A MODEL OF INTER-REGIONAL TRADE AND STORAGE OF GRAIN: AN APPLICATION TO ZIMBABWE AND TANZANIA

BY

PRABHAT BHASKAR VAZE

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THIS THESIS HAS BEEN COMPOSED BY THE CANDIDATE AND THE WORK IS THE CANDIDATE'S OWN.

PRABHAT VAZE

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ABSTRACT

This thesis looks at the economics of staples trade in the sub-Saharan region, verifying an economic model using data from the white maize markets of Zimbabwe and Tanzania. Both countries have reformed their grain marketing system in the recent past. In the early 1980s, the government was the main actor in the food distribution system, operating through large state-owned marketing boards. However, under pressure from international agencies, first Tanzania and then Zimbabwe, liberalised their food markets and the role of the private sector increased. The state has remained a player in the market and a mix between public and private marketing system has evolved.

White maize is the main staple of both the countries and there is only one harvest, around April. The peculiar agroecology of the crop means that inter-regional trade has to be combined with storage to meet consumer needs. The economics of this food system is analysed using an optimal control framework. In a model of inter-regional trade where there is a single harvest at the start of the period and an external market which fixes a low buying and a high selling price, it is shown that trade is intermittent. In particular, regions would first source consumption from own stocks, then trade and finally purchase grain from the external market until the following years harvest.

The model is first investigated using household survey data collected in 1994-95 from 356 households in Buhera Communal Area, Zimbabwe. The harvest was poor and private traders had, for the first time since liberalisation, established direct trade links between food deficit parts of Buhera and surplus neighbouring areas. Also, the analysis gives the first indication of the role of the state marketing agency, post-reform. The agency appears to anchor the market for grains - purchase price rises with distance from the board even when a trade does not involve the board. This supports the model's assumption of an external market. The importance of household grain stocking decision is also explored using parametric and semiparametric econometric techniques.

The optimal control model predicts that there is seasonality in inter-regional trade. This is modelled econometrically using a stochastic switching model applied to price data from Tanzanian maize markets. When inter-market trade is occurring, the price spread across the markets would equal the cost of transfer between the markets. When there is no trade, the two markets clear at price levels so that the price spread is less than or equal to the cost of transfer. In Tanzania, the markets were most likely not to trade in the months leading up to harvest, November to March. This is evidence that there is seasonality in inter-market trading. Further, the timing of the trading suggests that trading is concentrated post-harvest as the optimal program predicts.

ABBREVIATIONS USED

ADF	Augmented Dickey-Fuller
ADL	Autoregressive Distributed Lag
CLAD	Censored Least Absolute Deviations
DF	Dickey Fuller
EIU	Economist Intelligence Unit
GIS	Geographical Information System
GMB	Grain Marketing Board (of Zimbabwe)
MDB	Marketing and Development Bureau (of Tanzania)
NMC	National Milling Corporation (of Tanzania)
PBM	Parity Bounds Model
SGR	Strategic Grain Reserve
TSh	Tanzanian Shilling
WB	World Bank
Z$	Zimbabwe Dollar

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CHAPTER 1:

Introduction

1. Research Questions and Thesis Plan

This thesis looks at the economics of staples trade in the sub-Saharan region, focusing on the maize markets of Zimbabwe and Tanzania. White maize is the main staple of both the countries. It is only produced in the southern and eastern parts of Africa and so is thinly traded on international markets. Further, there is only one harvest, around April, for all the main producers. This is unlike the other major staples of the world, such as wheat and rice. The peculiar agroecology of the crop means that inter-regional trade has to be combined with storage to meet consumer needs.

Both countries have reformed their grain marketing system in the recent past. In the early 1980s, the government was the main actor in the food distribution system, operating through large state-owned marketing boards. However, under pressure from international agencies, first Tanzania and then Zimbabwe, liberalised their food markets and the role of the private sector increased. The state has remained a player in the market and a mix between public and private marketing system has evolved. Two research questions can be posed which the research addresses in the particular context of southern African food markets:

Does trade and storage combine in meeting food needs?
Is an understanding of this important?

The economic analysis of these issues starts from an analysis of regional maize prices. In particular, high costs of capital make grain storage expensive. Over the year after harvest, this makes prices rise. The dynamics of storage and inter-market trade derives from the rise in food prices.

In the following chapters, the operation of these markets is first modelled and then empirically assessed. The structure of the thesis is as follows:

The rest of this chapter will give more details about the specific areas explored in the thesis.

Chapter 2 will provide some historical and institutional background by detailing the history of food marketing in Tanzania and Zimbabwe. The agriculture and food marketing institutions of the countries have much in common with the other main producers of white maize - primarily South Africa, Kenya, Zambia, Malawi and Mozambique - and so the findings of this research should have relevance to a number of countries. The chapter also considers the reform process that the food markets of Tanzania and Zimbabwe have recently undergone.

Chapter 3 gives details of tests of market performance. These tests have become of interest post-reform because they help to measure the benefits of liberalisation. The spatial price equilibrium model (Takayama and Judge (1971)) underpins the most common tests of food market performance that have been used in assessing the efficiency of marketing systems. This model and the tests are detailed in the chapter. The tests are then applied to price data from six markets in Tanzania.

