods for dealing with these concerns and the justifications provided for the adoption of such methods. In addition, there are a number of issues specific to the markets investigated in this chapter, which require consideration.

The first issue arises as a result of the three measures of early adopted throughout this research programme. These measures are the first 45, 60 and 90 seconds of trade within a period. It conceivable that the first trade in a period could occur at a time in excess of either 45, 60 or 90 seconds. That is, any of the measures VOL45, 60 or 90 may be zero. If this was indeed the case for a certain trading period the three measures RMSD(45,60,90) would not be defined for that period. Whilst this phenomenon did not occur in any of the experimental markets of previous chapters, it did occur on a few occasions in four of the markets studied in this chapter[41]. It should be recalled that much of the analysis of market performance is based on matched, paired comparisons on a period by period basis. The inability to compute RMSD(45,60,90) for a particular period of a given market would prove problematic. This could be remedied by a variety of ways. Firstly, the use of the WSR test of differences in mean values of paired samples could be sacrificed and replaced by the Mann-Whitney U test for independent samples. However, the use of statistical tests based on paired observations offers far higher statistical power than is achievable with equivalent tests based on independent data. Furthermore, the pairing of observations on a period by period basis provides greater experimental control. An alternative remedy may be to drop all those paired observations where the measures RMSD(45,60,90) were not defined for one of the markets in the comparison. Neither of these options is ideal. Thus, an alternative remedy is adopted. Whenever one of the measures of RMSD(45,60,90) is not defined for a particular period of a given market the information inherent in the bid-ask spread at that point in time (either 45, 60 or 90 seconds) is utilised. As has been the convention in other experimental studies (for example Duxbury, 1997) the mid-point of the bid-ask spread is used as a proxy for the transaction price, thus permitting the relevant RMSD measure to be computed. This solution avoids dropping relevant observations and still allows the use of statistically more powerful paired analyses.

A second issue arises due to technical problems encountered in two of the markets studies here. For both the markets CKIM and VUIM technical problems caused the computer programme on which the experimental sessions where being conducted to freeze during period 11. The problem occurred after 120.5 seconds of trade in CKIM and after 139.7 seconds of trade in VUIM. On both occasions the

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[41] The first trade did not occur until post-45 seconds in period 14 of CKPM, period 7 of VKPM and periods 8 and 10 of VKIM, whilst the first trade did not occur until post-60 seconds in period 7 of VKIM.

programme waited until the end of the trading period before enacting the transaction initiated just prior to the programme freezing. From the moment the programme froze until the end of the period the participants were unable to input any bids or asks. After the period had timed out the programme circled through the usual post-period computer screens and reinitialised ready for the start of period 12. There were no subsequent problems encountered in either market. This technical problem will have obvious problems for some of the measures utilised in the analysis of market performance, but will not influence others. The programme froze post-90 seconds of trade in a period, therefore, there are no concerns for the measures VOL(45,60,90) and RMSD (45, 60, 90). The volume over an entire trading period is normalised (NORMVOL) to control for disparate period durations anyway, thus replacing the intended period duration with the time at which the programme froze in the two periods avoids any problems. The same is true for the NORM%GAIN measure. The RMSD measure over the entire trading period may have been influenced by the premature cessation of trade. Observation of the sequence of transaction prices in period 11 for both markets, however, reveals prices that are very stable and uniform and very close to the FRE price by the time the programme froze (see Figures 7.1-7.6 below). For these reasons it is believed that the technical problem did not impact in any obvious manner on the RMSD over the entire period. The number of assets misallocated and the break down of the efficiency losses between missed and error trades may both have been affected. The two measures, however, both form part of the comparative analysis of the FRE and PI models, for which there are a number of other measures adopted in the analysis that are not affected (for example, NORM%GAIN) and so can be relied upon to give unbiased representations. Whilst undesirable, the technical problem did not result in any problems that could not be remedied or avoided and so it is concluded that the results to be reported in the next two subsections are robust to this unfortunate occurrence.

7.4.2 FRE v PI: Comparative Performance Evaluation

Asset Markets

The discussion here is centred on a comparative evaluation of the predictive accuracy of the FRE and PI models with respect to asset market performance. The comparison is performed on the raw data generated by the experimental asset markets, including transaction prices, allocations and profits. For this period-by-period, within market comparative analysis the transformations to the data required to deal with outliers and dependence are not necessary.

As discussed previously, the two competing models of FRE and PI predict that traders use different information sets in the determination of their expectations of transaction prices. The two models, therefore, make disparate predictions concerning equilibrium prices. For the perfect information markets, CKPM, VKPM and VUPM, the FRE model predicts equilibrium prices, given the state contingent dividends[42], of 250, 400 and 950 for states of nature X, Y and Z, respectively. The FRE model predicts that both the informed and uninformed participants in the trader types 1, 3 and 2 will hold the assets at the end of the period in the states X, Y and Z, respectively. Note that the corresponding equilibrium predictions for the imperfect markets, CKIM, VKIM and VUIM are identical. This is because the parameter set governing the state contingent dividends is the same as for the PM markets. The same is not true of the price predictions of the PI model, which will change as a result of moving from a perfect to imperfect information structure. For the perfect information markets, assuming a uniform distribution of private information, the PI model predicts equilibrium prices of 500, 500 and 950 for the states X, Y and Z, respectively. For the imperfect markets the corresponding equilibrium prices are 575, 650 and 650 for states X, Y and Z, respectively. For the PM markets, under the uniform distribution of private information, the PI model's end of period asset allocation predictions are uninformed trader type 2 for states X and Y and informed trader type 2 for state Z. For the IM markets the corresponding predictions are trader type 2 receiving the clue 'Not Y' for state X and trader type 2 receiving the clue 'Not X' for states of nature Y and Z[43].

The endogenous determination of insiders does not, however, guarantee that the private information is distributed uniformly among the three trader types. In order to determine the PI model's equilibrium predictions reference must be made to the actual distribution of private information. For the vast majority of periods in the six markets the distribution of private information is such that the PI equilibrium price is not altered. Table 7.1 displays the PI model's equilibrium price and allocation predictions for those periods where the predictions are altered. These price and allocation predictions will be used in the comparative analysis of the FRE and PI

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[42] See Table 4.1, Chapter Four, parameter set B.

[43] See Appendix 3 for an explanation of the FRE and PI equilibrium calculations.

models that follows.

Market	*Periods*	*PI Price*	*PI Allocation*
CKPM	2, 7, 8, 9, 10, 13, 14, 15	400	Uninformed trader type 3
VKPM	9	400	Uninformed trader type 3
CKIM	8	500	Uninformed trader type 2
VUIM	4	575	Trader type 2 receiving the message Not Y

Table 7.1 Equilibrium Predictions of the PI Model when the Uniform Distribution of Private Information is Not Applicable

The FRE and PI equilibrium price predictions are included in Figures 7.1-7.6 as horizontal lines, towards which the convergence of transaction prices can be compared. All three PM markets display a tendency to converge to the FRE price from period 2 onwards. This is true even for state of nature Z in which the FRE price of 950 emus is far higher than the price predictions in the other two states. The degree of convergence is most marked in the VKPM market, closely followed by the CKPM market. The VUPM market exhibits slightly less tendency to converge, which is most noticeable for state of nature Z. Despite this all three markets display a level of convergence to the FRE price that is far higher than was witnessed in any of the previous perfect information markets of Chapter Five. All three PM markets clearly react to the state of nature and exhibit high levels of informational efficiency. The three PM markets studied in this chapter differ in design to the previous perfect information markets on two counts, the incorporation of a pre-trade information auction and the experience level of participants. Due to the confounding effects of the two experimental design changes it is difficult to determine decisively which one is responsible for the dramatic improvement in informational efficiency. It is conjectured that the improvement is the result of the increased experience level of participants for the following reason. The information auction favoured the trader type with the highest expected dividend value in the absence of private information. Given the state contingent dividend distributions trader type 2 had the highest expected dividend value. These traders may have valued the information more highly and, therefore, purchased the private information more frequently than the other trader type groups. This is substantiated by Table 7.2, which reports the frequency with which traders purchased information. On many occasions when the state of nature is

X or Y, therefore, there will be many periods where less than two traders[44] representing the FRE equilibrium allocation group (trader type 1 & 3 respectively) will purchase the private information. A priori this would be expected to reduce the competition for assets within the trader type group with the highest dividend valuation and so possibly impair the convergence towards the FRE equilibrium price. For states X and Y the presence of an information auction may impair the informational efficiency of the markets, however, this is not evidenced by the observed market behaviour. Convergence under states X and Y is observed for all three PM markets. Thus the increase in participants' experience levels must be responsible for the improved informational efficiency. By way of an example, the individuals purchasing information in periods 11 and 13 of the VKPM market are traders 7, 8, 9, 10, 11, 12. None of the FRE predicted holders of the assets (type 1 traders) had private information and yet the observed sequences of transaction prices cluster precisely around the FRE price of 250 emus.

The IM markets exhibit significantly reduced levels of convergence to the FRE equilibrium price than the PM markets. Nevertheless, the sequences of transaction prices cluster more closely to the FRE price than the PI price in most periods. These markets display more reaction to the states of nature than was observed in the previously studied imperfect information asset markets of Chapter Six. Again, the increased experience level of participants appears to have improved the convergence to FRE prices even in an imperfect information regime. From simple observation it is difficult to determine which, if any, of the three markets CKIM, VKIM or VUIM exhibits the greatest degree of convergence.

[44] In the previous asset markets for which no information auction was conducted there were always two traders from each trader type group with private information.

Trader	*CKPM*	*CKIM*	*VKPM*	*VKIM*	*VUPM*	*VUIM*
1	0	5	0	0	3	3
2	2	0	1	0	2	0
3	8	0	0	1	1	1
4	3	1	1	10	1	0
5	13	15	1	15	15	15
6	15	15	8	14	8	15
7	15	10	15	12	4	14
8	14	10	15	9	12	7
9	4	14	11	15	4	12
10	11	4	10	2	11	0
11	5	1	13	12	14	13
12	0	15	15	0	15	10

Table 7.2 Frequency with which Traders Purchase Information in the Pre-trade Information Auction.

To directly evaluate the FRE and PI models' predictions the RMSD of prices each period were computed for both and compared within a market on a period by period basis. In this comparative analysis the normal arithmetic mean is used to compute the RMSD, the use of Andrew's M-estimator is not necessary. Comparisons were made for the first 45, 60 and 90 seconds of trade in a period and over the entire trading period duration (RMSD45,60,90 and RMSD, respectively). Table 7.3 contains the outcomes of these comparisons for the two information structure types. The percentages are calculated based on the total number of periods for which the two models predicted disparate equilibrium prices[45]. The predictive accuracy of the price predictions of the FRE model are far higher than that of the PI model for both the PM and IM markets. Aggregated separately across all three markets in the PM and IM environments (Overall) the RMSD of the FRE model is less than that of the PI model in 88.89% and 82.22% of periods, respectively. The comparison also provides evidence of the superiority of the FRE model for all three measures of early in a period.

[45] Note that, because of the recalculation of the PI price in periods where the prediction changed due to non-uniform distribution of private information, the FRE and PI prices may be equivalent in certain periods. As with the occurrence of state Z in the PM markets, these periods can not be used in the comparative analysis. The periods in question are 2, 7, 8, 9 and 14 in CKPM and period 9 in VKPM.