Chapter 4 will present an alternative spatial model of the food system which incorporates storage and an external market into a model of inter-regional trade. The addition of these two features adapt the spatial equilibrium model for sub-Saharan Africa. This model, by the author, is the first application of optimal control methods to regional grain stocking decisions. The two distinctive aspects of the model - the external market and grain storage - are empirically explored in chapters 5 and 6.

Chapter 5 looks into the role of the external market in Zimbabwe. The analysis uses survey data which was collected as part of a research project in which the author worked. In the analysis, the external market is the state-owned marketing board which sets a purchase and a sale price for maize and then acts as a purchaser or seller of last resort.

The Zimbabwe survey data is used in chapter 6 to analyse the decision of households about how much maize to purchase. This is done with particular reference to the storage behaviour of the household. As the year in which the survey took place was particularly poor (1994/95), both chapter 5 and this chapter explore the effects of food stress on household grain stock management.

Chapter 7 uses a different dataset - time-series data regarding price of maize in markets in Tanzania. The model presented in chapter 4 suggests that consuming grain from stored harvest would substitute for trade between a pair of regions. When trade is taking place, inter-market price spread should equal the cost of transfer. This property in market price data is used to identify when trade took place between the six Tanzanian markets in the period 1985-90. The seasonality in inter-market trade is investigated in this chapter.

The thesis ends with some conclusions in chapter 8.

2. Food Market Liberalisation

Food market reform in Africa has recently become an area of intense research interest (see Jayne and Jones (1997) for a recent survey). Many countries in the continent have liberalised their staple food marketing systems in the last two decades. In the 1960s, food markets were heavily controlled by national governments. State institutions bought and sold almost all the agricultural production of the farm sector with private trade in food and cash crops sometimes outlawed altogether. The state had developed a network of purchasing points linked by rail or road transport to move agricultural production from areas of surplus to areas of deficit. This system was integrated with a processing sector which then sold its output on to consumers both at home and abroad. State marketing boards became the predominant actors in the agricultural sector.

Criticism of this system grew throughout the 1970s and into the 1980s (World Bank (1984)). The burgeoning state agencies had problems of administration and management. State marketing boards were sometimes highly inefficient so that the costs of marketing were inflated. In some cases, corruption had set in. Rising costs were matched by the rising expectations of both consumers and producers. Farmers demanded high prices for their produce while consumers expected low prices, especially for staples. This squeeze on margins and the spiralling costs meant that marketing systems increasingly became a drain on government reserves. As fiscal pressures on government budgets became more significant, the extent to which the marketing system could be rationalised became an issue.

A complication was the changing political demands made on governments during the period. At the start of the 1960s, the political power in many African countries was held in the hands of a minority. In Zimbabwe, Kenya and Zambia, this meant that the European farmers were the main beneficiaries of the marketing system. In Tanzania and Malawi, marketing systems were geared towards the large estates. Country after country became independent of colonial masters and enfranchised many more people. The demands of these citizens for the first time became a priority of the new democratically elected governments. As much of the newly enfranchised population was rural, popular demands translated into a large expansion of the state marketing system. Marketing board facilities were built in regions which were previously discriminated against. While this helped to reverse previous inequalities, the scale of government involvement in food marketing multiplied manifold.

The 1980s saw the debts of the state marketing agencies rising to unsustainable levels. Under pressure from international agencies, many governments began to reduce their intervention in food marketing systems. The private sector, which had previously been heavily curtailed, was allowed into more levels of the food marketing system. In some countries, the government agencies were wound up entirely (e.g. Zambia). However, in most post-reform food marketing systems, the government agencies were run in parallel to private trading of foodgrains. In these countries, the government agency intervened in maintaining strategic reserves for basic staple crops protecting countries from the worst effects of a poor harvest.

Thus, the 1990s have seen a new trading system in many countries of sub-Saharan Africa developing. The modern markets integrate some elements of the state-dominated marketing system of the past. However, there is an increasing role for the private sector. The grain trader, previously a maligned figure, has undergone something of a rehabilitation. A key question for the food market analyst has been whether these changes have improved the delivery of agricultural products to consumers. The focus has especially been on the food staples of the region as nutritional levels amongst the poor have historically been low. A poor food marketing system would exacerbate the low level of food access and have a detrimental effect on the food security of the poorest households. Improvements in the marketing system, however, may help to lift these households out of nutritional insecurity. The testing of the performance of food markets has therefore become of interest. In particular, the issue of whether the liberalised food market delivers cheaper food to households has become a key test of the liberalisation agenda.

3. Tests of market performance

The interest in empirical tests of food market performance has been a response to the market reform that many countries have undergone. Market monitoring systems at various levels of the food marketing system have generated data both for short-term analysis and for the gauging of long-term changes in the food delivery system. A very common dataset collected has been market price information. At regular intervals in local markets around a country, the price of a standard unit quantity of grain has been noted. Time-series have been collected which give a picture of the way prices develop within a year and over several years. Such data has become the most common starting point for the food market analyst.

The model of the food system that has underpinned research in food marketing was first suggested in Takayama and Judge (1971). The spatial price equilibrium model provides the arbitrage condition for spatially separated markets. When trade occurs, the price spread between in a pair of markets should equal the cost of transfer between the markets. A lower spread would make trade unprofitable. A spread which is higher than the cost of transfer would mean that more grain ought to be transferred from the market with lower prices. Arbitrageurs would step in seeing the profitable opportunity, in the process reducing the price spread to the cost of transfer. The primary result, that in trading markets prices would differ by the cost of transfer, has underpinned much recent work on food market performance.

Following Ravallion (1986), food price data has been analysed to see whether the Takayama-Judge results are borne out. Where prices in a pair of markets move together, this is taken as evidence that arbitrage is present maintaining price spreads at the cost of transfer. In such cases, markets are said to be 'integrated'. If markets are integrated in the long-run, a large divergence in the price levels of a pair of markets could not be sustained. If one has a set of prices over time for a pair of markets, this can be econometrically tested. The most common test has been the cointegration test. When cointegration is present in the time-series data for two markets, the markets are deemed 'integrated' in the long-run. Short-run integration is when arbitrage occurs as a response to price divergence very quickly or even instantaneously. In such cases, the price levels in two markets would not only be cointegrated, but there would be empirical evidence of co-movements in prices. This can be tested econometrically using an error correction model.

The usefulness of such tests is easily apparent. Market analysts appear to be able to use ordinarily available data to identify whether a marketing system is performing 'well'. Where there is evidence that arbitrage is not occurring so that market spreads widen without attracting trade, some market failure may be present. The market analyst would proceed by identifying why arbitrage is not occurring. Common problems include poor transportation systems, restrictions on access to markets, lack of market information. Government intervention may be available to alleviate such a shortcoming.

4. Storage and arbitrage

The Takayama-Judge spatial price equilibrium model has been applied to food marketing systems in Africa. The results have supported long-run integration, but there is less evidence for the presence of short-run integration. Price levels in regional markets do not tend to diverge in the long-run. Some force - trade between the markets - does appear to act to bind prices together in the long-run. However, transfer of price changes between markets is seldom found to be fast. Short-run market integration is routinely rejected. This thesis seeks to explain this observation.

It ought to be noted that the Takayama-Judge model only predicts that price spread equals the cost of transfer when there is trade. At other times, the model suggests that price spreads would be less than the cost of transfer and prices would be determined separately by demand and supply conditions in the two markets. Thus, the model allows for prices to be determined in a pair of markets independently. If demand and supply conditions in two regions are such that market prices are very similar or if the cost of transfer between the two markets is very high, there is no reason to expect trade to take place and for prices in the markets to be related. Short-run integration would then not be expected as the markets would seldom interact. This point has been generally known by market analysts. In using cointegration methods, the analyst has usually gathered evidence for why a pair of markets would always be trading. The most common reason given has been that one of the markets is a large city, the other market a proximate food surplus region. In such cases, the city would be expected to be importing all its food all year round so that trade would occur at all times.

This thesis investigates whether a more general model could be applied to food marketing. It does this by looking at the role of storage in food markets. Trade and storage can be viewed as substitutes. A market may choose to buy grain from another regional market. However, drawing down of own stocks may prove a cheaper source of food as it has the advantage of not incurring the costs of transfer. However, storage itself is expensive. Storing food ties up capital and developing countries have historically had high rates of discount so that capital is costly. The model presented in the chapter 4 integrates these aspects and looks into the timing, location and quantity of grain storage and grain trade between two regions. Further, an external market is hypothesised as another source of food grain. This may be viewed as the international market or government stocks (the marketing boards detailed above which still exist in many countries). The most important result is that trade would be intermittent with periods of non-trading occurring when regions source grain from harvest that has been stored or from the external market. A further finding is that there is a seasonal pattern to trade and the periods when alternative sources of food are utilised.

The model is empirically tested using survey data from Zimbabwe. In 1994-95, the author worked on an European Union-funded research project with the

Universities of Edinburgh and Zimbabwe looking at food security of Zimbabwe. The project administered a survey of 360 households from across Buhera District in Manicaland Province. Buhera is Communal Area and farms are small (less than 5 hectares) and unirrigated. To select the households a stratified sampling strategy was employed. The unusual aspect of the sample is that one level of the stratification used a measure of access to food markets. Thus, households were selected who were well-served by the marketing system and who were located in less accessible areas. The households were interviewed at regular intervals over an entire year and a picture of food transactions was built up which incorporated the changing behaviour of households over the agricultural season.

In chapter 5, the household survey data is analysed focusing on the role of the government-owned Grain Marketing Board (GMB) in the liberalised food market. The reform process in Zimbabwe has allowed private trade to exist in parallel with the state marketing system. The changes in 1992 saw private traders being allowed to transport, wholesale and store grains for the first time in three decades. The 1994-95 season was the first drought since the lifting of the restrictions on private traders and the manner in which the private individual or company has taken up the new opportunities at a time of food stress is explored. Further, a commonly cited role for the GMB is in guaranteeing food security and the impact of the GMB depot in northern Buhera district on household food access is relevant to future reform policy.

In chapter 6, the importance of household storage is investigated using the household survey. The model presented in chapter 4 shows the importance of storage as a substitute for trade. The household survey can provide much information on the extent to which rural household behaviour is consistent with this assumption. Households were asked how much grain they stored as well as how much was purchased. The year in which the survey took place saw a very poor harvest. However, agricultural yields vary enormously across even very small areas in the Communal Lands of Zimbabwe. Thus, there is much variation in household behaviour and an interesting picture is built up about how households decide to source their grain.