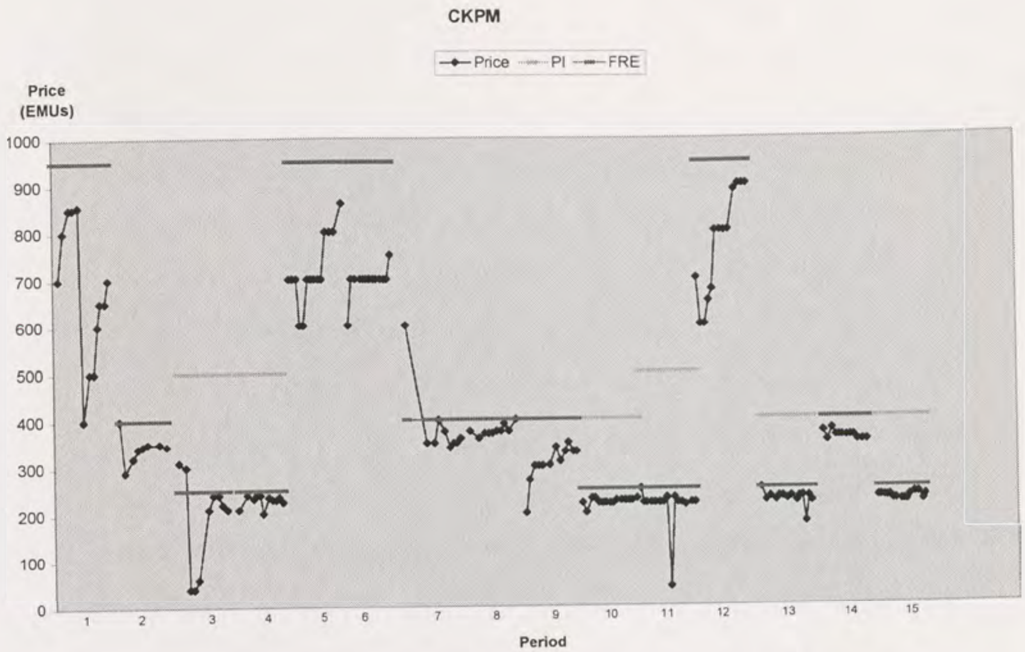


Figure 7.1 Sequence of Transaction Prices per Period – CKPM

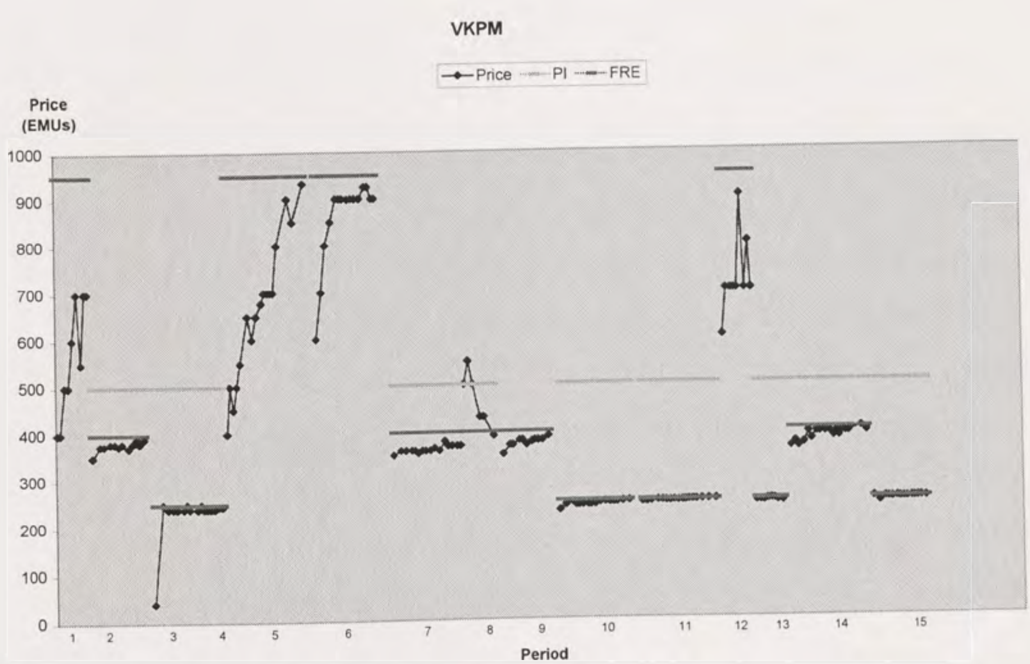


Figure 7.2 Sequence of Transaction Prices per Period – VKPM

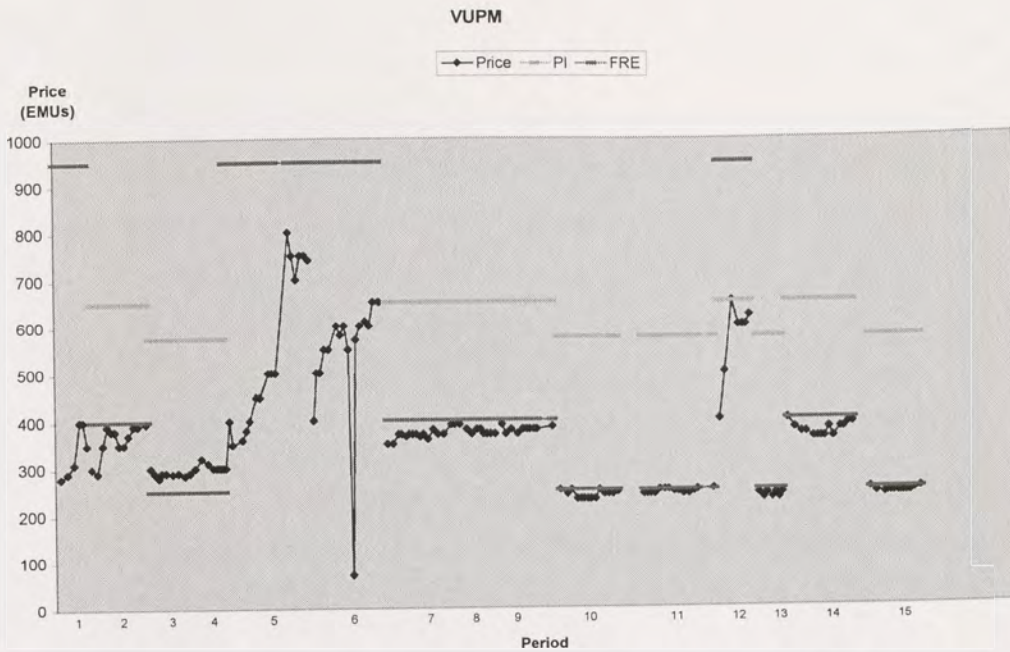


Figure 7.3 Sequence of Transaction Prices per Period – VUPM

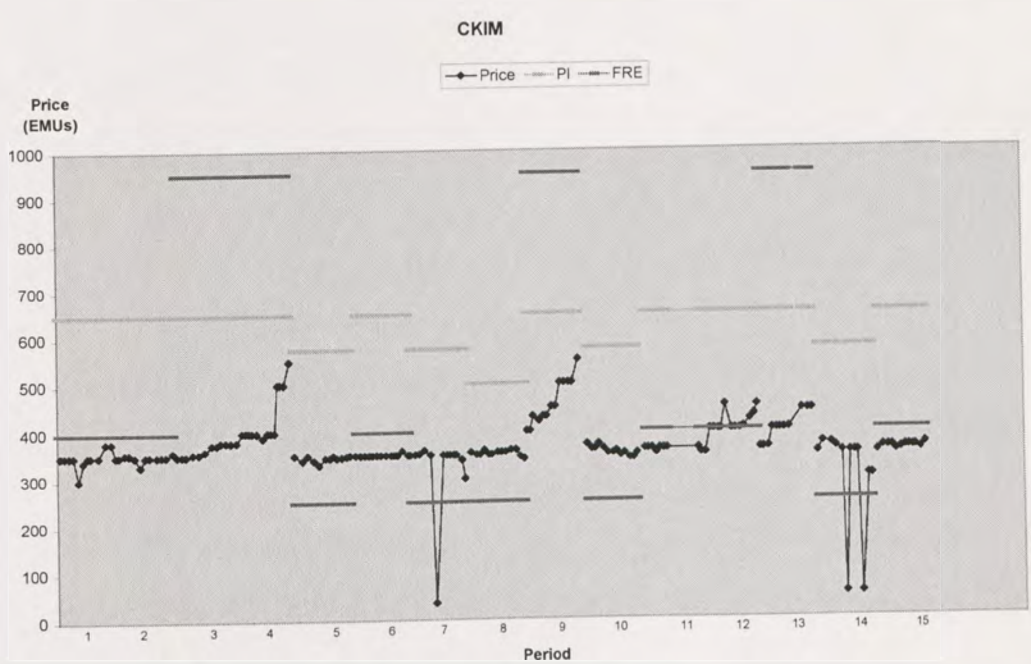


Figure 7.4 Sequence of Transaction Prices per Period – CKIM

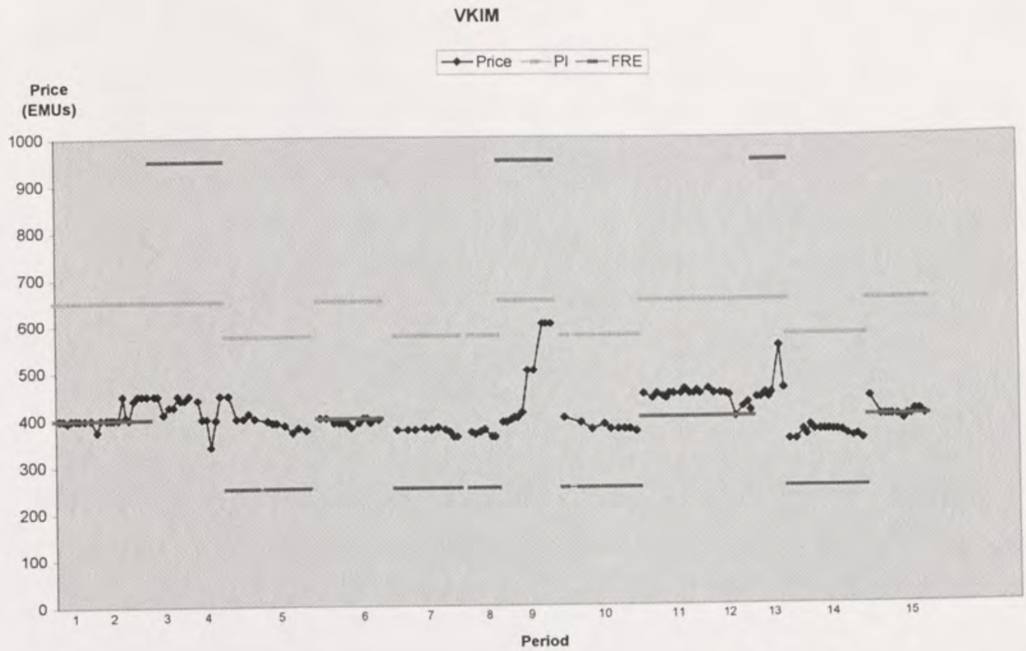


Figure 7.5 Sequence of Transaction Prices per Period – VKIM

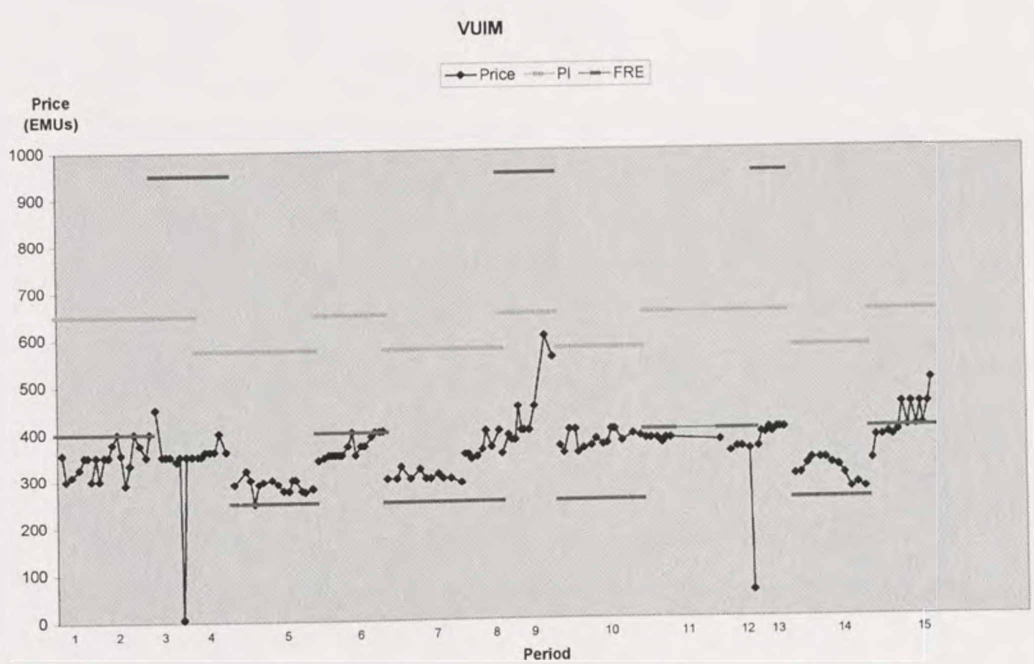


Figure 7.6 Sequence of Transaction Prices per Period – VUIM

Market	Performance	Percentage Comparison(%) RMSD45	RMSD60	RMSD90	RMSD
CKPM	FRE<PI	100.00	100.00	100.00	100.00
	FRE>PI	0.00	0.00	0.00	0.00
	FRE=PI	0.00	0.00	0.00	0.00
VKPM	FRE<PI	90.00	90.00	90.00	90.00
	FRE>PI	10.00	10.00	10.00	10.00
	FRE=PI	0.00	0.00	0.00	0.00
VUPM	FRE<PI	76.67	76.67	76.67	76.67
	FRE>PI	23.33	23.33	23.33	23.33
	FRE=PI	0.00	0.00	0.00	0.00
Overall	FRE<PI	88.89	88.89	88.89	88.89
	FRE>PI	11.11	11.11	11.11	11.11
	FRE=PI	0.00	0.00	0.00	0.00
CKIM	FRE<PI	73.33	73.33	73.33	73.33
	FRE>PI	26.67	26.67	26.67	26.67
	FRE=PI	0.00	0.00	0.00	0.00
VKIM	FRE<PI	66.67	66.67	66.67	66.67
	FRE>PI	33.33	33.33	33.33	33.33
	FRE=PI	0.00	0.00	0.00	0.00
VUIM	FRE<PI	100.00	100.00	100.00	100.00
	FRE>PI	0.00	0.00	0.00	0.00
	FRE=PI	0.00	0.00	0.00	0.00
Overall	FRE<PI	80.00	80.00	80.00	82.22
	FRE>PI	20.00	20.00	20.00	17.78
	FRE=PI	0.00	0.00	0.00	0.00

Table 7.3 Comparison of RMSD of Price Predictions for FRE and PI

The disparate predictions of the FRE and PI models regarding end-period allocations are now used to compare their predictive abilities. The two models can be evaluated based on a comparison of the number of assets misallocated when compared to their equilibrium predictions[46]. In this analysis it is possible to make use of all 15 periods, because the two models never make the same prediction. It must again be recognised that the PI equilibrium requires a greater number of trades than the FRE equilibrium. Caution must be exercised when comparing misallocations so as not to succumb to any bias that this would introduce. The ∂ measure introduced in Chapter Five is again used to avoid such bias. The size of the indiscriminate region depends on whether the information structure is perfect of imperfect, taking the values

[46] See Appendix 3 for an explanation of the FRE and PI end-period asset allocations.

$0 \leq \partial \leq 4$ and $0 \leq \partial \leq 6$, respectively. As displayed in Table 7.4, aggregated over all the PM markets, the FRE model makes superior allocation predictions in 68.89% of periods. In these markets the PI models never misallocates fewer assets than the FRE model. In contrast, the PI model is superior in the IM markets, though not as strikingly, with fewer misallocations in 33.33% of periods compared to a corresponding figure of 6.67% for the FRE model. For the majority of periods, 60.00%, the comparison of the number of assets misallocated falls within the indiscriminate region.

Market	*Performance*	*Percentage Comparison (%)*	*Market*	*Performance*	*Percentage Comparison (%)*
CKPM	FRE<PI	53.33	***CKIM***	FRE<PI	6.67
	FRE>PI	0.00		FRE>PI	46.67
	FRE=PI	46.67		FRE=PI	46.67
VKPM	FRE<PI	86.67	***VKIM***	FRE<PI	6.67
	FRE>PI	0.00		FRE>PI	40.00
	FRE=PI	13.33		FRE=PI	53.33
VUPM	FRE<PI	66.67	***VUIM***	FRE<PI	6.67
	FRE>PI	0.00		FRE>PI	13.33
	FRE=PI	33.33		FRE=PI	80.00
Overall	FRE<PI	68.89	***Overall***	FRE<PI	6.67
	FRE>PI	0.00		FRE>PI	33.33
	FRE=PI	31.11		FRE=PI	60.00

Table 7.4 Comparison of Misallocation of Assets for FRE and PI

To summarise the results so far, the comparison of the RMSD of prices from the theoretically predicted equilibrium price predictions of the two models offers conclusive support in favour of the superiority of the predictions of the FRE model, particularly in the PM markets. Comparison of the number of assets misallocated provides strong support in favour of the FRE model in PM markets, but weaker support for the PI model in IM markets.

Two further measures of performance readily adopted in the experimental asset market literature can also be used to distinguish between the two competing models. The first of these is the measure of trading efficiency, %GAIN. Recall that, given the definition, the initial allocation of assets each period produces a %GAIN of 0% whereas the end period equilibrium allocation of the FRE model produces a %GAIN of 100%. Table 7.5 illustrates that the level of %GAIN for the PM markets exhibits a degree of variability, from a maximum of 100.00%, through 0% to a minimum of –6.25%. The average %GAIN observed in the CKPM, VKPM and VUPM markets are 58.92%, 71.49% and 53.53%, respectively. The corresponding average %GAIN figures for the CKIM, VKIM and VUIM markets are much lower at 16.71%, 15.34% and 17.22%, respectively. The IM markets also exhibit far higher variability from a maximum %GAIN of 81.58%, through 0% to a minimum of –50.00%.

Period	*CKPM*	*VKPM*	*VUPM*	*CKIM*	*VKIM*	*VUIM*
1	73.6842	59.8684	4.6053	42.7083	-14.5833	-4.1667
2	29.1667	70.8333	79.1667	20.8333	33.3333	50.0000
3	12,5000	37.5000	6.2500	58.5526	56.5789	19.7368
4	43.7500	50.0000	-6.2500	81.5789	4.6053	21.0526
5	84.2105	100.0000	63.1579	-31.2500	18.7500	-6.2500
6	79.6053	92.1053	81.5789	62.5000	62.5000	70.8333
7	20.8333	100.0000	95.8333	-37.5000	-37.5000	0.0000
8	54.1667	4.1667	54.1667	-43.7500	-25.0000	-37.5000
9	0.0000	66.6667	41.6667	76.9737	76.9737	67.7632
10	81.2500	100.0000	75.0000	-50.0000	-31.2500	-50.0000
11	87.5000	100.0000	56.2500	-8.3333	20.8333	29.1667
12	79.6053	57.8947	47.3684	33.3333	29.1667	29.1667
13	68.7500	50.0000	43.7500	26.3158	33.5526	41.4474
14	75.0000	95.8333	79.1667	-18.7500	-31.2500	-6.2500
15	93.7500	87.5000	81.2500	37.5000	33.3333	33.3333
Mean	58.9181	71.4912	53.5307	16.7142	15.3363	17.2222

Table 7.5 Percentage of Gains from Trade Exhausted per Period

The low mean %GAIN figures for the IM markets could be interpreted as being more in favour of the PI model than the FRE model. However, consideration must also be given to the gains from trade to be exploited under the PI model, relative to the zero trade gains. These gains depend on the end-period equilibrium allocations of the PI model. Thus the PI gains from trade are state contingent and take the values of –400, 0 and 7,600 emus under the states X, Y and Z, respectively, for both PM and IM markets assuming the uniform distribution of private information. Before continuing it must be recognised that the gains from trade under the FRE and PI models are equal when the state of nature is Z, because both predict type 2 traders to hold the assets. For this reason those periods where the state of nature is Z cannot be used in the following comparative analysis. Note also that the endogenous determination of insiders impacts on the PI model's allocation predictions and so consequently on the gains from trade predicted. For the periods 2, 7, 8, 9 and 14 of CKPM (state Y) the PI model's allocation predictions change and become identical to the FRE model's, thus these periods cannot be used in the comparison. The allocation prediction for period 9 of VKIM alters, resulting in gains from trade of –400 for this occurrence of the state Y. For all other periods the gains from trade detailed above are applicable.

In the PM markets the number of periods where the realised gains from trade are negative when the state is X is 0 out of 19 discriminating periods (18 state X plus 1 state Y) offering overwhelming support for the FRE model. When the state is Y the PI model predicts zero gains from trade, however, in 9 out of 9 discriminating periods the realised gains from trade were positive for the PM markets. Again, overwhelming support for the FRE model. For the IM markets, however, there are 13 out of 15 discriminating periods where the realised gains are negative, offering support in favour of the PI model. In contrast, there are 15 out of 18 discriminating periods where the realised gains from trade are positive in state Y periods, providing strong evidence in favour of the FRE model. For the IM markets it is not possible to claim the superiority of one model over another.

Finally, the performance of the FRE and PI models are evaluated by comparing the profit of the informed to that of the uninformed on a period by period basis. The FRE model would predict no difference in the average level of profit across the two kinds of traders, whereas the PI model would predict higher average profits of informed traders over uninformed traders. These predictions stem from the value of private information under the two models, which is zero and positive for the FRE and PI models, respectively. Table 7.6 contains the average profit of the informed and the uninformed, in emus, for the PM and IM markets. The gross profits of the informed exceed those for the uninformed by considerable amounts in both PM and IM markets. Net of information costs the figures are much closer as would be expected, however, the informed still earn excess profits on average. The difference in average profits constitutes weak evidence against the strictest interpretation of the FRE model in which price signals instantaneously reveal the state the nature, therefore, it is not construed as fatally condemning.

Market	Gross Profit		Net Profit	
	Informed	Uninformed	Informed	Uninformed
CKPM	1031.9889	783.0111	813.7889	783.0111
VKPM	988.3667	844.9667	860.1000	844.9667
VUPM	1005.4889	723.2333	855.5556	723.2333
Mean	1008.6148	783.7370	834.1482	783.7370
CKIM	1024.6778	719.8778	897.4778	719.8778
VKIM	940.6444	744.3556	805.9111	744.3556
VUIM	946.1778	722.4333	802.8444	722.4333
Mean	970.5000	728.889	835.4111	728.8889

Table 7.6 Average Profit (Gross and Net) of Informed and Uninformed Traders

In conclusion, the evidence from this comparative analysis of the PM markets very strongly supports the superiority of the FRE model over the PI model for the majority of the comparative measures reported. In contrast the evidence from the IM markets is mixed. A comparison of the RMSD of prices from the equilibrium price predictions of the two models offers strong support in favour of the superiority of the predictions of the FRE model. Comparison of the number of assets misallocated, however, provides weak support in favour of the PI model. In the presence of increased state uncertainty due to imperfect information the FRE model does not dominate the PI model on most comparative measures as it clearly does when the information structure is perfect.

Information Markets

The pre-trade information auction can also provide discriminatory comparisons of the predictive accuracy of the two models. The FRE model predicts that the private information is worthless and so should not command a market price. In contrast, the PI model predicts the private information will retain positive value because the price signal does not reveal the underlying state of nature. The data generated by the information markets will now be exploited to discriminate between the two competing models. The purchase price is used as a measure of the private information's value.

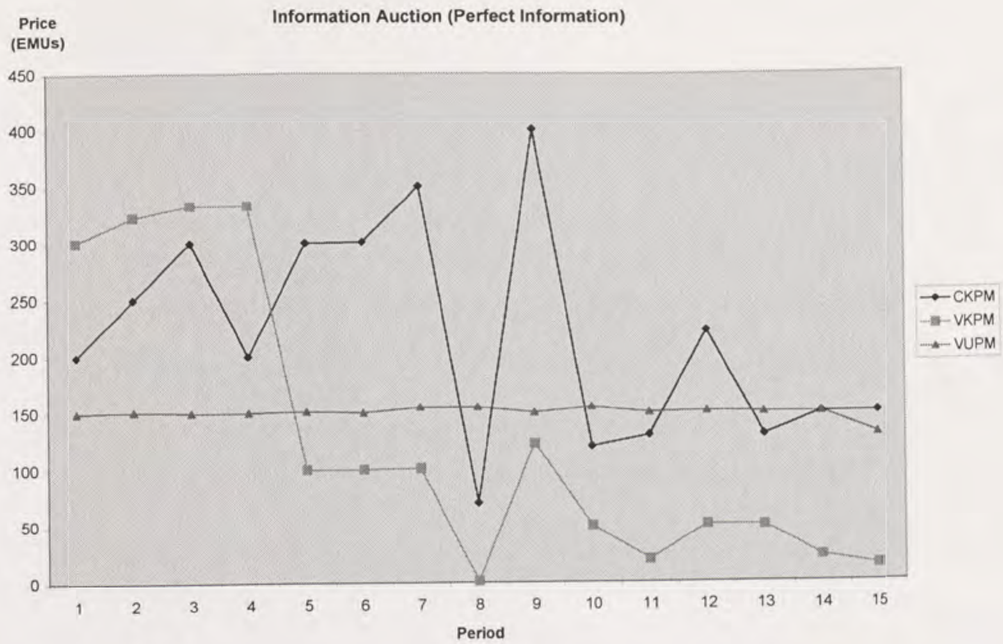


Figure 7.7 Purchase Cost of Information per Period – PM Markets

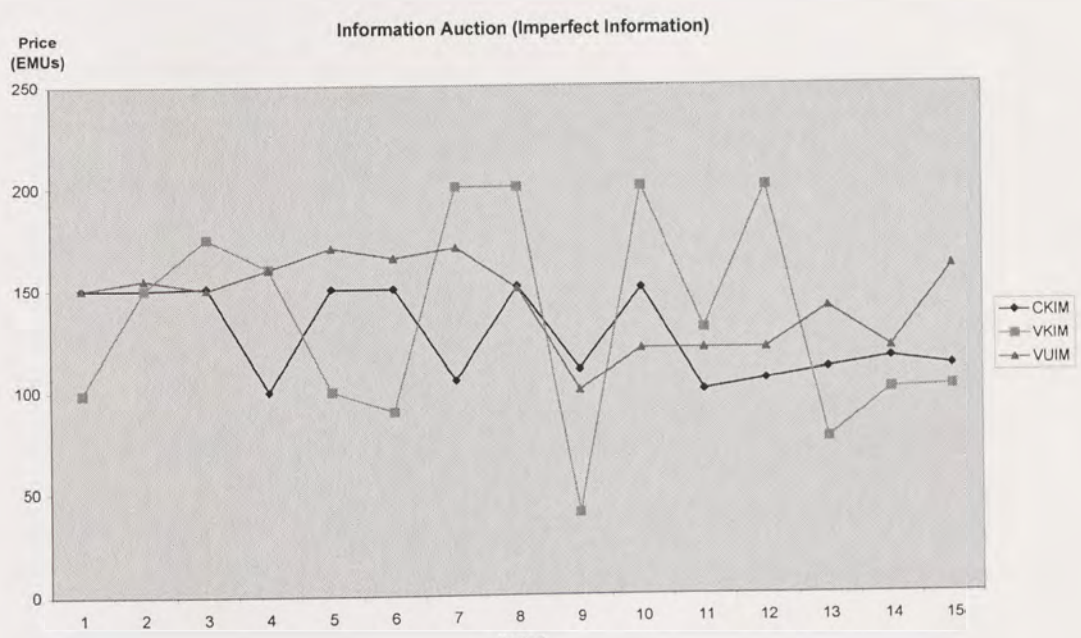


Figure 7.8 Purchase Cost of Information per Period – IM Markets

The Figures 7.7-7.8 display the purchase price paid for private information against the period number, for the PM and IM markets. The purchase price remains positive for all periods, but does, however, decline as low as 1 emu in period 8 of VKPM. The erratic nature of the information cost per period makes it difficult to draw any firm conclusions in favour of one model over another. The exception is VUPM where the cost shows no sign of declining and so provides support in favour of the PI model. More comprehensive analyses are required to come to a conclusion.

Sunder (1992) uses the β slope coefficient form an OLS regression of information cost against period number to determine whether the information cost shows any tendency to decline over time towards the FRE prediction of zero. Table 7.7 reports β coefficients and associated levels of statistical significance for the markets studied here. A negative β coefficient that is statistically significant is construed as strong evidence in favour of the FRE model, a negative coefficient that is not statistically significant provides week evidence in favour of the FRE model, whilst a positive β coefficient would be construed at strong evidence in support of the PI model. All reported β coefficients are negatively signed offering weak support for the FRE model (though the VUPM coefficient is only very marginally negative). Two of the markets generate β coefficients that are statistically significant from zero at, or below, the 5% level. This is interpreted as providing strong evidence in support of the FRE model. In no market is the β coefficient positively signed, therefore, the evidence does not support the PI model. Using linear regression it is possible to estimate the number of periods (independent variable) required for the information cost (dependent variable) to decline to zero. The estimated number of periods are 32, 13, infinity, 52, 88 and 68 for the markets CKPM, VKPM, VUPM, CKIM, VKIM and VUIM, respectively. The VUPM information cost is effectively a constant of approximately 150 emus and is independent of period number. With the exception of VUPM, the information cost in all markets would tend to zero if there were a sufficient number of periods (experience).

Market	β *coefficient*	α-*values*
CKPM	-9.0500	0.1172
VKPM	-23.7964	0.0001
VUPM	-0.4750	0.1631
CKIM	-2.9036	0.0257
VKIM	-1.6821	0.6115
VUIM	-2.3571	0.0709

Table 7.7 β Slope Coefficient of Information Cost Regressed Against Period Number

Sunder (1992) also reports a comparison of the mean information cost early in an experimental session with the mean cost late in an experimental session. The null hypothesis is of no statistical difference in the mean early information cost and the mean late information cost. The alternative hypothesis is that the mean early information cost is greater than the mean late information cost (in favour of the FRE model). Table 7.8 reports the results of a similar comparison for the markets studied here, where the first seven periods comprise the measure of early and the last seven periods comprise the measure of late. Period 8 is used as cut off to discriminate more cleanly between the two measures. The interpretation of the WSR test significance levels is problematic because of the dependence in the data that arises from increasing experience as the period number increases. It would not make sense to incorporate the adjustment process used elsewhere in this research to remove the dependence from the period by period data because the technique renders the effect of any treatment a purely levels effect. The comparison of mean information costs both early and late requires the trend component to be retained and present in the data. Thus caution must be exercised in the interpretation of the significance levels. For this reason little more is made of the results reported in Table 7.8 than to suggest that, aggregated across all six markets, the mean early information cost may well exceed the mean late information cost. If true this would be evidence in support of the FRE model.

Market	*WSR Test One-tail α-values*
CKPM	0.1036
VKPM	0.0900
VUPM	0.4270
CKIM	0.0574
VKIM	0.1990
VUIM	0.0089
Overall	0.00005

Table 7.8 Comparison of Mean Early and Mean Late Information Costs

In summary, the use of the data from the information auctions does not offer definitive evidence in favour of the FRE model, however, neither is the evidence particularly favourable for the PI model. Five of the six markets display clear evidence of information costs tending to zero. This result is in line with the findings reported in Sunder (1992) and Ackert et al (1997).

7.4.3 Impact of Period Duration on Market Behaviour

The analysis in this subsection is concerned with an evaluation of the impact of both varying period durations and uncertain period durations on the trading behaviour observed in experimental asset markets that are preceded by a pre-trade information auction. The analysis will be conducted relative to the benchmark provided by the FRE model's equilibrium predictions, as has been the convention in the two previous chapters. The discussion begins with a preliminary investigation of observed market performance by way of graphical representation, for which the unadjusted raw data is sufficient. The analysis concludes with a direct evaluation of the stated hypotheses (see Chapter Five) and incorporates the data adjusted to remove dependence and the influence of extreme observations. The use of the acronym RMSD in the discussion to follow will always refer to the root mean squared deviation of transaction prices where the mean is in fact replaced by Andrew's M-estimator.

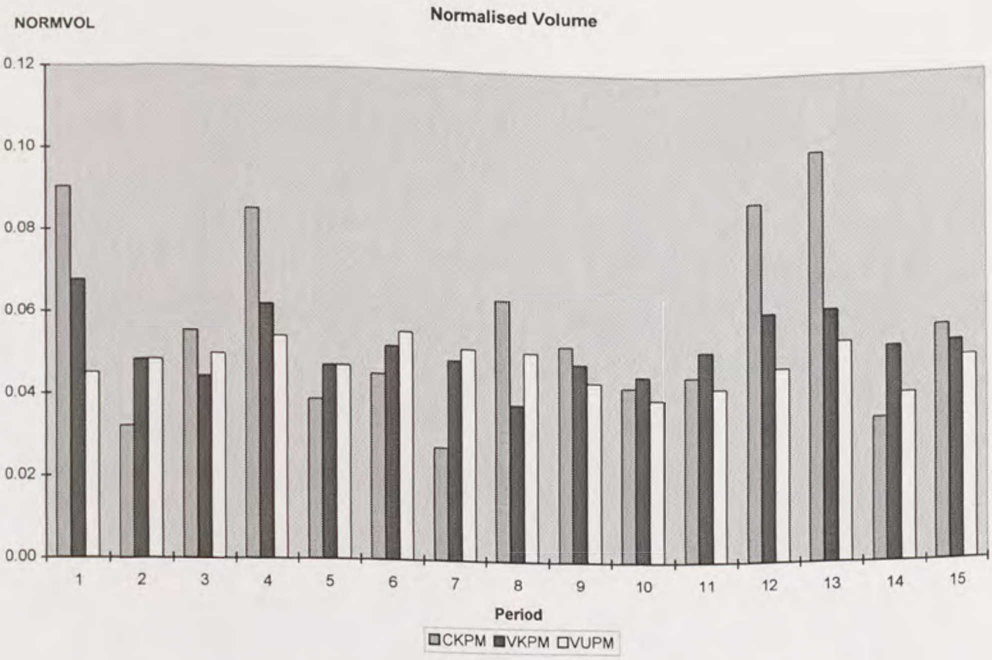


Figure 7.9 Normalised Volume of Trade per Period – PM Markets

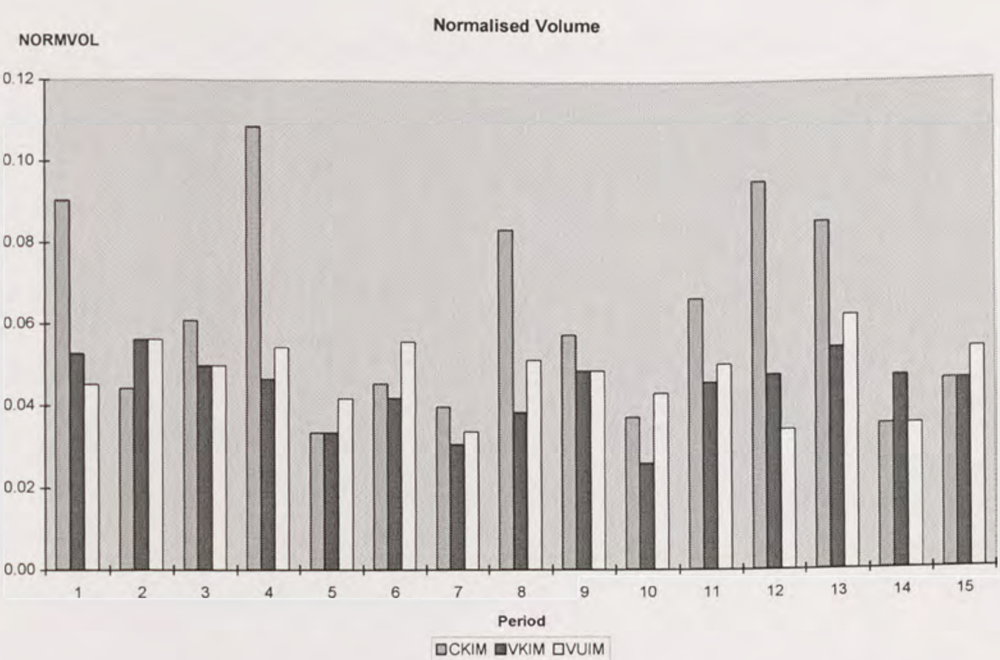


Figure 7.10 Normalised Volume of Trade per Period – IM Markets

The preliminary analysis begins by comparing the volume of trade per period across markets to observe the influence of period duration. So as to control for the disparate period durations across the six markets the NORMVOL measure previously defined (see Chapter Five) is once more used for the comparisons to avoid any bias due to the duration of trade in each period. Figures 7.9-7.10 display the normalised volume of trade per period for the markets grouped by information structure. The NORMVOL measure for the CKPM market exceeds those for the other two PM markets in 8 of the 15 periods. Thus it appears that the CKPM market generates the fastest rate of trade, with a mean of 0.0575 in comparison to the figures of 0.0524 and 0.0483 for VKPM and VUPM, respectively. The evidence is supported by the IM market results with CKIM's NORMVOL measure highest in of 9 out of the 15 periods. The mean CKIM rate of trade is 0.0619, exceeding the measures of 0.0443 and 0.0476 for VKIM and VUIM, respectively. The comparison between the VKPM and VUPM NORMVOL measures results in the former exceeding the latter in 9 periods, whereas the reverse is true in only 4 periods. Thus the uncertainty over period duration, relative to varying period durations appears to result in a less aggressive trading when the information structure is perfect. In contrast, the reverse is true for the VKIM and VUIM comparison, with the former exceeding the latter in only 3 periods, whereas the reverse is true in 9 periods. Thus the uncertainty over period duration, relative to varying period durations appears to result in a more aggressive trading when the information structure is imperfect. A more comprehensive analysis of the impact of uncertain period durations on the rate of trade in a period is reported shortly.

Figures 7.1-7.6 display the sequence of transaction prices per period for each of the six markets. All three PM markets display a tendency to converge to the FRE price from period 2 onwards. The degree of convergence is most marked in the VKPM market, closely followed by the CKPM market. The VUPM market exhibits slightly less tendency to converge, which is most noticeable for state of nature Z. The IM markets exhibit significantly reduced levels of convergence to the FRE equilibrium price than the PM markets. From simple observation it is difficult to determine which, if any, of the three markets CKIM, VKIM or VUIM exhibits the greatest degree of convergence. It appears, however, that the VUIM market is more responsive to the state of nature than the other two markets.

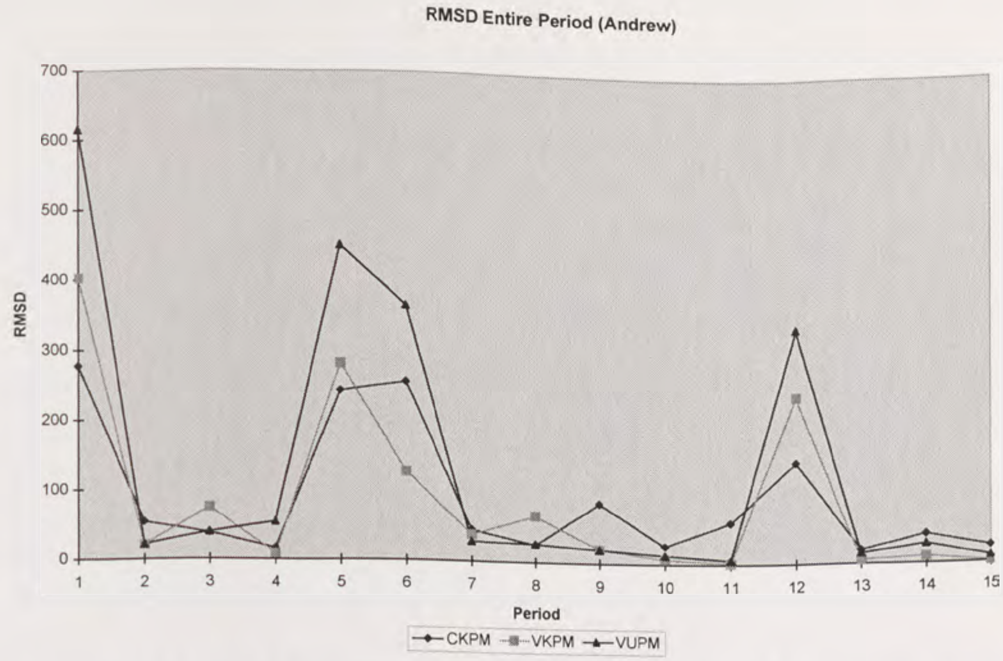


Figure 7.11 Root Mean (Andrew) Squared Deviation of Transaction Prices per Period – PM Markets

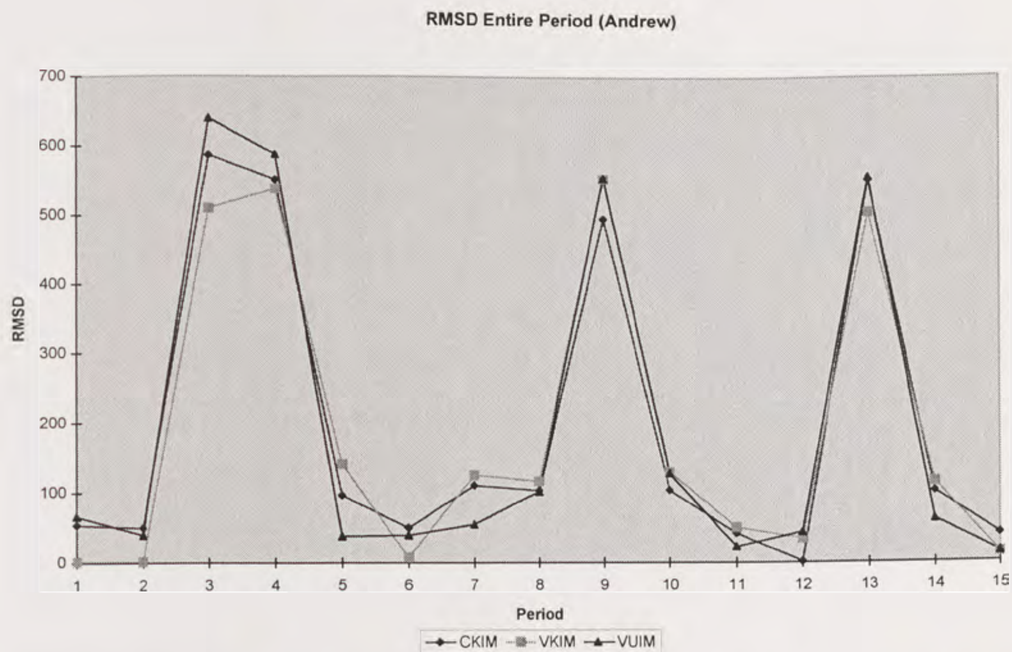


Figure 7.12 Root Mean (Andrew) Squared Deviation of Transaction Prices per Period – IM Markets

In an attempt to better see the convergence of transactions to FRE prices the Figures 7.11-7.12 illustrate the RMSD of prices per period, computed using the Andrew M-estimator, for the three markets grouped by information structure. Unfortunately these functions are fairly erratic with the market type with the highest/lowest RMSD changing on a regular basis from period to period. It is very difficult, therefore, to draw any conclusions concerning the impact of period duration on the informational efficiency of the experimental markets simply from a graphical representation of the data. The only striking observation to be drawn concerns the failure of all IM markets to fully react to state of nature Z, the occurrence of which corresponds to all the peaks in RMSD displayed in the two figures. A more comprehensive investigation by way of statistical testing is required to determine if any effect of period duration is present. The results of such an evaluation are reported after the preliminary investigation is concluded. Preliminary investigations of the trading efficiency and the profits earned by informed and uninformed traders are now considered.

The %GAIN measure was used to compare the trading efficiency across market types. The measure was normalised to control for disparate period durations, giving the measure NORM%GAIN. Figures 7.13-7.14 display the NORM%GAIN figures per period for each market, grouped by information structure. The NORM%GAIN figures for the PM markets are generally relatively high. On 6 occasions out of the 15 periods the CKPM markets generate the highest, NORM%GAIN measure. The corresponding figures for the VKPM and VUPM markets are 7 and 2, respectively. The VKPM markets seem to generate a slightly higher level of NORM%GAIN than the CKPM markets and a much higher level compared to the VUPM markets. This is evidenced by the higher mean NORM%GAIN of 0.3032 for the VKPM markets compared to the values of 0.2455 and 0.2145 for the CKPM and VUPM markets, respectively. It appears that on average the level of trading efficiency attained is lowest under the VUPM markets. The mean NORM%GAIN figures for the IM markets (0.0673, 0.0784 and 0.0950 for CKIM, VKIM and VUIM, respectively) are generally much lower than the PM market figures and display a greater tendency for negative realised gains from trade. The NORM%GAIN figures for all three IM markets are very erratic and so it is difficult to draw any decisive conclusions regarding any impact of period duration on these markets.

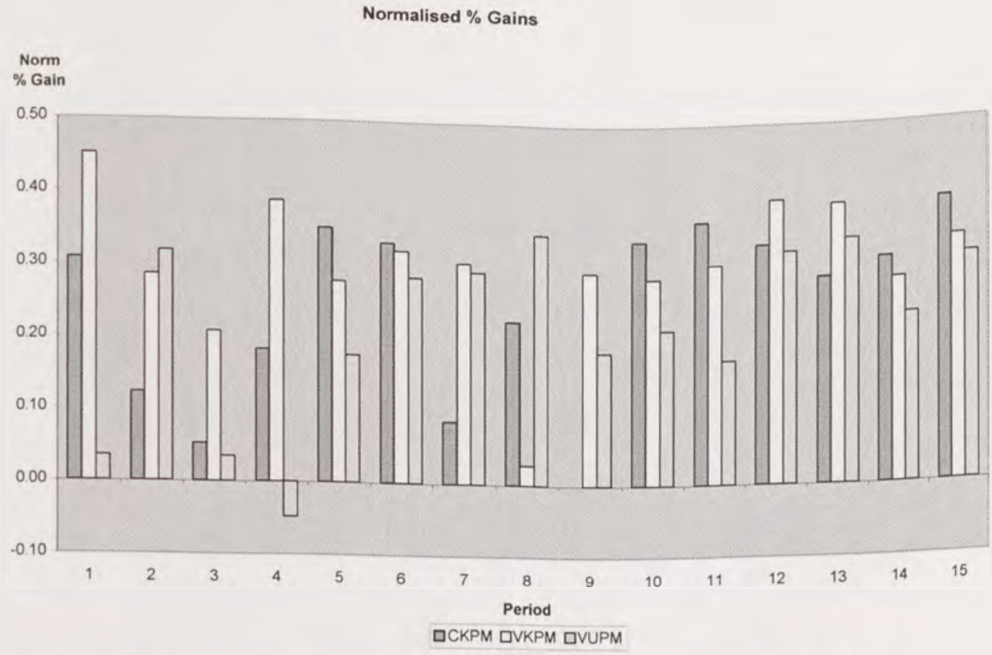


Figure 7.13 Normalised Percentage Gains from Trade – PM Markets

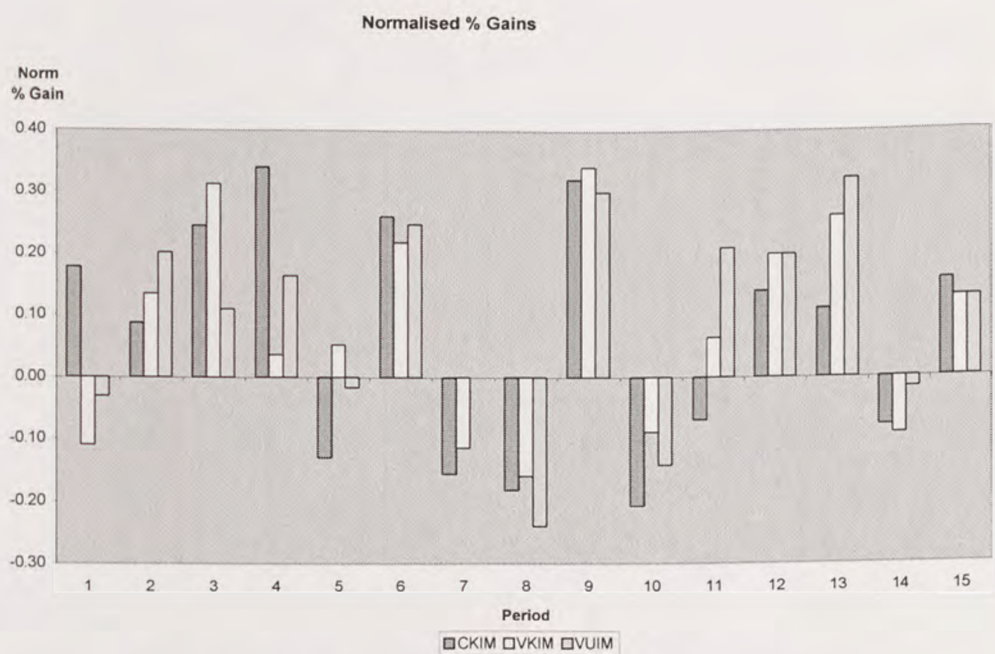


Figure 7.14 Normalised Percentage Gains from Trade – IM Markets

The mean %GAIN values reported in Table 7.6 can be investigated more closely to separate the efficiency loss between either a *missed trade* or an *error trade*. The mean percentage efficiency loss associated with missed and error trades are reported in Table 7.9. For five of the six markets the mean efficiency loss figures for missed trades exceed those error trades, with the effect most pronounced in the PM markets. The exception is the CKIM market. It is difficult to conclude from this analysis how, if at all, period duration impacts upon the manner in which the efficiency losses arise.