The model presented in this thesis treats trade and regional stocks of grain as substitutes. When modelled in these terms, important predictions on the timing of when the Takayama-Judge arbitrage condition should bind can be made. The seasonality in trading means that some part of the year, price spreads would be lower than the costs of transfer. This can be empirically evaluated using stochastic switching models. Baulch (1994) has recently used this form of modelling to design a test of market integration, the parity bounds model (PBM). He suggests that there are three regimes in which a market pair could be found. They might firstly be trading so that the price spread is equal to the cost of transfer. The markets may be integrated but not trading because price spread is less than the cost of transfer. This second regime is the case where stored grain or grain sourced from another market would be substituting for inter-market trade. The PBM's third regime is where the price spread *exceeds* transfer costs. This regime, if occurring, would indicate some impediment to trade and be a cause of concern for the food analyst. In chapter 7, a switching model is used to see the seasonal aspects of the switch between regimes and to see whether these switches are consistent with the results of the model presented in chapter 4.

CHAPTER 2:

Grain Market Liberalisation in Zimbabwe and Tanzania

1. Introduction

The performance of marketing systems in Sub-Saharan Africa has been much discussed in the recent decades. A history of heavily controlled markets for food is a common feature of the countries of the region. While social priorities have been identified as justification for the degree of state involvement, assessments have generally been negative with regard to the overall performance of the marketing systems. The calls for reform made by international agencies, particularly the World Bank (World Bank (1984), Smith (1989)), have recently begun to be heeded. By 1992, the World Bank could note that 35 African countries had implemented agricultural reform (World Bank (1994)).

This chapter will focus on the maize marketing systems of Tanzania and Zimbabwe. The two countries are often considered together due to the similarity in their crop production systems and marketing institutions (see surveys by Jayne and Jones (1996), Coulter (1994)). In this chapter, some reference to other sub-Saharan African countries will also be made. The institutional and agricultural features which allow a comparison between Zimbabwe and Tanzania to be made can be widened to include the four other large producers of white maize: South Africa, Kenya, Malawi and Mozambique (again, the surveys cited above make this point). This means that the findings of the later chapters should have wider relevance to other countries of Southern and Eastern Africa.

White maize is the prominent staple both for producers and consumers. Consumers purchase white maize flour to make a porridge which is commonly eaten with a meat or vegetable stew. Surveys have indicated the widespread preference for white maize over alternatives such as yellow maize (grown in the U.S. and Europe), rice, millets and sorghum. For farmers, maize production dominates all other crops. Both countries have a single, rainfed growing season with harvest occurring at approximately the same time. Harvest of white maize in Tanzania, the more northern country, would begin in March. Zimbabwe, begins its harvesting in April. As the production level is dependent on rainfall and the two countries fall within the same climate belt, maize yields are highly correlated between the countries (Jayne et al. (1994)).

Institutional similarities exist largely due to the common Colonial past of the countries. At independence, a legacy of British rule was that a large state-owned marketing board dominated grain marketing. This has meant that both the countries have experimented with pan-territorial and pan-seasonal pricing (these terms are explained later) and the associated restrictions on private grain trading. At the start of the 1980s, the marketing boards monopolised the large-scale buying and selling of foodgrains and fixed buying and selling price (though the nature of this was different in each country). As reform progressed in the 1980s and into the 1990s, the policies were gradually jettisoned with Zimbabwe more cautious than Tanzania.

Reforms have largely transferred the responsibility of food marketing from the state to private traders and companies. For a generation, Zimbabwe and Tanzania had had limited experience of food marketing by the private sector as state control had prohibited most of the private channels of food distribution. Only retailing remained in private hands. Research has therefore increasingly focused on the extent to which traders have responded to the new realities of the market by entering into food purchase, storage, transportation, wholesaling, processing as well as the historical role of retailing.

The next section will discuss the historical aspects of marketing in the two countries. In each of the countries there was a large expansion in the scope of state marketing in the period after independence and this is detailed. It is this period which has altered the financial position of the marketing boards most dramatically. The third section will consider critically the performance of the marketing systems and, in the fourth section, there will be a discussion of the country experiences of market reform. The final section will consider the extent of private involvement in the market post-reform and new roles for state intervention.

2. State Intervention in the Market for Foodgrains

2.1 The nature of state intervention

The first food marketing boards of Africa were formalisations of trading cartels begun after the First World War. The cartels were made up of the European farmers who would jointly seek out export markets for their surplus production. In Southern Rhodesia, co-operating in pricing decisions was seen by exporters as a means to reduce the uncertainty of trading in international markets. The cartel was highly successful and export became the main source of income for a white farmer. However, as the number of settlers grew, exporting grew more competitive. Further, the inter-war depression reduced the size of foreign demand. Settler farmers increasingly began to see the local market as more promising than selling abroad. However, this would bring the settlers in competition with the more productive African farm sector. This disadvantage was reduced with the establishment of the Grain Marketing Board (GMB) in 1931. The GMB gave the European farmers access to the institutional support afforded by a government-owned marketing institution.

From a small trading cartel serving the needs of an uncompetitive European-owned sector, grain marketing became an area of the economy controlled by government laws. These laws favoured the settler farmers and this inequality began the decline of the African farming sector (see Schmidt (1992) for a history of Zimbabwe's marketing system). The Board administered a marketing system which paid higher prices for the produce of European-owned farms over their African competitors. Similar Boards were established in other British colonies[1]. Kenya had eight Boards by 1945 covering a variety of crops and other southern and eastern African countries followed suit.