	Percentage of Efficiency Loss	
Market	***Missed Trades***	***Error Trades***
CKPM	89.89%	10.11%
VKPM	68.75%	4.58%
VUPM	82.89%	17.11%
CKIM	39.79%	60.21%
VKIM	57.26%	42.74%
VUIM	59.52%	40.48%

Table 7.9 Mean Percentage of Efficiency Losses due to Missed and Error Trades

The final preliminary analysis of trading behaviour incorporates a comparison of the average profits earned by informed and uniformed traders on a period by period basis. The FRE model in its strictest interpretation would predict no difference in the average profits of the two groups of traders. Figures 7.15-7.18 display the difference between the average (gross or net) profit of the informed and uninformed traders for each of the markets on a period by period basis. A positive observation indicates excess informed profits and a negative observation indicates excess uninformed profits.

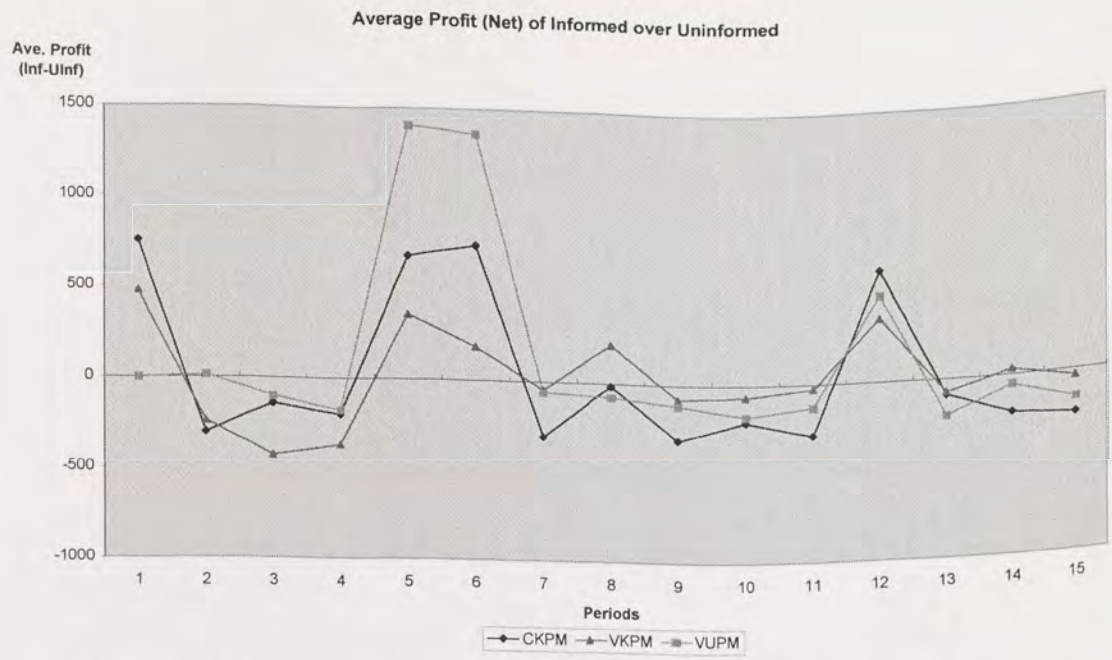


Figure 7.15 Difference between the Average Net Profit of Informed and Uninformed Traders per Period – PM Markets

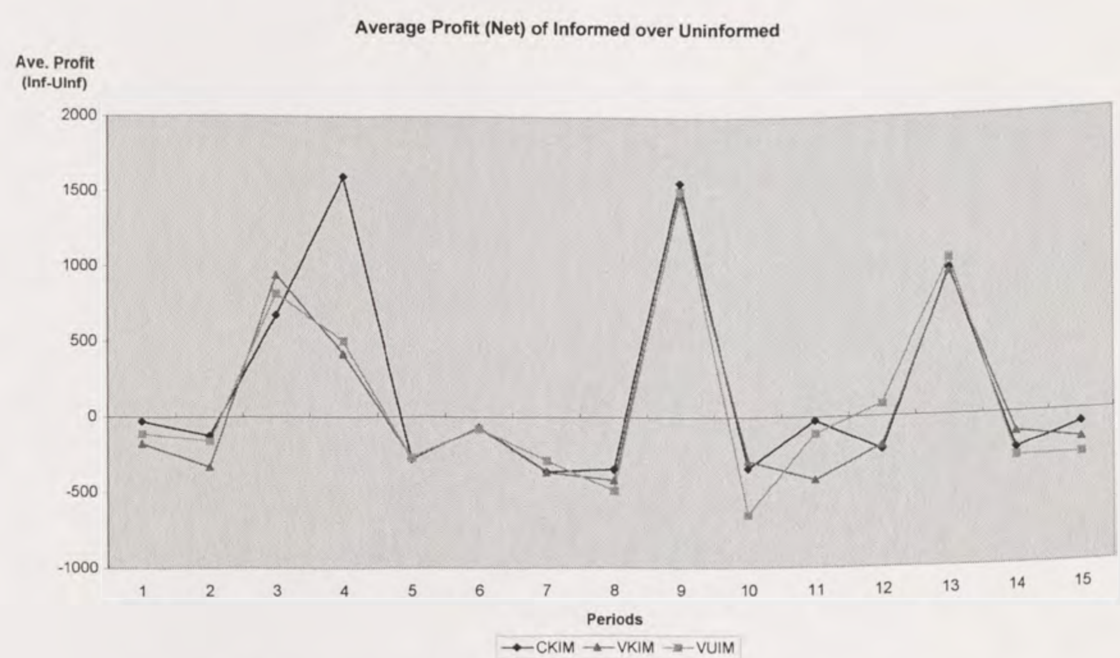


Figure 7.16 Difference between the Average Net Profit of Informed and Uninformed Traders per Period – IM Markets

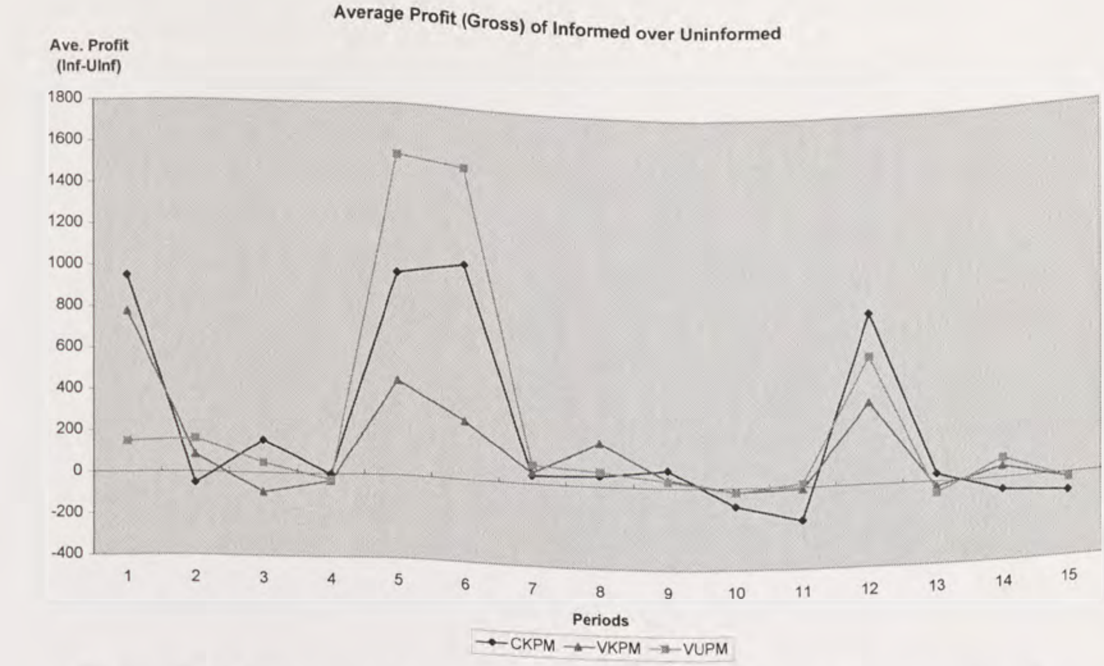


Figure 7.17 Difference between the Average Gross Profit of Informed and Uninformed Traders per Period – PM Markets

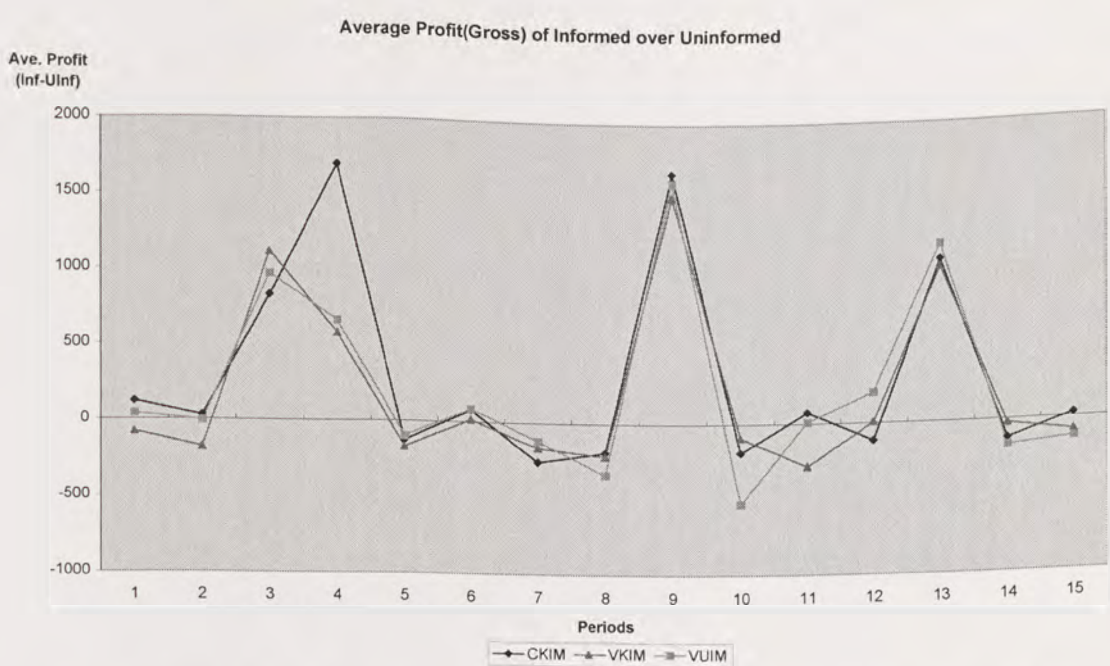


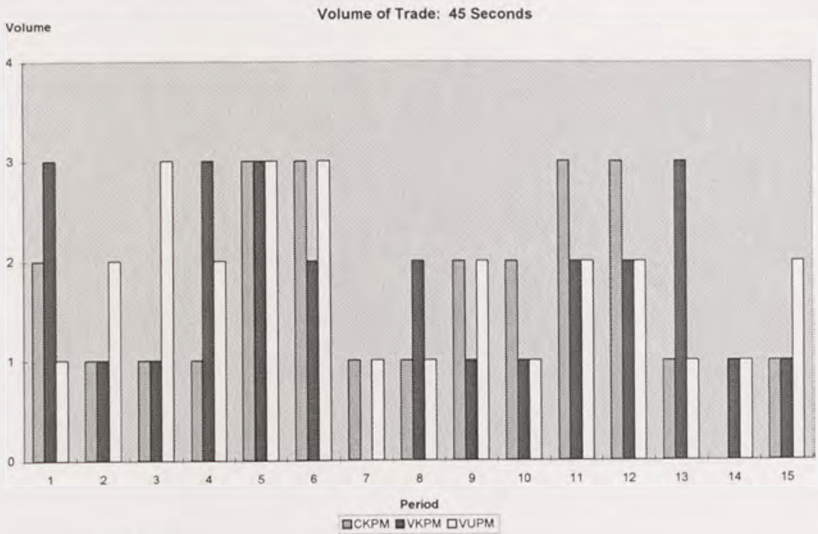
Figure 7.18 Difference between the Average Gross Profit of Informed and Uninformed Traders per Period – IM Markets

The gross profit functions from all six markets exhibit very little by way of trend, thus, it is difficult to draw strong inferences from the two figures. In terms of the impact of period duration, the same is true of the net profit functions. These functions, however, do provide one interesting insight. With the exception of the state of nature Z, the net profit of the uninformed exceeds that of the informed in most other periods. This is true irrespective of information structure. It is possible to conclude from this that the informed traders are paying too much for the private information they receive[47]. This result has implications for the comparative analysis of the FRE and PI models carried out above on the information auction data. The FRE model predictions the zero worth of private information, insiders may, however, have 'overvalued' the information thus biasing the analysis against the FRE model and in favour of the PI model. This can only strengthen the case for the FRE model. Figures 7.17-7.18 below display the excess average net profit of the informed traders over the uninformed. The majority of periods display a negative value for this measure, providing evidence to support the belief that the informed traders are paying too much for the private information.

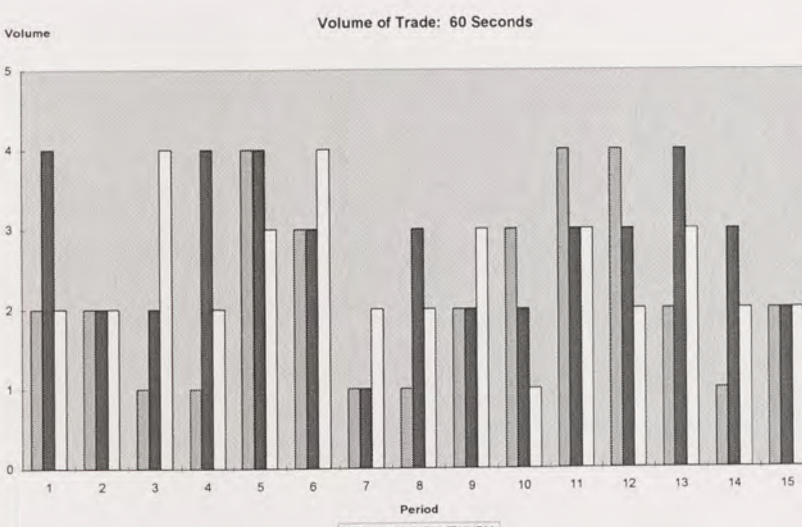
The results of a more comprehensive investigation of the impact of period duration on market behaviour by way of formal hypotheses testing will now be reported. The analysis of the stated hypotheses begins with a brief commentary of the Figures 7.19-7.20, which display the three measures of the volume of trade early in a period (VOL45,60,90) for the markets grouped by parameter design. This is followed by a commentary on the Figures 7.21-7.22, which graph the three measures of RMSD early in period (RMSD45,60,90). The analysis concludes by reporting and interpreting the statistical significant levels for the rejection of the null hypotheses ($1H_O$, $2.1H_O$, $2.2H_O$, $3.1H_O$ and $3.2H_O$).

[47] A form of winner's curse.

Panel A



Panel B



Panel C

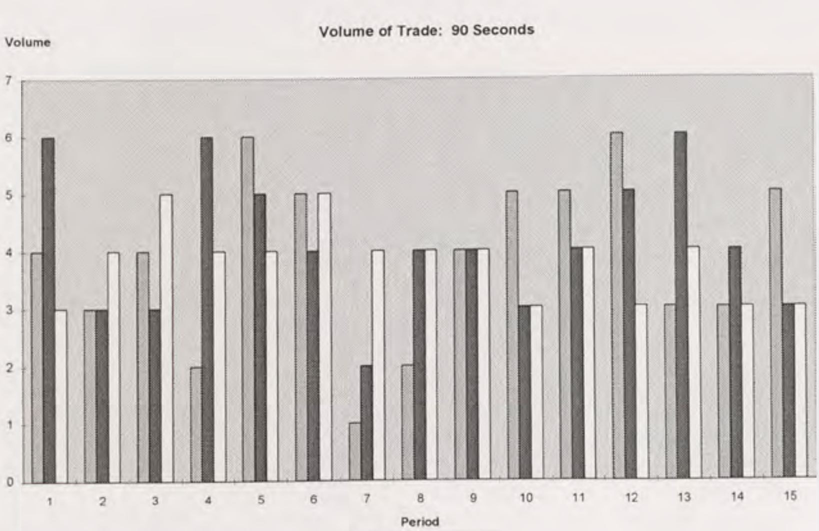
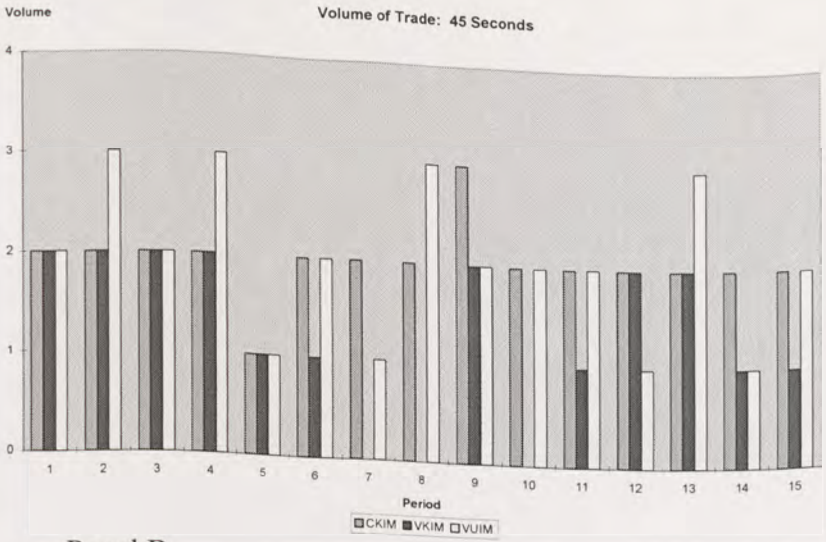


Figure 7.19 Volume of Trade in the First 45, 60 and 90 Seconds of Trade – PM Markets

Panel A



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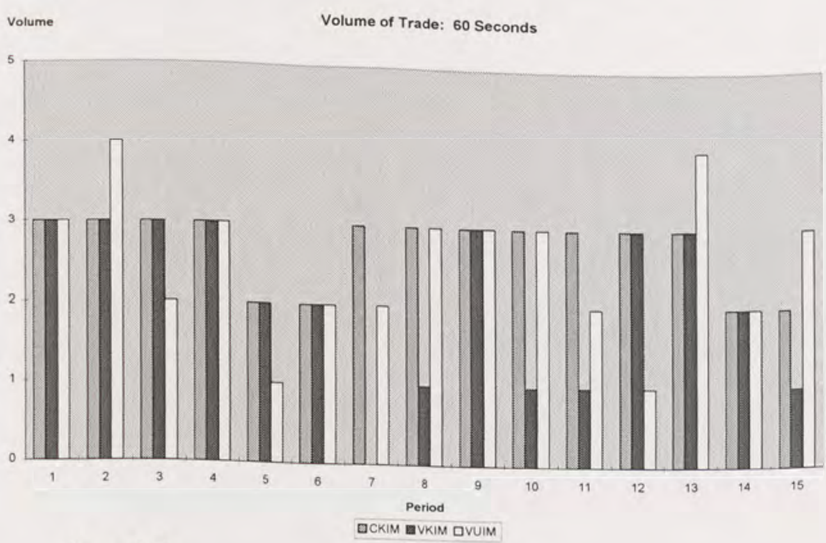