One feature of this policy was that marketing services were not provided to farms where the costs would be high. The formal marketing system was largely the preserve of the larger farmers. These farms were usually connected to the urban areas by good quality roads and so costs of transfer were low. The farms each produced large amounts of grain so that other transaction costs, such as quality assessment, payment etc., would be spread over a large value of crop. Low costs combined with the small number of such farmers so that the total costs of running the highly controlled system would never be high. This meant that a cap on the financial demands on the public purse could be maintained quite easily. Pre-Independence, the subsidy that the system demanded certainly could not absorb government finances in the same manner as food marketing would in later years when the system was extended to include many more of the population.

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[1]A different pattern of crop market regulation was followed in francophone Africa. Based more on the American system of the farm price support agency, they tried to moderate market prices through buying and selling crops in different years in response to harvest levels. The agencies thus became buyers and sellers of last resort, holding stocks from a surplus year to sell in poorer years. In poor years, the incentive to by-pass the boards undermined the financial viability of these operations. Thus, to maintain this system, regulations regarding trading rapidly were legislated to avoid large operating losses for the marketing agencies and, over time, the francophone marketing board began to resemble their counterparts in English-speaking countries.

Independence in 1964 for Tanzania and 1980 for Zimbabwe saw explosive growth in the scale of government intervention. The timing of the expansion differed for each of the countries, but a common feature was an increase in the number of buying points in areas previously under-served. Countries emerging into independence had a variety of reasons for expanding their marketing systems. The new Zimbabwe government saw expansion of the state's role as merely extending the benefits of government marketing of staple crops from the few to the many. Prior to Independence, the marketing boards had serviced the commercial farmers neglecting the needs of the numerous smallholders. Bryceson (1993) sees Tanzanian marketing policies in terms of an Africanisation of grain marketing. In Tanzania, Asian traders had dominated the food supply chain and some in power were hostile to the wealth and power that the role afforded non-Africans.

The general framework of the marketing institutions were similar in both countries. Certain crops - mainly the staples - were deemed as 'controlled' crops. The purchase price for these crops was set once a year by the marketing agencies, usually just prior to harvest, in consultation with the government. Different prices were set for different types of grains and different quality of grains (measured by the moisture content). However, the pricing policy was pan-seasonal and pan-territorial. 'Pan-seasonal' pricing meant that the marketing board was expected to purchase grains at its purchase price throughout the year. 'Pan-territorial' meant that the same purchase prices were applied to all the marketing board's buying points ignoring location. The marketing system was integrated with the processing sector and marketing agency grains were transferred or sold to the processors and then retailed through private shops. Again, there was price controls so that flour was sold to consumers at pre-determined prices.

Generally, the purchase price was set to meet the transfer costs of producers in areas an average distance from the cities. This meant areas where the cost of transfer to the cities was low were not earning a locational premium. Over time, this resulted in a change in the cropping patterns of the most accessible areas. As noted above, these were the commercial farming areas which were European-owned. The result, particularly in Zimbabwe, was that large-scale farmers began to switch from the controlled crops towards uncontrolled crops. The most popular of the crops which were not controlled was tobacco (Bryceson (1993); GMB (1991)).

The pan-territorial and pan-seasonal pricing regime cannot be maintained as an equilibrium in a free market as the marketing agency would make a loss. This would occur because disintermediation would take place. Consider the role of the marketing board in the year after a harvest. As discount rates are very high in rural Africa, producers could 'bank' grain by investing the cash of a post-harvest sale then purchasing flour back later in the year, keeping any profits. Clearly, any profits are at the expense of the marketing agency. This was observed to happen in poorer areas where credit markets were particularly underdeveloped (Heddon-Dunkhorst (1990)).

However, more common was spatial disintermediation. In a static scenario, consider one producer near a city and one distant from the city. For the marketing board to break even, the total of the margins on both producers' output must cover the costs of transport for both farmers (ignoring other costs for the moment). However, the producer nearer the board would then be receiving a price which would be lower than the city price by a margin more than cost of transfer. In other words, a tax has been imposed on the more accessible producers to subsidise the more remote farmer; this producer would be able to get a better price by directly selling to the city. The accessible farmer would have an incentive to avoid this tax, with the loser, should this occur, being the marketing agency who would continue trade in the grain of the remote farmer.

To protect the boards' pan-territorial pricing policy from spatial disintermediation, regulations banning the private movement of grains across district boundaries were legislated. Policing of illegal trade, particularly at times of shortage, became essential to maintain the fixed prices. Both Zimbabwe and Tanzania introduced road checks: people carrying amounts of grain suggesting they would sell on the grain would not be allowed to pass. Undoubtedly, the regulations could not stop trade across districts completely. However, it made trade considerably harder. Cox (1984) noted the clandestine trade occurring in Kenya where similar restrictions were in place. Jones (1987) (p377) studies the case of Zambia and notes that illegal trading was highest in countries with the severest food deficit. Thus, during poor harvest, up to eighty per cent of trade would by-pass the formal marketing system, while this would be as low as 20% in an average year. In Tanzania, illegal trading was particularly severe in the early 1980s (Bryceson (1993)). In Kenya, where a detailed study on the functioning of private markets was conducted, such parallel markets that resulted from government controls were also found to extract considerable rents (Bates (1989)).

While accessible producers sought to by-pass the formal marketing system, the opportunities offered to smaller farms greatly increased after the introduction of pan-territorial pricing. Over time, this resulted in changes in the structure of agriculture. The pricing system meant that, for example, maize grown anywhere in the country would get the same price. Farmers responded to such incentives through raising the amount of land growing controlled crops such as maize. The areas brought under cultivation were often in the most remote parts of the countries and the marketing boards were expected to purchase the production and transfer it to the distant cities. The additional cost of transfer to the urban areas had to be met entirely by the marketing board.

In the post-Independence era, the concerns of the urban population also had an impact on food marketing policy. The large cities became the most politically active areas of the country and the supply of their inhabitants with cheap white maize became an important role for the marketing system. The international white maize market is very thin. Also, the other main producers of the crop are all in the same agroecological region so that levels of production of the five main producers are correlated. This means that importing of white maize at times of drought is expensive as drought results in shortages throughout southern Africa. Countries have then to rely on the importing of yellow maize (which is a major internationally traded commodity). Yellow maize has proven highly unpopular giving the impression of failure of agricultural policy. This has generally reflected badly on governments (Jayne and Rukuni (1993)). To avoid this, the maintenance of reserves became of some significance. Government stockpiles of white maize rose considerably after Independence in both countries and the costs of maintaining the stocks began to climb (Bryceson, 1993).

2.2 The institutional structure of intervention

While the institutional frameworks of Zimbabwe and Tanzania have much in common, the history of the two marketing systems have some significant differences. Tanzania underwent a dramatic attempt at socialist transformation after its independence. This involved huge state engineering of social structures especially in rural areas. In particular, the government pursued a collectivisation programme through the 'villagisation' of the rural areas. Between 1973 and 1977, almost 60 per cent of the rural population were moved to villages. The village and the village council became the local means of promoting planned growth. In Zimbabwe, independence came much later and though the political party in power espoused socialism, the measures taken were far less dramatic. Mugabe's government were keen to promote the best farm practises and to integrate the peasant farmer better into the marketing system, but did this through providing subsidised agricultural support for small-scale farmers. This section details the institutional framework of each country's marketing system and gives some of the early history.

2.2.1 Tanzania

Tanzania underwent a dramatic socialist transformation in the 1960s and 1970s. In the rural areas, the 'villagisation' programme instituted village collectives. The government was keen to promote agrarian development through the village committees, but was keen to maintain regional equality between the collectives. Food marketing was seen as a main instrument in the development programme and so came under close government control. The form of this state control in cereal markets centred on: pan-territorial pricing; the elimination of private intermediaries; and the replacement of private trading with a state marketing system (Coulter and Golob (1992)). It can be seen immediately that the first policy helped to maintain regional equality. However, the logic behind the latter two forms of control was more contentious.

Private traders had been resented in rural Tanzania as they were generally considered to be exploitative. Some of this resentment was based on the ethnicity of the intermediaries who were generally Asian. The main African competition to the private trader had been the village co-operative. Traditionally, such organisations have had a strong presence in the rural areas of Tanzania and, after independence, the structure of the marketing system integrated the co-operatives largely to lessen the grip of the traders. However, the government remained uneasy about rural co-operatives, supporting the co-operatives' local roots but suspicious of their independence from the state. Drawing a line between the state and the co-operative remained an issue in the following years.

The state's intervention into food marketing was channelled through the government-owned National Milling Corporation (NMC). The NMC was primarily a processor of grains with, until 1975, the co-operative sector acting as local intermediaries for the NMC. A co-operative would combine the sales of a number of village collectives and then sell this on to the Corporation. But growing dissatisfaction with the co-operative sector led the government to rethink their inclusion in the marketing system. Thus, in 1975, the NMC began to purchase cereals directly from villages. This was the height of direct government involvement in the marketing of cereals with 7,768 villages registered as NMC purchase points (Bryceson (1993)). The NMC was forced to deal, for the first time, with such large number of purchase points taking it far further from its original role as an urban-based grain processor.

The NMC purchased using a pan-territorial pricing regime. To guarantee that all grains were directed through the government system, road blocks were set up to check that the illegal transporting of grains across the country was not occurring. Covert trading undoubtedly took place as the total in-take of the state system was always a very low proportion of total national production. However, the restrictions imposed by the government undoubtedly lessened the extent of private trade.

The price of the NMC's product, maize flour, was linked to the minimum wage rather than a cost of living indicator. Between 1975 and 1983, the minimum wage and so the price of maize flour rose by 60%. The cost of living, however, tripled. The effect was a fall in NMC revenue over the period. NMC revenue was further dented by regular government calls to provide food relief without then fully compensating the Corporation. The costs of the NMC system were high as well. The largest city in the country - Dar es Salaam - is on the eastern coast of the country and so very far from agricultural areas. The poor quality of the transport network combined with the enormous distances involved in food movements to make transfer very expensive. The NMC found its revenue getting lower each year and its costs high. The NMC's losses rocketed up and the pressure for reform began to grow.