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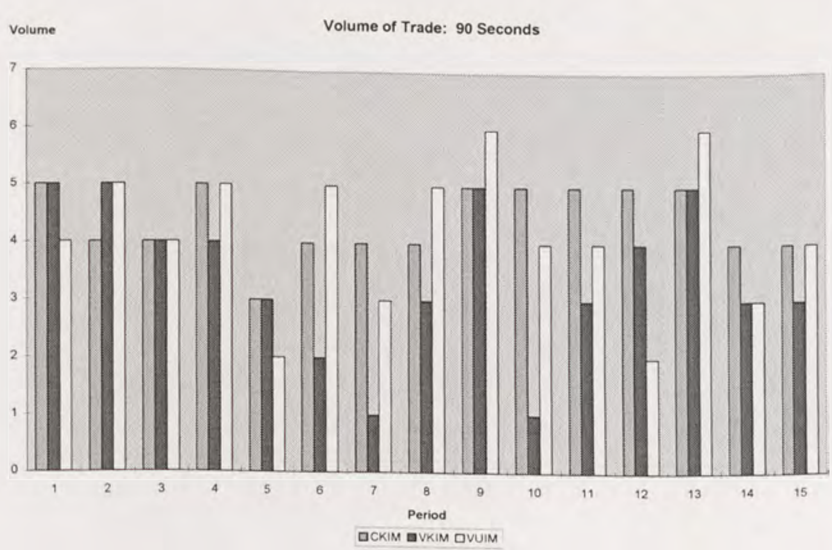
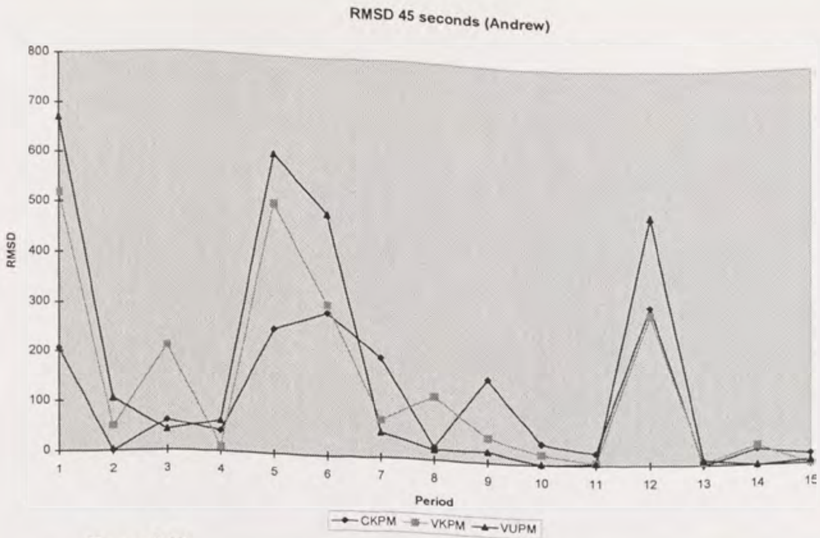


Figure 7.20 Volume of Trade in the First 45, 60 and 90 Seconds of Trade – IM Markets

Panel A



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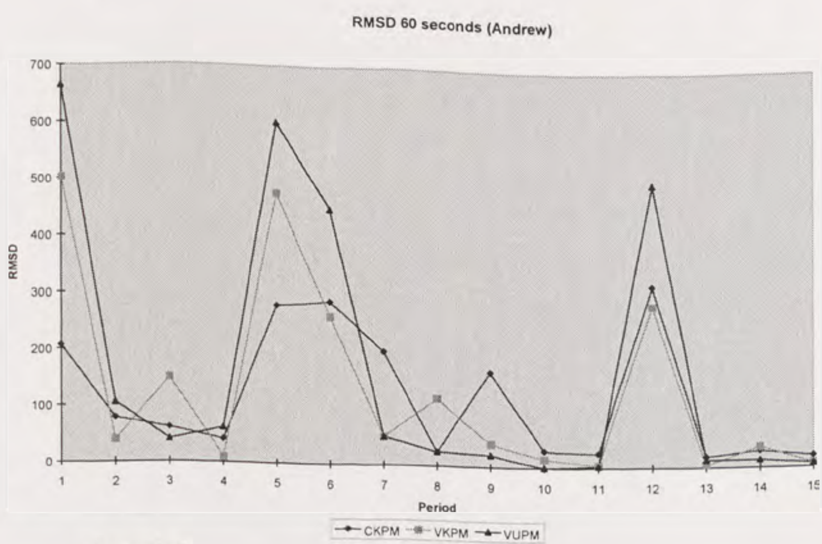

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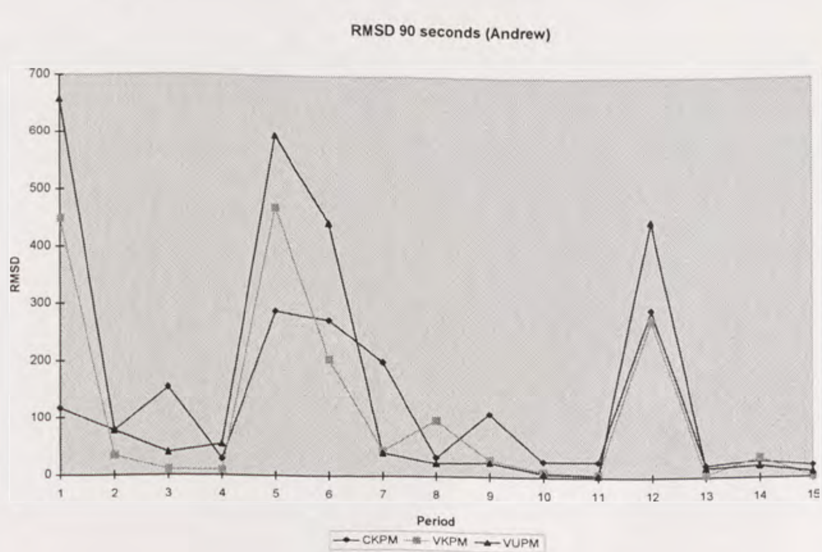
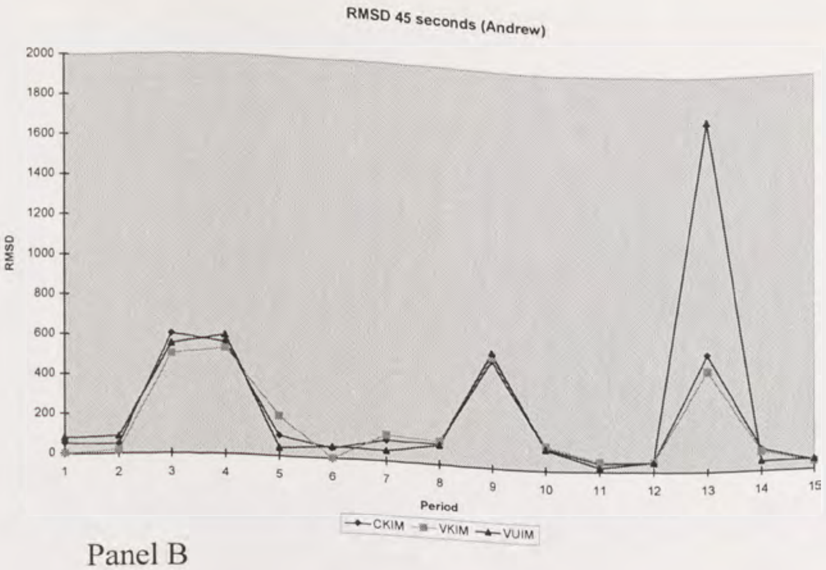


Figure 7.21 RMSD of Prices in the First 45, 60 and 90 Seconds of Trade – PM Markets

Panel A



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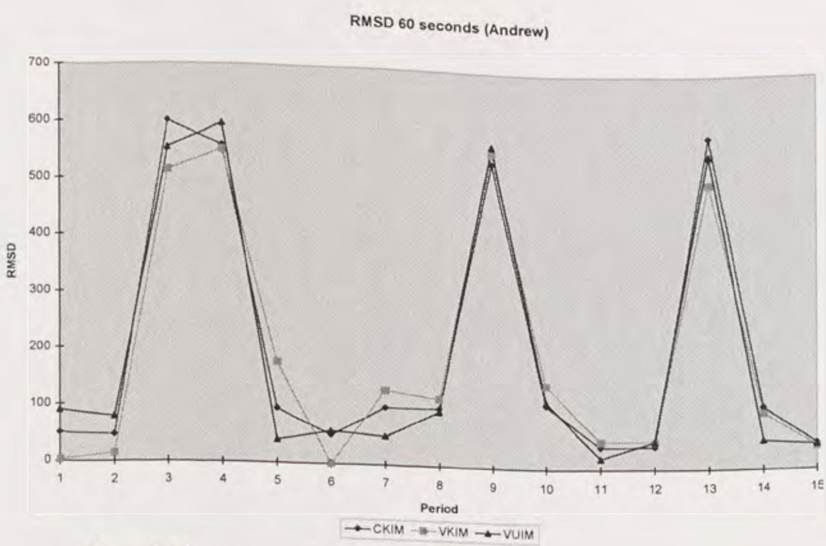

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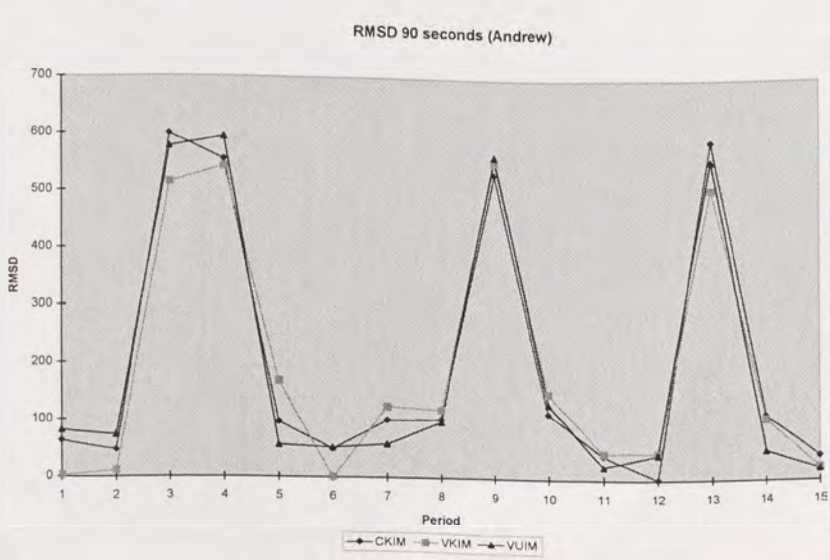

Figure 7.22 RMSD of Prices in the First 45, 60 and 90 Seconds of Trade – IM Markets

For all three measures of 'early' the volume of trade in the PM markets is very erratic, with the market with the highest volume changing on a regular basis from period to period. No clear indication of the impact of period duration can be inferred. For the IM markets this is not the case. The volume of trade across the three markets is not as erratic. Across all three measures of early the CKIM markets appear to generate a volume of trade in excess of the VKIM market in a number of periods. Whilst there appears little to differentiate between the CKIM and VUIM markets, the later market also seems to generate higher volumes of trade in some periods, relative to the VKIM market. A graphical interpretation of the IM data supports the belief that the volume of trade, early in a period, is influenced by the period duration with the VUIM market generating a higher volume of trade. The results of statistical tests of the impact are reported shortly.

Graphical representation of the RMSD early in a period is provided by Figures 7.21-7.22. For all three measures of early in a period the RMSD measures are fairly erratic for the PM markets, with the market with the highest/lowest value changing on a regular basis. In contrast the IM markets all exhibit very similar functions for all three of the measures RMSD(45, 60, 90). It is impossible to arrive at any strong conclusions concerning the impact of period duration on the RMSD of prices from the FRE price.

The failure to draw any strong inferences of the influence of period duration on observed early market behaviour (VOL or RMSD) from simple graphical representation necessitates a more formal approach. The investigation, therefore, will now turn to an explicit statistical evaluation of the stated hypotheses.

Tables 7.10 and 7.11 report the level of statistical significance for which the null hypotheses, of no statistical difference in mean values across the two paired markets can be rejected for the PM and IM market, respectively. Attention is once more drawn to the fact that the data used in the following statistical tests has been adjusted in order to remove the intra-market dependence of observations across periods. For the RMSD, VOL, NORMVOL and NORM%GAIN variables, the figures reported are means of the unadjusted values, across all trading periods. For each variable, the figure in parentheses reports the mean of the adjusted values. The Wilcoxon signed ranks test (WSR) was used to compute two-tail significance levels, based on 15 paired observations, for the comparisons between the three market types. Recall that the CK:VU comparison confounds the effects of both varying period durations and uncertain period durations. The two effects can be isolated and analysed separately from one another via the CK:VK and VK:VU comparisons. The results of the CK:VU comparisons will not, therefore, generally be discussed directly. The remainder of this section will consider separately the impact of period duration on the volume of trade early in a period, the informational efficiency and the overall allocational efficiency of the experimental markets CK, VK and VU. The analysis is performed separately on the PM and IM markets.

Variable	*Market means (Adjusted Means)*			*WSR Two-tail α-values*		
	CKPM	*VKPM*	*VUPM*	*CKPM: VKPM*	*CKPM: VUPM*	*VKPM: VUPM*
VOL45	1.6667 (1.8299)	1.7333 (1.6413)	1.800 (1.8959)	0.3343	0.5321	0.1556
VOL60	2.2000 (2.4743)	2.8000 (2.7330)	2.4667 (2.5420)	0.9096	0.9096	0.6909
VOL90	3.8667 (4.1440)	4.1333 (4.0030)	3.800 (3.8244)	0.4603	0.4265	1.0000
NORMVOL	0.0575 (0.0545)	0.0524 (0.0509)	0.0483 (0.0485)	0.4955	0.3635	0.2805
RMSD45	111.6958 (127.2370)	147.9507 (119.1727)	171.9100 (143.9317)	0.4603	0.7333	0.4603
RMSD60	119.4077 (131.1053)	133.4501 (105.6831)	170.6865 (142.4290)	0.2330	0.6496	0.3635
RMSD90	113.1627 (130.4018)	111.8327 (92.7783)	163.9640 (134.9071)	0.1118	0.5701	0.0995
RMSD	90.7525 (102.4972)	87.1397 (65.6754)	135.3720 (106.9726)	0.0268	0.6496	0.1728
NORM% GAIN	0.2455 (0.2678)	0.3032 (0.2891)	0.2145 (0.2577)	0.6092	0.7764	0.0884

Table 7.10 Summary Table of Market Means (Adjusted Means) and Wilcoxon Signed Ranks Test Two-tail Significance Levels.

Variable	Market means (Adjusted Means)			WSR Two-tail α-values		
	CKIM	VKIM	VUIM	CKIM: VKIM	CKIM: VUIM	VKIM: VUIM
VOL45	2.0000 (2.0320)	1.2667 (1.1327)	2.0000 (1.9326)	0.0007	0.2330	0.0022
VOL60	2.7333 (2.6529)	2.0667 (1.8363)	2.5333 (2.3940)	0.0007	0.0609	0.0409
VOL90	4.4000 (4.4042)	3.4000 (3.0939)	4.1333 (4.1217)	0.0012	0.0995	0.0090
NORMVOL	0.0619 (0.0591)	0.0443 (0.0432)	0.0476 (0.0479)	0.0199	0.1556	0.0409
RMSD45	206.8142 (205.6309)	195.1038 (200.7549)	279.4136 (302.9129)	0.9096	0.2330	0.3066
RMSD60	205.4429 (203.9369)	197.4537 (202.5641)	198.3139 (190.5495)	0.8203	0.3066	0.6906
RMSD90	203.4377 (198.0157)	194.5666 (199.0151)	199.1760 (190.2554)	0.8203	0.3635	0.6496
RMSD	195.5250 (191.2118)	189.3137 (193.2263)	196.2242 (188.6278)	0.8203	0.7764	0.7764
NORM% GAIN	0.0673 (0.0083)	0.0784 (0.0820)	0.0950 (0.0927)	0.0268	0.0468	0.4265

Table 7.11 Summary Table of Market Means (Adjusted Means) and Wilcoxon Signed Ranks Test Two-tail Significance Levels

Volume of Trade

Beginning with the PM market comparisons, the mean volume of trade in the VKPM markets, for all three measures of early (VOL 45, 60, 90), do not differ statistically from the corresponding values for the CKPM markets (α=0.4603, 0.23330 and 0.1118, respectively). In perfect information markets the mean volume of trade early in a period is not influenced by the varying of period durations. By the end of the trading period the mean rate of trade in the CKPM and VKPM markets does not differ significantly. Analysis of the IM markets reveals a totally different interpretation. The mean volume of trade in the CKIM market is significantly higher than that in the VKIM market for all three measures VOL(45,60,90) with significance levels of α=0.0007, 0.0007 and 0.0012, respectively. By the end of the period the mean rate of trade of 0.0591 for the CKIM markets is still statistically higher than the value of 0.0432 for the VKIM markets (α=0.0199). As argued in a previous chapter, there is no obvious reason for varying period durations to influence either the early volume or rate of trade in a market because the average period duration is identical for both the CK and VK markets. It is unclear, therefore, why the early volume and rate of trade in the CKIM markets should be so significantly higher than those observed in the VKIM market.

The comparison of the VKPM and VUPM markets reveals no impact of the uncertain period duration on any of the volume measures. Thus the conclusion from Chapter Five of more aggressive trading behaviour as a result of uncertainty concerning period durations, is not supported. In contrast, the evidence from the IM markets reveals significantly higher mean values for all three measure of early volume in the VUIM market relative to the VKIM market. The mean values of 1.9326, 2.3940 and 4.1217 for the measures VOL(45,60,90) significantly exceed the corresponding figures of 1.1327, 1.8363 and 3.0939 for the VKIM market (α=0.0022, 0.0090 and 0.0409, respectively). In addition, the rate of trade of 0.0479 witnessed in the VUIM market is significantly higher than the rate of trade of 0.0432 in the VKIM market (α=0.0409). In the more complex environments (imperfect information) of the IM markets the increased uncertainty over period duration results in more aggressive trading behaviour. This is entirely the opposite conclusion arrived at in Chapter Six markets with imperfect information structures, which exhibited significantly more cautious trading behaviour. There is no obvious reason why this should be the case. The holistic analysis of Chapter Eight will attempt to reach a definitive conclusion.

Informational Efficiency

As with the previous two chapters the formal analysis continues with an investigation of the informational efficiency observed in the experimental asset markets. The investigation begins with an evaluation of hypothesis 2.1H_O to determine the extent of any difference in transaction prices early in a period across the three markets, within an information structure. As reported in Tables 7.10 and 7.11, there are no significant differences in mean RMSD values for any of the three measures of early. This is true for all market comparisons in both the PM and IM markets. The null hypothesis 2.1H_O can not, therefore, be rejected. As a result, it would make no sense to formally evaluate hypothesis 2.2H_O for any of the PM or IM comparisons because no *difference* exists in the RMSD of early prices from the FRE model.

The markets were further compared to see if any difference existed between the RMSD of prices over an entire trading period. The only significant difference is reported in Table 7.10 for the comparison of the mean RMSD for the CKPM market and the VKPM market. The latter is significantly lower than the former, indicating a higher degree of informational efficiency (α=0.0268). Once again it would make no sense to formally evaluate hypothesis 2.2H_O because there is no significant *difference* in the mean NORMVOL measures of the two markets.

The results reported in this chapter provide no evidence in support of Friedman's (1984) view that a predetermined, known trading period duration is one of a number of features that enhances the informational efficiency of experimental markets, irrespective of information structure.

Allocational Efficiency

In this final analysis it remains to determine the impact of the two treatments (VK and VU) on the level of allocational efficiency observed in the experimental asset markets studied. For the PM markets the analysis fails to reject the null hypothesis 3.1H_O of no statistical difference between the mean NORM%GAIN figures in any of the paired comparisons. Therefore, in markets with perfect information structures there is no impact on the allocational efficiency of the markets as a result of the treatment period duration. In contrast, the results reported in Chapter Five for both the CKPN: VKPN and CKPN: VUPN comparisons provide statistically significant differences between the mean NORM%GAIN figures. It can be inferred, therefore, that the increase in experience level of the participants in the PM markets results in an increase in the allocational efficiency of both the VKPM and VUPM markets relative to the CKPM market.

The results reported for the CKIM: VKIM and CKIM: VUIM comparisons provide evidence of statistically significant differences in mean NORM%GAIN figures. Once more this is in contrast to early results, this time reported in Chapter Six. Of particular interest is the significantly higher mean NORM%GAIN figure for the VUIM market compared to the CKIM market (α=0.0468). In the complex environment of imperfect information the uncertainty over period durations appears to facilitate the level of allocational efficiency attained.