In 1984, the failing system was partly reformed with the co-operatives being reinstated. The new co-operatives began buying in the 1985-86 agricultural season purchasing cereals from producers and then selling on to the NMC. Despite being endowed with many of the NMC's regional assets and few of the financial liabilities of the NMC, the co-operatives had a precarious existence. A complex network of links between the co-operatives and the NMC was set up. Co-operatives were to sell cereals on to the NMC and the price was to be negotiated. At the same time, finance and credit for the co-operatives was sourced from the NMC. Dealings between the NMC and the regional co-operatives were not friendly and the system staggered for a few more years with finances in turmoil before full reform was completed.

2.2.2 Zimbabwe

At independence in 1980, the government-owned Grain Marketing Board (GMB) of Zimbabwe had a network of over thirty depots across the country. By 1990, the GMB had expanded this number to 74 with the expansion targeting the smallholder sector. Almost all the new depots were located in the Communal Lands, the areas set aside for the black population as European settlers took over the more fertile highvelt. These areas consisted of numerous small-scale farmers with their food marketing constrained by poor transport infrastructure. Clearly, the government's aim of widening support to the smallholder sector was the main force behind the GMB's expansion. However, unlike the Tanzanian example, Zimbabwe's food marketing system did not undergo a socialist collectivisation.

Some use of the private sector was made within the marketing system. Most of the processing of grains into flour was done by five large urban-based millers. While the millers were private companies, their grain business was highly regulated. Sales by the GMB to the millers was at government determined prices. Further, the retail price of maize flour was set by the government. The pricing system in fact meant that the GMB subsidised the private millers. By 1992/93, this 'maize subsidy' had mushroomed to be 2 per cent of GDP (Jayne et al. (1995)).

The GMB made use of private grain traders through sub-contracting traders (called 'licensed agents') to procure grains. Surplus farmers some distance from a marketing board depot or buying point would sell to licensed agents. The agents would then sell on all purchased grain to a marketing board depot. Where necessary, such agents were allowed to transport grains across long distances, an act which would otherwise have not been allowed.

The post-independence expansion of the GMB system caused a rise in the production sold to the Board from the smallholder sector. However, it increased the financial pressures on the Board. The large number of small inaccessible farmers did increase procurement costs for the Board. To meet the higher procurement costs, the gap between purchase and sale price was allowed to widen. The GMB sought to off-set the increase in costs by lowering purchase prices. However, a detrimental effect of this was the increase in the incentive for larger farmers to bypass the Board. The most common means was to switch from maize production to other crops, especially tobacco. The in-take of maize from the commercial farmers thus began to decline (Rukuni and Eicher (1994)).

The financial problems of the GMB forced the Board into the disastrous decision to sell stored grain in the international markets in 1991. This saw losses drop from an average of Z$60 million over the previous three years to Z$6 million. However, the sale was months before one of the worst droughts in the post-war period. As production failure spread and the shortage became a regional as well as national problem, international white maize prices soared. The government of Zimbabwe instructed the Board to import maize at international prices and sell to the millers at the below cost sale price thus incurring huge losses. The GMB deficit for 1992/93 was Z$759 million. The government had agreed to underwrite the enormous losses incurred, but the debt has not been paid by the government and the GMB accounts have been in huge deficit since then with hefty interest charges adding to the financial burden. The financial burden of the Board's operation has precipitated reform: Zimbabwe has been one of the slowest reformers and only in 1993 was the monopoly that the GMB enjoyed removed.

3. Performance of Parastatal Marketing

The marketing systems in both Zimbabwe and Tanzania struggled to maintain financial viability in the post-independence era. This section looks into some of the problems that have since been identified about the marketing boards. Firstly, however, the section details a positive aspect of the state's venture into food marketing - the success of the small-scale producer.

3.1 The success of the smallholder farmer

The commonly held view in the early 1980s was that the parastatal marketing system depressed food production by keeping prices low (WB (1981); Cleaver (1985); Schiff and Valdes (1992)). However, evidence from both countries suggests that policies before reform benefited the small-scale food producers and this resulted in a large increase in the output of the smallholder sector. Producers were helped through the subsidised provision by the state of inputs such as seed and fertilisers, especially for maize. The role of the marketing system was pivotal also. Prices paid for maize production were generally quite competitive, with other food crops also receiving reasonable prices. Further, the expansion of the marketing system was targeted at helping the smallholder.

In Tanzania, the policy of rural development was set into motion through the Arusha declaration of 1967. The National Maize Promotion programme was begun in 1976 so that hybrid seeds, fertilisers and other inputs were provide to farmers at subsidised prices (Geier (1995)). In the ensuing two decades, maize production more than quadrupled (Putterman (1995); Amani and Kapunda (1989)). However, the source of this production increase was the bringing under cultivation of lands which were not previously farmed. By 1990-94, area under maize had risen by 89% from two decades earlier. It is worth contrasting this with Malawi. Increases in incentives to the small farmers resulted in an increase in the amount of grain sold to the board, but not in production (Kaluwa and Kandoole (1989)). In comparison to Tanzania, Malawi had little spare land.

Zimbabwe's production success in the 1980s has recently been termed an 'agricultural revolution' (Rukuni and Eicher (1994)). Expansion of the marketing system into the smallholder sector, the provision of credit and agricultural technology and a rise in the purchase price for maize combined to increase the proportion of marketed surplus sourced from the small-scale communal sector from 11% in 1980/81 to 63% by 1988/89. This rise in the GMB intake from the communal areas is not reflected in a rise in overall intake suggesting that the government incentives had a negative impact on the commercial farmer's maize production. The post-Independence era has seen a decline in the number of large farms planting maize with a switch towards tobacco.