7.5 Discussion and Conclusions

The chapter initially reviewed the few experimental asset market studies that included a pre-trade auction for the costly acquisition of private information. Section

7.3 moved on to an explanation of the specifics of the experimental design employed for the six markets investigated in this chapter. Section 7.4 moved on to report and discuss the results of the analysis conducted. It is to a review of these results that the discussion in this final section now turns.

The comparative analysis of the FRE and PI models provided additional opportunities to evaluate the predictive accuracy of each model. The results from the three PM markets provided strong additional evidence in line with that reported in Chapter Five concerning the superiority of the FRE model. This was particularly evident from an analysis of the prices at which assets trade. In contrast, the evidence in favour of the FRE model is weaker in the IM markets. This too is in line with previous results, this time reported in Chapter Six. Casual comparison of the PN and IN markets with the PM and IM markets shows a significant improvement in all measures of convergence to FRE equilibrium predictions. These improvements were attributed to the increased level of experience of participants in the PM and IM markets.

Whilst not conclusive the results from the information auctions conducted could be construed as evidence in favour of the FRE model over the PI model. The purchase price of information shows signs of convergence to zero in most of the markets studied. The fact that the value of private information did not actually converge to zero could be due to a tendency to ‘overpay’ for the information on the part of the informed traders. The higher net profit of the uninformed over that of the informed in many periods replicated the results in Ackert et al (1997) and was deemed evidence of a kind of winner’s curse. The use of the purchase cost to proxy the value of private information introduces a positive bias into the measure, to the detriment of the FRE model.

The results reported in the investigation of the impact of period duration on observed market behaviour did not provide any decisive conclusions. For many of the comparisons the evidence reported in this chapter was contradictory to that reported in Chapters Five and Six for perfect and imperfect information structures, respectively. This is true of many comparisons of the volume of trade plus the informational and allocational efficiency in all PM and IM markets. It is difficult to conclude whether uncertainty regarding period duration has a beneficial or detrimental effect on observed performance in DA markets. It is, therefore, not possible to generalise and infer the effect for the on-line auctions that have developed with the growth in virtual communities. In an attempt to provide definitive conclusions regarding the effect of period duration the following chapter will exploit the statistical power of the 3x2x2 full factorial design of the entire experiment via a holistic analysis of the data.

Chapter Eight

8 HOLISTIC ANALYSES

8.1 Introduction

The previous three chapters reported the results of various analyses of market performance grouped by experimental design. In the perfect information markets of Chapter Five the FRE model was clearly superior to the PI model. Uncertainty concerning period duration played a role in these simple markets, with a resultant increase in the both the early volume and the rate of trade observed, plus a reduction in the level of informational efficiency displayed over an entire trading period. The complexity of the trading environment was increased in the Chapter Six markets with the incorporation of imperfect information structures. The obvious superiority of the FRE model was no longer as apparent, with the PI model making better predictions under a number of performance measures. Furthermore, contrary to the results reported for the PN markets, the coupling of increased state uncertainty with period duration uncertainty resulted in a reduction in the volume of trade early in a period. There was little effect, however, on the level of informational efficiency. The markets in Chapter Seven replicated those in Chapters Five and Six, with the inclusion of a pre-trade information auction and increased experience as slight modifications to the experimental design. The perfect information markets clearly displayed the superiority of the FRE model, whereas the imperfect markets only offered weak evidence in the model's support. Unfortunately the reported results were contradictory with respect to the effect of uncertain period durations for many of the measures of market performance adopted.

The purpose of this chapter is to offer an overall analysis of all 18 experimental asset markets conducted in an attempt to derive clear conclusions concerning the performance of the FRE model and the influence of uncertain period durations on observed market performance. The experimental design also allows other interesting effects to be investigated, including the impact of the information structure and the confounded effects of information auctions and experience level. To this end the analysis to follow will exploit the strength of the 3x2x2 full factorial experimental design that is constructed when the four groups of experimental asset markets are combined layer upon layer. Table 4.4 of Chapter Four summarises how the four groups are combined to create the full factorial experiment. The benefit of analysing all four groups of markets collectively is an increased number of paired observations, providing greater discriminatory power to the statistical tests employed.

The benefit derived from the use of a full factorial design is the ability to block out confounding effects, which provides for the analysis of a single treatment effect in isolation. The result is a heightened conviction in the results reported from such an analysis.

The chapter is separated into sections investigating different aspects of market performance and the influence of different treatment effects. The structure of the chapter is as follows. The next section reports the results of a comparison of the predictive powers of the FRE and PI models. Section 8.3 reports the results of the investigation of the impact of period duration on observed market behaviour. This issue is the main focus of this research. The subsequent section reports the results from an analysis of the impact of information structure on observed market behaviour. Section 8.5 offers a discussion concerning the effect of the confounded factors, information auction and experience level. The concluding section offers a summary and draws conclusions.

8.2 FRE v PI: Comparative Performance Evaluation

The results from previous chapters support the belief that the FRE model is clearly a superior predictor of market performance in the simple, perfect information markets. The evidence from the more demanding imperfect information markets is not so decisive one way or another, but offers the conclusion that the performance of the FRE model is at least weakened. The analysis here will attempt to draw definitive inferences concerning the superiority of one model over another. The various performance measures adopted in previous chapters will once more be employed.

Firstly, the RMSD of transaction prices from the equilibrium predictions of the FRE and PI models across all the 270 trading periods (18 markets each with 15 trading periods) were computed and compared over the first 45, 60 and 90 seconds of trade plus an entire period's trade. Of the 270 trading periods, however, the price predictions of the two models were identical on 39 occasions, thus preventing any discrimination between the two models. These periods were not included in the analysis, which was based on the remaining 237 trading periods. For the four measures RMSD45, RMSD60, RMSD90 and RMSD entire period the percentage of periods in which the RMSD of prices from the FRE prediction is lower than for the PI prediction are 74.68%, 75.11%, 76.79% and 78.06%, respectively. The evidence supports the view that the FRE model is clearly superior to the PI model. In addition, whilst slight, there is a clear increase in the percentage of periods in which the FRE model is superior as the duration of trade increases. This is interpreted as evidence of an adaptive component in trading behaviour towards the FRE equilibrium price, within a period.

The second performance measure employed is the number of assets misallocated with respect to the FRE and PI models' end period allocation predictions. The number of periods upon which this analysis is based is all 270, because there are no periods where the two models make the same predictions concerning the allocation of assets. In 45.93% of periods the number of assets misallocated by the FRE model is lower than the figure for the PI model, whilst the reverse is true in a only 12.59% of periods. Recall that in order to prevent any bias in the misallocation comparison an indiscriminate region, ∂, was defined. A total 41.48% of periods fall into this indiscriminate region. Similar comparisons were performed across all perfect information markets and all imperfect information markets. The percentage of periods in which the FRE model makes fewer misallocations is 62.96% and 28.89% for the perfect and imperfect markets, respectively. The corresponding percentages for the PI model are 5.19% and 20.00%, respectively. Therefore, even in the more demanding imperfect information environment the FRE model performs better than the PI model. The evidence regarding the misallocation of assets is more favourable to the FRE model than the PI model and so is interpreted as supporting the superiority of the FRE model.

Previous chapters made use of a simple test to discriminate between the FRE and PI models based on the sign of the predicted gains from trade. The predicted gains are always positive for the FRE model, whereas the PI model predicts negative or zero gains from trade in some periods. The results from the previous chapters will be aggregated here to give an overall indication of this measure. Across all 18 markets there were 105 occasions where the PI prediction was either negative or zero. On only 46 occasions (43.81%) were the realised gains from trade either negative or zero. Therefore, on the majority of occasions (56.19%) this simple test favours the FRE model over the PI model.

A final measure reported in previous chapters is the degree of excess profits earned by informed traders over uninformed traders. The FRE model would predict this measure to be zero in equilibrium, whilst the PI model would predict a positive value. On many occasions this measure was interpreted as weak evidence against the

FRE model. Aggregated over all 270 trading periods, the percentage of periods where the measure was positive is 62.59%, which again offers weak support of the PI model. This is only interpreted as weak support because the FRE prediction of zero excess profit would require the price signal to reveal the state of nature immediately upon the commencement of trade. This interpretation of the FRE model is excessively strict. As indicated in the RMSD comparisons above, the observed market behaviour appears to be adaptive towards the FRE equilibrium rather than instantaneous. For this reason this measure of comparative performance is given less emphasis than the other ones employed.

To conclude this comparative analysis of the predictive performances of the FRE and PI models, the evidence reported above, which utilises all 18 asset markets, is interpreted as providing much greater support in favour of the FRE model than it generates for the PI model. Whilst trading behaviour may not instantaneously adhere to the prescriptions of the FRE model, it does, however, converge to these equilibrium predictions over time. The role of experience, both within a period and within a market, is clearly important. The importance of experience was alluded to in Chapter Seven when the performance in the PM markets relative to the FRE benchmark far exceeded that in the PN markets in which participants were less experienced.

8.3 Period Duration

This section employs the data from all 18 experimental asset markets to analyse the impact of period duration on the observed market behaviour. The effect is separated between the influence of varying the period durations (VK markets) and the effect of uncertainty concerning the period durations (VU markets). The data analysed has been adjusted to remove the influence of outliers and dependence. The data is aggregated across the CK, VK and VU markets in a number of paired comparisons. The observations are paired across markets where the only difference in experimental design is the period duration type (that is, CK, VK or VU), therefore, the impact of all other confounding treatment effects is blocked out and thus controlled. The measures VOL(45,60,90), NORMVOL, RMSD(45,60,90), RMSD over the entire period and the NORM%GAIN are used to compare the observed market behaviour. Table 8.1 reports the two-tail statistical significance levels for which the null hypothesis of no difference in mean values can be rejected for all the paired comparisons, based on the WSR test on the data aggregated across the CK, VK and

VU markets. The number of paired observations employed in each test is n=90.

The comparison of the CK and VK markets for the measures of the volume of trade provide evidence of a statistically significant reduction in the mean VOL45 and NORMVOL measures as a result of incorporating varying period durations. In contrast the uncertainty over period duration clearly has a major significant influence on the observed volume. The VK:VU comparison reveals higher mean values for the VU markets, which are highly significant for all measures with the exception of the VOL60 measure. This measure is only marginally insignificant and would have been classed a significant result had one-tail tests been employed. The uncertainty over period duration clearly results in a more aggressive trading behaviour.

A comparison of the measures of RMSD for the CK:VK pairing also results in significant differences in mean values. The mean RMSD45 measure for the VK markets is significantly higher than the mean CK value, however, by the time 60 seconds of trade in a period has passed the mean VK values are significantly lower than the corresponding values for the CK markets. The VK markets, therefore, are informationally more efficient than the CK markets. For the VK:VU markets the comparison reveals little by way of significant results for the three measures of early in a period. By the end of a trading period, however, the mean RMSD in the VU markets significantly exceeds that witnessed in the VK markets. It can be concluded that the uncertainty over period duration results in a reduced level of informational efficiency observed over an entire trading period.

The three market types do not differ with respect to the level of allocational efficiency generated. This is evidenced by the insignificant differences in mean NORM%GAIN figures. Despite the lower mean NORM%GAIN figure in the VU markets it can not be concluded that the uncertainty over period duration impacts on the allocational efficiency in experimental asset markets[48].

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[48] A similar analysis was performed to compare the mean information cost across the three different market types, CK, VK and VU. It is possible that varying or uncertain period duration may influence the cost paid to purchase information. No statistical differences in mean information costs were found for any of the paired comparisons.

Variable	*Market Means (Adjusted Means)*			*WSR Two-tail α-values*		
	CK	*VK*	*VU*	*CK:VK*	*CK:VU*	*VK:VU*
VOL45	1.7800	1.6200	1.9300	0.0427	0.2604	0.0110
	(1.8226)	(1.6820)	(1.9795)			
VOL60	2.4400	2.4300	2.6400	0.9920	0.0335	0.0873
	(2.5031)	(2.4832)	(2.7358)			
VOL90	3.9300	3.8100	4.0800	0.2676	0.0082	0.0054
	(3.9148)	(3.8120)	(4.2084)			
NORMVOL	0.0547	0.0462	0.0479	0.0418	0.3537	0.0432
	(0.0520)	(0.0463)	(0.0489)			
RMSD45	155.7800	234.9600	206.6500	0.0037	0.7613	0.0705
	(152.0324)	(153.0756)	(210.4140)			
RMSD60	156.1700	441.2100	182.6800	0.0027	0.5746	0.0711
	(148.5504)	(141.2839)	(186.7395)			
RMSD90	148.9600	147.9600	160.3400	0.0079	0.1238	0.4315
	(144.0205)	(138.1392)	(137.2264)			
RMSD	139.9400	127.9000	146.9500	0.0011	0.1707	0.0498
	(136.1854)	(5.4494)	(120.5776)			
NORM%GAIN	0.1357	0.1406	0.1172	0.9055	0.1856	0.4514
	(0.1483)	(0.1513)	(0.1353)			

Table 8.1 Summary Table of Market Means (Adjusted Means) and Wilcoxon Signed Ranks Test Two-tail Significance Levels - Period Duration Comparison

8.4 Information Structure

Many of the previous experimental studies find that an imperfect information structure weakens the predictive ability of the FRE model compared to the PI model. The analysis to follow compares the market performance across the two information structures, perfect (P) and imperfect (I). The data analysed has been adjusted to remove the influence of outliers and dependence. The data is aggregated across the P and I market types and observations are paired across markets where the only difference in experimental design is the information structure (that is, P or I), therefore, the impact of all other confounding treatment effects is blocked out and thus controlled. The measures VOL(45,60,90), NORMVOL, RMSD(45,60,90), RMSD over the entire period and the NORM%GAIN are used to compare the observed market behaviour. Table 8.2 reports the two-tail statistical significance levels for which the null hypothesis of no difference in mean values can be rejected for all the paired comparisons, based on the WSR test on the data aggregated across the P and I markets. The number of paired observations employed in each test is n=180.

Whilst the mean volume of trade early in a period does not differ across the information structure types for the two measures VOL45 and 60, the mean VOL90 and NORMVOL measures are both significantly higher for the P markets than the I markets. This is evidence that the increased state uncertainty inherent in the imperfect information markets causes traders to be more cautious over their trading strategies.

The reported caution in response to the more complex and uncertain trading environment does not effect the informational efficiency observed early in a period. This is evidenced by the failure to reject the null hypothesis of no statistical difference in mean values between the P and I markets for the three measures RMSD(45,60,90). By the end of a trading period, however, the mean RMSD in the I markets is significantly higher than the mean figure for the P markets. The increased state uncertainty and associated cautious trading behaviour ultimately results in a lowering of informational efficiency attained by the asset markets. This evidence provides direct support for many of the findings in other experimental studies incorporating imperfect information structures (for example, Plott and Sunder, 1988).

Again in line with earlier findings, the evidence from this holistic analysis of the P and I markets provides conclusive evidence of a dramatic reduction in the level of allocational efficiency observed in imperfect information markets. This conclusion is strongly supported by the highly significant difference in the mean NORM%GAIN figures for the two information structures, with the P market figure far higher than the I market figure (α=0.0000).

Variable	*Market Means (Adjusted Means)*		*WSR Two-tail α-values*
	P	*I*	*P:I*
VOL45	1.8000 (1.8699)	1.7500 (1.7861)	0.7146
VOL60	2.5600 (2.6643)	2.4500 (2.4837)	0.0661
VOL90	4.0300 (4.0958)	3.8500 (3.8610)	0.0544
NORMVOL	0.0513 (0.0507)	0.0479 (0.0475)	0.0016
RMSD45	220.8600 (177.2399)	177.3900 (166.4413)	0.2163
RMSD60	356.5800 (166.6397)	163.4600 (151.0760)	0.1678
RMSD90	142.6600 (129.9423)	162.1500 (149.6485)	0.3252
RMSD	116.3200 (26.1787)	160.2000 (148.6296)	0.0008
NORM%GAIN	0.1963 (0.2207)	0.0660 (0.0692)	0.0000

Table 8.2 Summary Table of Market Means (Adjusted Means) and Wilcoxon Signed Ranks Test Two-tail Significance Levels - Information Structure Comparison

8.5 Information Auction and Experience Levels

The PN and IN markets differ from the PM and IM markets in two respects. The latter markets incorporate a pre-trade information auction plus individuals that had previously participated in one of the PN or IN markets and are, therefore, more experienced. Given the experimental design it is not possible to differentiate between the effect of these two changes in design. The confounding effect of one of the changes in design can not be separated from the other change in design by blocking. Recall that the reason for using experienced participants in the PM and IM markets resulted from the recruitment problems experienced in the PN and IN markets. It had not originally been the intention to use experienced participants in any of the markets studied. It was only after half of the experimental design had been conducted that the decision was taken to recruit experienced participants. At this point it was too late to adjust the experimental design to block the effect of experience from the effect of incorporating pre-trade information auctions.

A priori, there is no obvious reason to believe that the incorporation of an information market will impact in any systematic manner on observed market performance. The endogenous determination of insiders does not guarantee the uniform distribution of private information across trader types. Indeed, as discussed in Chapter Seven, the information auction favoured the type 2 traders because they had the highest expected dividend value in the absence of private information. This point was supported by the actual distribution of private information, which clustered around the type 2 traders. The implication is a number of periods where the information is distributed to less than two traders from the trader type group predicted by the FRE model to hold the assets by the end of the period. There were a number of periods where none of the predicted traders received private information, see Chapter Seven for the discussion of examples. Despite this fact many of the markets exhibited strong convergence to the FRE equilibrium. The incorporation of information markets would be expected to impede the level of efficiency attained. Comparison of the PN with PM markets and of the IN with IM markets, however, shows this not to be the case. The only logical conclusion to draw is that the increased experience level in the markets with information auctions results in an increase in market efficiency.

Due to the confounding effects of experience and information auctions the use of statistical tests (WSR test) and the interpretation of significance levels to provide evidence of the effect of experience on market behaviour would not be methodologically sound practice. For this reason the results from such an analysis are not reported. However, it is possible to support the conjecture with reference to less formal evidence. The Figures 7.1-7.6 of Chapter Seven provide evidence of the improved informational efficiency relative to the corresponding figures for the Chapter Five and Six markets. The mean %GAIN figure of 38.20% across all M markets exceeds that of 26.64% for all N markets providing evidence of the improved allocational efficiency. The positive effect of experience on observed market behaviour is in line with the evidence reported in numerous other experimental studies (for example, Forsythe and Lundholm, 1990) that have designed experiments where the effect of experience is isolated and formally tested.

8.6 Discussion and Conclusions

The results reported in this chapter were based on a holistic analysis of the data generated by all 18 asset markets conducted in this research programme. The choice of a full factorial design permitted the investigation of individual treatments in isolation of any other confounding effects. The use of observations paired on a period by period basis provided for the strict control of all changes in the experimental design other than the one designated treatment effect, by blocking out confounding effects. The benefits associated with the use of all 18 markets in this holistic investigation were discussed in section 8.1. This was followed by a comparative evaluation of the performances of the two equilibrium models in section 8.2. The impact on market performance of period duration was investigated in section 8.3. This was followed by an investigation of the effect of type of private information available, perfect or imperfect. Section 8.5 reported the joint effect on market performance of information auctions and increased participant experience. This final section now summarises the results reported in the earlier sections.

The comparative holistic analysis of the two equilibrium models, based on 270 period observations, provided strong and conclusive support for the superiority of the FRE model over the PI model. The major focus of this research programme, however, was an investigation of the effect of period duration on market performance. The holistic analysis reported in section 8.3 provided evidence that uncertainty over period duration influenced both the early volume of trade and the rate of trade over an entire period. The uncertainty (VU markets compared to the control VK markets) resulted in relatively more aggressive trading behaviour. It was also evident that uncertainty over period duration lowered the relative level of informational efficiency over an entire trading period, but had no effect on the level of allocational efficiency. These results are generally in line with the results from the pilot analysis reported in Duxbury (1997).

The evidence from the holistic analysis regarding the effect of the type of information structure was conclusive. The move from a perfect to an imperfect information structure reduced the rate of trade observed over an entire period. The levels of informational and allocational efficiency obtained over an entire period were also significantly impaired. The increased uncertainty surrounding the state of nature impeded the convergence to FRE equilibrium predictions.

By way of conjecture it was also argued that the level of participant experience was an important factor on observed market performance. Indirect evidence was offered in support of the facilitating influence of increased experience on the convergence of market behaviour to FRE equilibrium predictions. Increased experience levels improve both informational and allocational efficiency.

To conclude, there is a significant impact of uncertain period duration on observed market performance, in particular the volume of trade and informational efficiency. In general, uncertain period durations result in a higher volume of trade and a lower level of informational efficiency in markets governed by the rules of exchange of the DA institution. This evidence directly supports Friedman's (1984) conjecture regarding the influence of predetermined, known period duration on the convergence tendency of transaction prices to competitive equilibrium outcomes in DA markets. The robust convergence of transaction prices to FRE predicted equilibrium values reported in previous experimental asset market studies from Plott and Sunder (1982) onwards, may partly be a product of the constant and known period durations employed in the experimental design of those markets. In the markets with uncertain period durations studied here the price signal does not reveal the same amount of information regarding the underlying state of nature as is observed in markets with known period durations. Despite this, there is no significant difference between the level of allocational efficiency and gains from exchange exhausted by the two market types.

The results have implications for the rules of exchange developed to govern trade across electronic networks. If the vendors of commodities are the designers and implementers of the institutional rules of exchange it may be in their interest to incorporate on-line auctions with uncertain period durations. The effect of which would be an increase in the volume of trade. It is not clear whether the inefficient pricing of commodities would benefit vendors or customers. It would depend on whether the assets traded at prices above or below their true economic worth. Further research is required to provide a definitive conclusion.

Chapter Nine

9 SUMMARY OF RESULTS AND CONCLUSIONS

9.1 Introduction

The efficient functioning of the world's financial asset markets in the allocation of scarce capital among competing investment alternatives is central to the economic well being of society in general. The generation of economic wealth via gains from exchange is essential for economic prosperity. Just how efficient the financial markets are, therefore, is an issue of paramount importance. To date the academic literature has yet to come to a consensus, and the jury is still out. Whilst there does not appear to be a consensus on the issue of market efficiency the institutional rules governing trade clearly play a key role in the price formation process and consequently the overall efficiency of the financial markets. The double auction (DA) is a trading institution used the world over, from the London Stock Exchange to the New York Stock Exchange. The wide spread adoption of the DA as the institution of exchange results from the high levels of informational and allocational efficiency that it generates. This research programme has attempted to shed light on why the rules governing trade under the DA are so efficient, paying particular attention to the influence of known period duration.

The purpose of this concluding chapter is double focused. Firstly, a brief summary is offered of the contributions made by the previous chapters, paying particular attention to the results of the analyses conducted in Chapters Five to Eight. The second focus of the chapter is reflective, drawing inferences and interpretations from the evidence reported in earlier chapters. The structure of the chapter is as follows. Section 9.2 reiterates the motivation and restates the objectives of the current research programme. Also included is a brief review of the research method adopted to achieve those objectives. Section 9.3 then summarises and interprets the main results generated by the investigation of the experimental asset markets conducted. The concluding section voices the lessons to be learned from this research.

9.2 Research Objectives

Despite the wide ranging evidence documenting the rapid and relatively robust convergence tendencies of the double auction (see Chapter Three for a comprehensive literature review), no consensus has emerged on why the double auction institution performs so efficiently. Also, despite recent advances the theoretical literature has failed to produce a generally accepted model of the bid, ask and transaction price behaviour observed under the DA market. The intention here was to aid further theoretical refinement by conducting a series of boundary experiments designed to investigate the importance of prior knowledge of period duration on the tendency of experimental asset markets to converge to a FRE equilibrium (Chapter Two introduced the theoretical equilibrium models). The few studies attempting to develop dynamic models of the DA market generally incorporate, either explicitly or implicitly, known period duration (for example, Friedman, 1984, 1991). Knowledge of period duration may be a key variable in the determination of the price adjustment process and the convergence to competitive equilibrium in the double auction institution. Chapter Five offered a comprehensive discussion of the issues motivating this research programme and introduced a number of hypotheses designed to facilitate the investigation into the effect of period duration on trading behaviour.

A number of experimental asset markets were designed with the specific intention of isolating and observing the effect of period duration, as a treatment variable, on market behaviour. The experimental design adopted was similar to the earlier design of Plott and Sunder (1982), as adapted by Banks (1985) and further developed by Sunder (1992). The novel feature of the experimental design adopted is the introduction of varying period durations and uncertain period durations. Other treatment variables investigated included perfect versus imperfect information structures and costless versus costly private information. Chapter Four detailed the specifics of the general experimental design adopted and provided justification for the design's choice.

9.3 Summary of Results

Chapters Five, Six and Seven reported the results from the four groups of experimental asset markets conducted, whilst Chapter Eight exploited the benefit of the combined 3x2x2 full factorial design to report the results from a number of holistic analyses. The holistic analyses allowed a number of strongly supported conclusions to be drawn concerning the superiority of the FRE model over the PI model and the effects of period duration and information structure type on observed market performance. The evidence also supported the conjecture that participants' experience levels were important for the convergence of market behaviour to FRE equilibrium. It is to a review of these conclusions that the discussion now turns.

9.3.1 Superiority of the FRE Model

The results from Chapter Five support the view that the FRE model is clearly a superior predictor of market performance in simple, perfect information markets. The evidence from the more demanding imperfect information markets of Chapter Six, however, is not so decisive, but offers the conclusion that the performance of the FRE model is at least weakened. Overall the evidence from the holistic analysis reported in Chapter Eight was strongly in support of the FRE model. For the four measures RMSD45, RMSD60, RMSD90 and RMSD over an entire period, the percentage of periods in which the RMSD of prices from the FRE prediction is lower than for the PI prediction were 74.68%, 75.11%, 76.79% and 78.06%, respectively. The results, therefore, support the view that the FRE model is clearly superior to the PI model. In addition, whilst slight, there is a clear increase in the percentage of periods in which the FRE model is superior as the duration of trade increases. This was interpreted as evidence of an adaptive component in trading behaviour towards the FRE equilibrium price, within a period.

The number of assets misallocated with respect to the FRE and PI models' end period allocation predictions were also compared. In 45.93% of periods the number of assets misallocated by the FRE model is lower than the figure for the PI model, whilst the reverse is true in only 12.59% of periods. The evidence regarding the misallocation of assets was more favourable to the FRE model than the PI model. Again this was interpreted as supporting the superiority of the FRE model.

The results from a simple test to discriminate between the FRE and PI models based on the sign of the predicted gains from trade were also more supportive of the FRE model. Across all 18 markets there were 105 occasions where the PI prediction was for either negative or zero gains from trade. On only 46 occasions (43.81%), however, were the realised gains from trade either negative or zero, whilst for the majority of periods (56.19%) the gains were positive providing further evidence in support of the FRE model over the PI model.

The only measure for which the PI model was the superior predictor was the comparison of gross profits across the informed and uninformed traders. To offer support in favour of the FRE model, however, this measure would require the instantaneous convergence of transaction prices to the FRE equilibrium price. Such an interpretation is excessively strict and so the measure is effectively biased in favour of the PI model. It was for this reason, therefore, that little emphasis was placed on the results of this test.

In conclusions, the evidence from all 18 asset markets was interpreted as providing much greater support in favour of the FRE model than for the PI model. Whilst trading behaviour may not instantaneously adhere to the prescriptions of the FRE model, it does, however, converge to these equilibrium predictions over time.

9.3.2 The Effect of Period Duration on Market Performance

The effect of period duration on observed market behaviour formed the central issue of consideration for this research programme. The effect was separated between the influence of varying the period durations (VK markets) and the effect of uncertainty concerning the period durations (VU markets). The observations were paired across markets where the only difference in experimental design was the period duration type (that is, CK, VK or VU), therefore, the impact of all other confounding treatment effects were removed.

The comparison of the CK and VK markets for the measures of the volume of trade provide mixed evidence. There was some indication of a reduction in the volume figures as a result of varying period duration. The evidence, unfortunately, was not conclusive. In contrast the uncertainty over period duration clearly had a major significant impact on the volume of trade. The VK:VU comparison reported higher mean values for the VU markets, which were highly significant for all measures with the exception of the VOL60 measure. The uncertainty over period duration clearly resulted in a more aggressive trading behaviour and was associated with a higher volume of trade.

The prices at which assets traded will now be considered. A comparison of the measures of RMSD of transaction prices from the FRE predictions for the CK:VK pairing resulted in significant differences in mean values. By the time 60 seconds of trade in a period had passed the mean VK values were significantly lower than the corresponding values for the CK markets. This was interpreted as an increase in informational efficiency as a result of varying period durations. For the VK:VU markets there was no effect on the informational efficiency reported for the three measures of early in a period. By the end of a trading period, however, the mean RMSD in the VU markets significantly exceeded that witnessed in the VK markets. This was interpreted as evidence that uncertainty concerning period durations resulted in a reduction in the level of informational efficiency obtained over an entire trading period. In contrast, there were no significant differences in the level of allocational efficiency generated in any of the three market types.

In conclusion, the uncertainty surrounding period duration resulted in a relatively more aggressive trading behaviour. It was also evident that uncertainty over period duration lowered the relative level of informational efficiency over an entire trading period, but had no effect on the level of allocational efficiency. The results were generally in line with the results from the pilot analysis reported in Duxbury (1997).

9.3.3 The Effect of Information Structures on Market Performance

Many of the previous experimental asset market studies find that an imperfect information structure weakens the predictive ability of the FRE model compared to the PI model. Markets with imperfect information structures generally exhibit a reduced level of both informational and allocational efficiency relative to perfect information markets. The experimental asset markets studied here were also able to address the effect of information structure on the trading behaviour observed in DA markets.

Whilst the mean volume of trade early in a period did not differ across the information structure types for the two measures VOL45 and 60, the mean VOL90 and NORMVOL measures were both significantly higher for the P markets than the I markets. The increased state uncertainty inherent in the imperfect information markets, therefore, caused traders to be more cautious over their trading strategies.

Over an entire trading period the mean RMSD of transaction prices from FRE predictions in the I markets was significantly higher than the mean figure for the P markets. The increased state uncertainty and associated cautious trading behaviour ultimately resulted in a lowering of the level of informational efficiency attained by the asset markets. This conclusion is directly in line with the evidence from many other experimental studies that incorporate imperfect information structures (for example, Plott and Sunder, 1988). Also in support of earlier findings, the results from the P and I markets studied here provided conclusive evidence of a dramatic reduction in the level of allocational efficiency observed in imperfect information markets.

In conclusion, the move from a perfect to an imperfect information structure reduced the rate of trade observed over an entire period. The levels of informational and allocational efficiency obtained over an entire period were also significantly impaired. The increased uncertainty surrounding the state of nature impeded the convergence to FRE equilibrium predictions.

9.3.4 The Effect of Experience on Market Performance

The experimental design did not permit the effect of increased experience levels to be isolated from the effect of including a pre-trade information auction. For this reason it was not possible to decisively tie the increased convergence to FRE equilibrium predictions observed in the PM and IM markets with the increased experience of the participants in those markets.

It was conjectured, however, that the level of participant experience was the important factor in the increased convergence observed. The reasoning was based on the fact that the endogenous distribution of private information resulted in distributions that would frustrate the convergence to FRE values relative to the uniform distribution in the PN and IN markets. The improved convergence observed, therefore, could only be the result of the increase in experience levels. The positive effect of experience on observed market behaviour supports the evidence reported in numerous other experimental studies (for example, Forsythe and Lundholm, 1990) that have designed experiments where the effect of experience is isolated and formally tested.

9.4 Discussion and Conclusions

The experience gained from the design and conduct of eighteen experimental financial asset markets provided valuable lessons to be learned regarding best practice in experimental methods. The experimental results also permit a number of conclusions, which raise important theoretical considerations and that are of substantive practical interest. The implications drawn from this study will now be discussed.

9.4.1 Experimental Method

Firstly, replication is an essential feature of the experimental method. This lesson was learned from the results of the markets studied in Chapter Five. Six experimental markets were conducted with only one treatment effect (period duration) and three levels (CK, VK and VU). Thus, each of the three cells of the experimental design were in fact replicated, resulting in the two groups of markets PN1 and PN2. Had this not been the case, with only the PN1 markets conducted, the conclusions drawn would have changed dramatically. The results from PN1 markets were directly in line with the results reported in Duxbury (1997), however, the PN2 results provided limited supportive evidence. This is despite there being no treatment effect change in the experimental design between the PN1 and PN2 markets. Experimental replication is, therefore, essential if robust results are to be generated. Connected with this issue is Roth's (1994) criticism of the selective reporting of experiments, discussed in Chapter Four. Had the results from the PN2 markets not been disclosed the overall flavour of the results would have fundamentally altered. The only acceptable practice, therefore, should be the replication of cells of the experimental design and the full reporting of all experimental sessions conducted.

Secondly, many previous experimental studies have reported tests of statistical significance based on data that is not independently distributed and, therefore, violates the assumption of independent observations required for all statistical tests. This research adopted a method of data adjustment, based on a covariate adjustment technique, which permits the dependence in the data to be removed. This allows the valid use of statistical tests in the evaluation of stated hypotheses. Future experimental studies should endeavour to follow this example so as to ensure that the technique becomes accepted in the experimental method.

Finally, the findings in Chapter Seven suggest that the use of information purchase price may not be a good proxy for the value of private information. The purchase price, whilst showing signs of declining, did not converge to zero. The proxy, therefore, implied that private information retained value. At the same time, however, the net profit of the uninformed exceeded that of the informed in the majority of periods. This implies that the purchasers of private information paid more for the information than it was actually worth. Thus, the use of purchase price as a proxy for value is biased against the FRE model's prediction of zero value.

9.4.2 Theoretical Refinement

It is not possible to adequately address the concept of market efficiency using conventional empirical techniques based on data generated in the real world. Instead the level of efficiency generated by different trading institutions must be judged by theoretical and experimental techniques. The double auction is an exceptionally efficient mechanism, but thus far there is no generally accepted model of bid, ask and acceptance behaviour. Thus, theory alone is not yet able to provide decisive answers. The role for experimental methods is double edged. Experiments provide a means of measuring the comparative efficiencies of disparate trading institutions and a means of identifying variables that have important implications for the levels of market efficiency observed. This latter point sums up the central intention of this research.

The role of a predetermined, known period duration was identified as possibly being important for the convergence tendency observed in experimental asset markets and the few theoretical models developed to date. The significant effect on observed market behaviour of uncertain period durations indicates that knowledge of period duration has an important impact on the convergence to FRE equilibrium predictions. Uncertain period durations cause traders to adopt more aggressive trading strategies and result in a lower level of informational efficiency obtained. There was no significant effect on allocational efficiency, however. These results are the major contribution provided by the current research programme.

9.4.3 Electronic Networks and On-Line Auctions

Whilst this research focuses solely on the double auction, and more specifically on experimental financial asset markets conducted under the rules of the double auction, the results will be of interest to those individuals designing and implementing on-line auctions for the conduct of trade across electronic networks. Many, if not all, of these on-line auctions are conducted for fixed, known durations. The incorporation of uncertain period durations in DA markets resulted in an increase in the volume of trade and a reduction in the level of informational efficiency obtained. Therefore, on-line auctions conducted for fixed and known durations will result in a more efficient pricing of the commodity for sale, but will also result in a reduced volume of trade. This conclusion requires that the impact of uncertain period duration generalises across trading institutions. It is not immediately apparent that this will indeed be the case, therefore, future experimental work could fruitfully investigate the impact of uncertain period duration on observed market performance for markets conducted under rules of exchange other than those of the DA institution.

In conclusion, this study began by highlighting a scientific mystery and set out to shed some light on the convergence tendency observed in double auction markets. Whilst it is not possible to proclaim the mystery resolved, the research has indicated the importance of predetermined, known period duration on the convergence tendency of the double auction institution. The future theoretical refinement of models of bid, ask and acceptance behaviour must explicitly incorporate known period duration as an important variable. Proposed refinements to institutional rules of exchange must also recognise the importance of known period duration on observed market characteristics.

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Appendix One

Instructions for all markets (CK, VK and VU) with no information auction.

Instructions.

Introduction.

This is an experiment in the economics of market decision making. The reward for participating is in the form of a *£2 participation fee plus additional money*. Depending upon your decisions you could make a *considerable amount of money*. This will be paid to you in *cash* immediately after the experiment. It is highly unlikely, but possible, that you may have to repay the £2 participation fee. However, you will *not* have to give up money you had prior to the experiment.

We are going to simulate a market where you can *buy and sell* certificates in a sequence of *fifteen* trading periods. The trade of certificates will take place between twelve participants, via computer terminals. At the beginning of each trading period you will be endowed with *two certificates* and *50,000 units* of an experimental currency, EMUS. You are able to make a profit by collecting *dividend earnings* on all the certificates you hold at the *end* of each trading period and/or from *buying and selling* certificates. The rules governing the trade of the certificates are detailed below. The market for the certificates will be conducted over a series of fifteen sequential trading periods. [Each period will last for 240 seconds (4 mins.).](CK) [Each period will last for a variable length of time. This time will be shown to you via a countdown timer on the computer screen.](VK) [Each period can end at any time, therefore, the duration of a period may vary. This time will not be known to you. The duration of each period is randomly drawn from a uniform distribution.](VU)

The value of the dividend payable to you may take any of *three equally likely* values. These values will be given to you at the start of the experiment. This is your own *private information* and must *not* be revealed to any other person, to do so would be detrimental to your ability to earn a profit.

The value payable to you at the end of each period has been randomly generated via computer, thus the value may differ from period to period. If you desire, at the end of the experiment you can inspect the values for yourself to ensure that this is indeed the case.

Note that the three equally likely dividend values may differ from person to person.

At the end of each period, after the dividends have been paid for certificates held and the initial 50,000 EMUS have been deducted, any EMUS you have remaining are your *trading profit* for that period. After payment of dividends at the end of a period, the certificates held expire and so are not carried forward to the next trading period. The trading profit you make each period is carried forward to the end of the experiment.

At the beginning of each trading period you will always be given two certificates and 50,000 EMUS with which to trade.

The total profit you earn in EMUS by the end of the fifteen trading periods will determine your reward for taking part in the experiment. The total profit is the sum of each individual periods' trading profit, net of any losses. The higher the total profit you earn, the higher your reward. All EMUS will be converted into £'s at the end of *the experiment and immediately paid in cash.*

Prior to trade in any particular period *clue cards* will be distributed to individuals. These cards will provide information concerning the *value of the dividend* payable to you at the end of the period. [The cards may contain information which enables you to determine your exact payoff at the end of the period or they may provide no information about the value of the payoff to you.](PN) [The cards may contain information which enables you to eliminate one of the three equally likely payoffs you will receive for certificates held at the end of the period or they may provide no information about the value of the payoff to you.](IN) This is your *own private information* and must *not* be revealed to any other person, to do so would be detrimental to your ability to earn a profit.

The type of information you receive in each period has been determined randomly via computer. Again you are welcome to observe that this is so at the end of the experiment.

Trading Rules.

1. If you wish to enter an offer to buy or sell you must better any outstanding offer. That is, enter an offer to buy (bid) at a higher price or sell (ask) at a lower price than the outstanding offers.

2. If you wish to buy at a price equal to the latest offer to sell then simply enter an offer to buy at that price. If you wish to sell at a price equal to the latest offer to buy then simply enter an offer to sell at that price.

3. When the outstanding offers to buy and sell are equal a transaction takes place. At this point all previous offers to buy or sell are eliminated and the process begins again.

4. All trades are for one certificate at a time only.

5. You are prevented from holding a negative amount of either certificates or EMUS.

6. If you hold the outstanding offer to buy/sell you are prevented from entering an offer to sell/buy.

Computer Keys.

To enter an offer to buy:	Press	'b'
	Type price	'xxx'
	Press	'↵' (Return)
	Press to confirm	'y'
To enter an offer to sell:	Press	'a'
	Type price	'xxx'
	Press	'↵' (Return)
	Press to confirm	'y'

Information.

1. A history of *previous transaction prices* will be available to you (your own trades highlighted in red).

2. Outstanding offers to buy and sell are displayed (your own offers highlighted in pale blue).

3. The number of certificates you own and the amount of EMUS you possess are updated as you trade.

4. [A countdown timer displaying the number of seconds remaining in the current trading period.](CK and VK) [Omitted](VU)

5. At the end of each period you will be told the value of the dividend paid to you for any certificates you still hold.

6. The total dividend you are paid at the end of a period will be added to your holding of EMUS, less the initial loan of 50,000 EMUS. The final figure represents your EMUS profit for the period. The trading profit each period is carried forward to the end of the experiment.

Remember, you could make a *considerable amount of money*. The more profit you earn during the experiment, the more money you will make. All money will be paid in *cash* immediately after the experiment.

If you are unclear about anything please ask the experimenter.

Instructions for all markets (CK, VK and VU) with an information auction.

Instructions.

Introduction.

This is an experiment in the economics of market decision making. The reward for participating is in the form of a *£2 participation fee plus additional money*. Depending upon your decisions you could make a *considerable amount of money*. This will be paid to you in *cash* immediately after the experiment. It is highly unlikely, but possible, that you may have to repay the £2 participation fee. However, you will *not* have to give up money you had prior to the experiment.

We are going to simulate a market where you can *buy and sell* certificates in a sequence of *fifteen* trading periods. The trade of certificates will take place between twelve participants, via computer terminals. At the beginning of each trading period you will be endowed with *two certificates* and *50,000 units* of an experimental currency, EMUS. You are able to make a profit by collecting *dividend earnings* on all the certificates you hold at the *end* of each trading period and/or from *buying and selling* certificates. The rules governing the trade of the certificates are detailed below. The market for the certificates will be conducted over a series of fifteen sequential trading periods. [Each period will last for 240 seconds (4 mins.).](CK) [Each period will last for a variable length of time. This time will be shown to you via a countdown timer on the computer screen.](VK) [Each period can end at any time, therefore, the duration of a period may vary. This time will not be known to you. The duration of each period is randomly drawn from a uniform distribution.](VU)

The value of the dividend payable to you may take any of *three equally likely* values. These values will be given to you at the start of the experiment. This is your own *private information* and must *not* be revealed to any other person, to do so would be detrimental to your ability to earn a profit.

The value payable to you at the end of each period has been randomly generated via computer, thus the value may differ from period to period. If you desire, at the end of the experiment you can inspect the values for yourself to ensure that this is indeed the case.

Note that the three equally likely dividend values may differ from person to person.

Prior to trade in any particular period an *information auction* will take place, in which you will be able to bid to purchase information concerning the *value of the dividend* payable to you at the end of the period. [The information will enable you to determine your exact payoff at the end of the period.](PM) [The information will enable you to eliminate one of the three equally likely payoffs you will receive for certificates held at the end of the period.](IM) This is your *own private information* and must *not* be revealed to any other person, to do so would be detrimental to your ability to earn a profit.

The information auction will proceed as follows. All participants will offer a price at which they are willing to buy information. The six participants offering to buy at the six highest prices will win the information auction and receive the information for that period. The *cost of the information* is equal to the *seventh highest price offered* to buy the information and all six purchasers will be charged this amount. [The information will be available for display on the computer screen when requested and will take the form X, Y, or Z if the state of nature for the forthcoming period is X, Y or Z, respectively.](PM) [The information will be available for display on the computer screen when requested and will take the form Not X, Not Y, or Not Z. For example, if the state of nature for the forthcoming period is X you may receive information either Not Y or Not Z.](IM)

The six participants that do not purchase information will not be charged the information cost. The information will not be revealed to these six participants and the computer screen will simply display the word 'BLANK' when information is requested.

After all bids have been received the cost of information will be calculated and revealed to all participants, as will the information for the forthcoming period.

In the event of tied bids to buy the information the tie will be resolved by reference to the time at which the bid was received. The earliest received bid will be ruled the winner. Therefore, if you enter a price equal to the revealed cost of information, but your information is 'BLANK', then your bid was involved in a tie and was not the earliest bid received. In this event you will not be charged for information. If you do not wish to enter an offer to purchase the information for a certain price enter the price of zero when your offer is requested.

No other information concerning the state of nature during the period will be made available until the end of the period.

At the end of each period, after the dividends have been paid for certificates held and the initial 50,000 EMUS and any information costs have been deducted, any EMUS you have remaining are your *trading profit* for that period. After payment of dividends at the end of a period, the certificates held expire and so are not carried forward to the next trading period. The trading profit you make each period is carried forward to the end of the experiment.

At the beginning of each trading period you will always be given two certificates and 50,000 EMUS with which to trade.

The total profit you earn in EMUS by the end of the fifteen trading periods will determine your reward for taking part in the experiment. The total profit is the sum of each individual periods' trading profit, net of any losses or information costs. The higher the total profit you earn, the higher your reward. All EMUS will be converted into £'s at the end of the experiment and immediately paid in cash.

Trading Rules.

1. If you wish to enter an offer to buy or sell you must better any outstanding offer. That is, enter an offer to buy (bid) at a higher price or sell (ask) at a lower price than the outstanding offers.

2. If you wish to buy at a price equal to the latest offer to sell then simply enter an offer to buy at that price. If you wish to sell at a price equal to the latest offer to buy then simply enter an offer to sell at that price.

3. When the outstanding offers to buy and sell are equal a transaction takes place. At this point all previous offers to buy or sell are eliminated and the process begins again.

4. All trades are for one certificate at a time only.

5. You are prevented from holding a negative amount of either certificates or EMUS.

6. If you hold the outstanding offer to buy/sell you are prevented from entering an offer to sell/buy.

Computer Keys.

To enter a bid for information:	Type price	'xxx'
	Press	'↵' (Return)
To view information before the period begins:	Press	'f'
To signal you are ready for the period to begin:	Press	'c'
To enter an offer to buy:	Press	'b'
	Type price	'xxx'
	Press	'↵' (Return)
	Press to confirm	'y'
To enter an offer to sell:	Press	'a'
	Type price	'xxx'
	Press	'↵' (Return)
	Press to confirm	'y'

Information.

1. A history of *previous transaction prices* will be available to you (your own trades highlighted in red).

2. Outstanding offers to buy and sell are displayed (your own offers highlighted in pale blue).

3. The number of certificates you own and the amount of EMUS you possess are updated as you trade.

4. [A countdown timer displaying the number of seconds remaining in the current trading period.](CK and VK) [Omitted](VU)

5. At the end of each period you will be told the value of the dividend paid to you for any certificates you still hold.

6. The total dividend you are paid at the end of a period will be added to your holding of EMUS, less the initial loan of 50,000 EMUS and any information costs. The final figure represents your EMUS profit for the period. The trading profit each period is carried forward to the end of the experiment.

7. The price at which information was purchased for the forthcoming period (ie. the seventh highest price offered).

Remember, you could make a *considerable amount of money*. The more profit you earn during the experiment, the more money you will make. All money will be paid in *cash* immediately after the experiment.

If you are unclear about anything please ask the experimenter.

Appendix Two

Computer Screen Illustrations

Figure 1 Initial Endowments Screen

Trader no. 1 | Start: | Period no. 1

Endowment.

Assets	=	2
Emus	=	50,000
Profit	=	0

Figure 2 Trading Screen

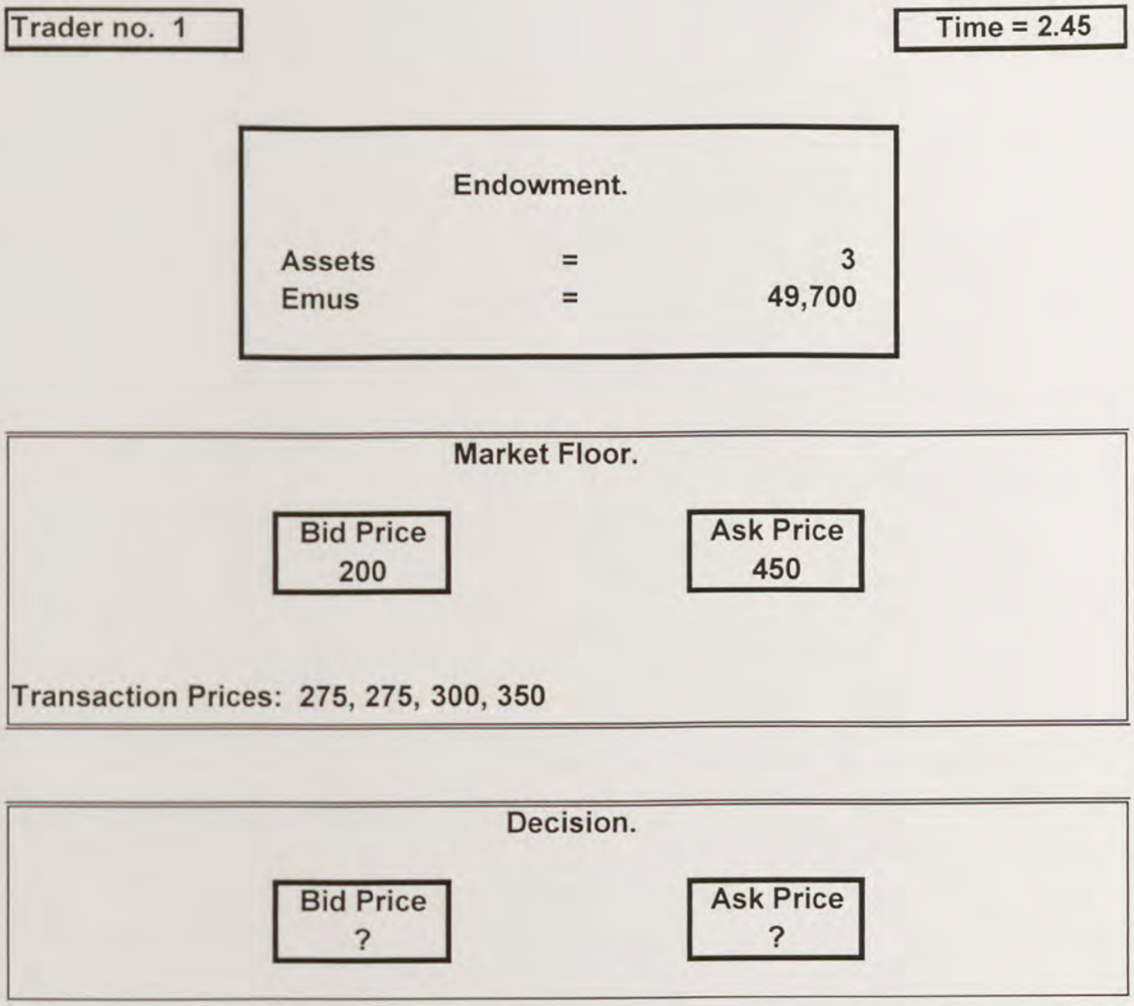

Figure 3 State of Nature Screen

Period no. = 1

State of Nature = X

Figure 4 Financial Position Screen

Trader no. 1 End: Period no. 1

Financial Position

Assets	3
Dividend	350
	1050
Emus	49,700
less loan	50,000
	-300
Profit	750

Figure 5 Closing Financial Position Screen

Trader no. 1

Closing Financial Position

Period no.	Profit per Period
1	750
2	300
3	559
4	845
5	503
6	504
7	651
8	-55
9	625
10	750
11	300
12	559
13	605
14	547
15	895
Total Profit	8338
Conversion	0.000667
Profit in £s	5.56

Figure 6 Information Auction Screen

Trader no. 1

Period no. 1

Information Auction.

Bid Price
350

Enter the number of emus you wish to bid or '0' for no bid.

Outcome

Winning bids at prices greater than or equal to 300

Figure 7 Financial Position Screen (including Information Auction)

Trader no. 1	End:	Period no. 1

Financial Position

Assets	3
Dividend	350
	1050
Emus	49,700
less loan	50,000
less info cost	300
	-600
Profit	450

Appendix Three

Explanation of the FRE and PI Models' Equilibrium Predictions

The FRE and PI models make equilibrium price predictions that are contingent on the parameters chosen for traders' state contingent dividend distributions. These equilibrium price predictions dictate the models' end of period equilibrium asset allocations. Two parameter sets (A and B) were used in the overall experimental design. The PI model's predictions are further dependent upon the nature of the information structure adopted in the experimental design, perfect or imperfect, and the distribution of the private information.

The FRE model predicts that in equilibrium the state of nature will be revealed by the price signal. Thus the model predicts that the equilibrium price will be equal to the highest dividend payout given the state of nature. Those traders in the trader type group with this highest dividend are predicted to hold all the assets, irrespective of whether they are informed or uninformed. The PI model predicts that traders condition their expectations of transaction prices based solely on their own private information, forming reservation prices computed with reference to their own expected dividend value. The equilibrium price is predicted to be equal to the highest reservation price, with the assets held by those traders with the highest reservation price. The expected dividend values, and so reservation prices, are contingent upon traders' private information signals, therefore, the equilibrium allocation prediction will not include both informed and uninformed traders from a particular trader type group.

The calculations of the equilibrium predictions for the two models are now demonstrated.

PN Markets – Perfect information, no information auction

Table 1 displays the state contingent dividend distributions for the three trader types used for all PN markets. Based on these dividend distributions Table 2 illustrates traders' reservation prices (expected dividend values) based on a perfect information structure. The equilibrium price predictions for the FRE and PI models are also included.

Trader Type	State		
	X	Y	Z
1	350	200	200
2	100	300	200
3	300	200	700

Table 1 State Contingent Dividend Distributions - Parameter Set A

Trader Type	State	Private Information	Reservation Price (EV)	FRE Price	PI Price
1	X	None	250	350	400
1		X	350		
2	X	None	200		
2		X	100		
3	X	None	400		
3		X	300		
1	Y	None	250	300	400
1		Y	200		
2	Y	None	200		
2		Y	300		
3	Y	None	400		
3		Y	200		
1	Z	None	250	700	700
1		Z	200		
2	Z	None	200		
2		Z	200		
3	Z	None	400		
3		Z	700		

Table 2 Reservation Prices and Equilibrium Predictions - PN Markets

EXAMPLE ASSUMING STATE X

The FRE price is simply equal to the highest dividend given state X, which is 350 emus paid to trader type 1 traders. Both informed and uninformed type 1 traders are predicted to hold the assets in equilibrium.

The PI price is equal to the highest reservation price given the state contingent dividend distributions and the private information, this is 400 emus for uninformed type 3 traders. The figure of 400 = ⅓(300+200+700). The type 3 informed traders know with certainty that they will receive a dividend of 300 emus, therefore, they are not predicted to hold the assets in the end of period equilibrium.

IN Markets – Imperfect information, no information auction

Table 1 displays the state contingent dividend distributions for the three trader types used for all IN markets. Based on these dividend distributions Table 3 illustrates traders' reservation prices (expected dividend values) based on a imperfect information structure. The equilibrium price predictions for the FRE and PI models are also included.

Trader Type	*State*	*Private Information*	*Reservation Price (EV)*	*FRE Price*	*PI Price*
1	X	None	250	350	500
1		Not Y	275		
1		Not Z	275		
2	X	None	200		
2		Not Y	150		
2		Not Z	200		
3	X	None	400		
3		Not Y	500		
3		Not Z	250		
1	Y	None	250	300	450
1		Not X	200		
1		Not Z	275		
2	Y	None	200		
2		Not X	250		
2		Not Z	200		
3	Y	None	400		
3		Not X	450		
3		Not Z	250		
1	Z	None	250	700	500
1		Not X	200		
1		Not Y	275		
2	Z	None	200		
2		Not X	250		
2		Not Y	150		
3	Z	None	400		
3		Not X	450		
3		Not Y	500		

Table 3 Reservation Prices and Equilibrium Predictions - IN Markets

Example Assuming State X

The FRE price is simply equal to the highest dividend given state X, which is 350 emus paid to trader type 1 traders. Both informed and uninformed type 1 traders are predicted to hold the assets in equilibrium. Notice that the move from a perfect to imperfect information structure does not alter the equilibrium predictions of the FRE model.

The PI price is equal to the highest reservation price given the state contingent dividend distributions and the private information, this is 500 emus for informed type 3 traders receiving the clue 'Not Y'. The figure of 500 = ½(300+700). The type 3 informed traders receiving the clue 'Not Z' do not have as high an expected value reservation price and thus are not predicted to hold the assets in equilibrium.

PM Markets – Perfect information, with information auction

Trader Type	***State***		
	X	***Y***	***Z***
1	250	300	350
2	200	350	950
3	200	400	600

Table 4 State Contingent Dividend Distributions - Parameter Set B

Table 4 displays the state contingent dividend distributions for the three trader types used for all PM markets. Based on these dividend distributions Table 5 illustrates traders' reservation prices (expected dividend values) based on a perfect information structure. The equilibrium price predictions for the FRE and PI models, assuming uniform distribution of private information across trader types, are also included.

Trader Type	*State*	*Private Information*	*Reservation Price (EV)*	*FRE Price*	*PI Price*
1	X	None	300	250	500
1		X	250		
2	X	None	500		
2		X	200		
3	X	None	400		
3		X	200		
1	Y	None	300	400	500
1		Y	300		
2	Y	None	500		
2		Y	350		
3	Y	None	400		
3		Y	400		
1	Z	None	300	950	950
1		Z	350		
2	Z	None	500		
2		Z	950		
3	Z	None	400		
3		Z	600		

Table 5 Reservation Prices and Equilibrium Predictions - PM Markets

Example Assuming State X

Once more the FRE price is simply equal to the highest dividend given state X, which is 250 emus paid to trader type 1 traders. Both informed and uninformed type 1 traders are predicted to hold the assets in equilibrium.

The PI price is equal to the highest reservation price given the state contingent dividend distributions and the assumed uniform distribution of private information, this is 500 emus for uninformed type 2 traders. The figure of 500 = ⅓(200+350+950). The type 2 informed traders know with certainty that they will receive a dividend of 200 emus, therefore, they are not predicted to hold the assets in the end of period equilibrium.

IM Markets – Imperfect information, with information auction

Table 4 displays the state contingent dividend distributions for the three trader types used for all PM markets. Based on these dividend distributions Table 6 illustrates traders' reservation prices (expected dividend values) based on an imperfect information structure. The equilibrium price predictions for the FRE and PI models, assuming uniform distribution of private information across trader types, are also included.

Trader Type	*State*	*Private Information*	*Reservation Price (EV)*	*FRE Price*	*PI Price*
1	X	None	300	250	575
1		Not Y	300		
1		Not Z	275		
2	X	None	500		
2		Not Y	575		
2		Not Z	275		
3	X	None	400		
3		Not Y	400		
3		Not Z	300		
1	Y	None	300	400	650
1		Not X	325		
1		Not Z	275		
2	Y	None	500		
2		Not X	650		
2		Not Z	275		
3	Y	None	400		
3		Not X	500		
3		Not Z	300		
1	Z	None	300	950	650
1		Not X	325		
1		Not Y	300		
2	Z	None	500		
2		Not X	650		
2		Not Y	575		
3	Z	None	400		
3		Not X	500		
3		Not Y	400		

Table 6 Reservation Prices and Equilibrium Predictions - IM Markets

EXAMPLE ASSUMING STATE X

The FRE price is simply equal to the highest dividend given state X, which is 250 emus paid to trader type 1 traders. Both informed and uninformed type 1 traders are predicted to hold the assets in equilibrium. Notice that the move from a perfect to imperfect information structure does not alter the equilibrium predictions of the FRE model.

The PI price is equal to the highest reservation price given the state contingent dividend distributions and the assumed uniform distribution of private information, this is 575 emus for informed type 2 traders receiving the clue 'Not Y'. The figure of 575 = ½(200+950). The type 2 informed traders receiving the clue 'Not Z' do not have as high an expected value reservation price and thus are not predicted to hold the assets in equilibrium.

Information Auction Markets

The assumption of uniform distribution of private information among trader types is necessary of the PI model's equilibrium predictions. In those experimental markets where no information auction is present the exogenous determination of the identity of informed traders ensures that a uniform distribution is obtained. The endogenous determination of informed traders in those experimental markets where an information auction is present does not guarantee a uniform distribution of private information among trader types. If the private information was not distributed to traders in the trader type identified above as having the highest reservation price, then the PI equilibrium price prediction may well change.

EXAMPLE ASSUMING STATE Z AND PERFECT INFORMATION

Assume all four type 1 traders and two type 3 traders receive the perfect private information. The PI price is equal to the highest reservation price given the state contingent dividend distributions and the assumed distribution of private information, this is 600 emus for informed type 3 traders.

The above example illustrates how the PI model's equilibrium predictions are contingent upon the distribution of the private information, because of the implications for traders' reservation prices (expected dividend values).