3.2 Inefficiency in the controlled marketing system

3.2.1 Unnecessary movements of grain

There has been a high degree of centralisation in the processing and marketing network. In Zimbabwe, a main criticism levelled at the marketing system was the circuitous routes through which grain was channelled before reaching the consumer. The storage and processing facilities were located in the main urban centres and this meant that grains were sent to the two large cities - Harare and Bulawayo - neglecting where final demand for the grains may be concentrated.

Many rural areas in Zimbabwe are grain deficit, especially in years of poor rainfall. Econometric evidence indicates that between 130,000 and 275,000 tonnes of grain are involved in the rural to urban then back to rural flows each year (Jayne and Chisvo (1991)). This is a considerable share of the average million tonnes of marketed surplus. Sometimes, the producer areas neighbouring the areas where maize was eventually consumed were surplus!

Inefficiency in the marketing and distribution system was exacerbated by the uniform pricing across a country ignoring transport costs. This distorts the comparative advantage a region has by virtue of its location. A miss-allocation of resources then may occur. In Tanzania, areas suitable for maize production in terms of agroecological factors came under cultivation despite being very distant from consumers (Bryceson (1985)). The cost of transporting to Dar es Salaam a tonne of maize in 1979, at the height of the marketing intervention, ranged from TSh 22 to TSh 660. In particular, Ruvuma, a district suited to maize production but at the southern, opposite end of the country from the capital responded to the pricing regime by producing large surpluses. The marketing board was obliged to buy this production and incur the loss of hundreds of Tanzanian shillings per tonne.

3.2.2 Low marketing margins

The marketing boards were generally integrated with a large-scale urban processing system involved in milling grains to flour, the brewing of beers, etc.. In Tanzania, marketing and processing came within the same state-owned institution. In Zimbabwe the roles were separated with processing being privately owned. As noted earlier, the purchase price of grains was government determined and pan-seasonal and pan-territorial. The sales of grain or grain products would be at a fixed price, also determined by the government. The spread between the government determined purchase and sale prices was nominally based on the costs of the marketing and processing. However, political pressures were often of greater importance. On the one hand, farmers expected good prices for their products, while at the same time, urban consumers wanted cheap food. Marketing boards found the margins on which they operated to be squeezed.

Even when governments were inclined towards establishing price levels which would fully compensate the marketing boards, determining prices proved problematic because of the chaotic nature of marketing board accounts. Records regarding the financial position of the marketing board were rarely up-to-date. Further, the board's main operations were determined by highly variable weather patterns. It became very difficult to determine the nature of costs, especially determining what costs were attributable to the pattern of rainfall and yields.

3.2.3 Inappropriate food products

The marketing system channelled all surplus grains through the formal sector. The formal marketing system was linked to large-scale processors which would mill the grains to produce flour. Different grades of flour are possible from maize grains and the commercial sector was equipped to produce the two highest quality levels of flour. Coarser flour, which would have been cheaper, was not produced by the commercial millers. Restrictions on competition, especially the prohibiting of informal grain trade, meant this higher cost processing system could be maintained. It also lessened consumer choice considerably so that the standard of the flour catered more to the tastes of the higher income population.

The extent to which this was at the expense of the lower income households could only be estimated indirectly as trading restrictions meant that the informal sector was small and covert. A sample survey study in Harare indicated the preferences of the urban poor. Jayne et al. (1991) found that sixty-two per cent of low-income households would purchase the coarse straight-run maize flour if it was 12 per cent cheaper than the medium quality flour (the cheapest commercially produced maize flour). Interestingly, they found very little interest in low quality flour amongst the middle and high income groups, even at substantial price discounts. There is further evidence that consumers preferred the cheaper forms of flour. The survey found a burgeoning informal clandestine processing sector. Grain was being brought illegally to Harare to be processed in small-scale hammer mills of which there were about 30 to 40 in the city.

The commercial millers extracted a rent from their monopoly position in the processing sector and this has been estimated by Chisvo et al. (1991). The study calculates the margins on informal small-scale milling through looking at the cost of processing and the before-and-after weight measurements of maize processing. This was compared to the margin on the commercial product (the difference in flour price and grain price in Buhera). Commercial milling had three times the margins of the small-scale technology.

3.2.4 Poor management of grain reserves

Mismanagement of the grain reserves has increasingly been a feature of the parastatal marketing boards. Government interference has contributed to the losses incurred with many governments showing a marked reluctance to approve crop sales on the export markets. This has meant delay in making sales. This has added unnecessarily to the parastatal's storage costs. However, more seriously, the timing of grain sales has been fated to precede drought years. Then, the parastatal has been forced to purchase from the international markets just as prices have escalated. The financial losses have been particularly disastrous as a consequence of these poor decisions. EIU (1992) details the effect on Zimbabwe's GMB in the 1991 drought of government intervention in import/export decisions.

4.2.5 Poor administration and staffing

The delivery of marketing services became increasingly unreliable. In Tanzania, payment for crops was often delayed (Amani and Maro (1992)) Theft and corruption also crept into the parastatal organisations. Staff wages generally failed to keep pace with inflation and the expansion of the role of the marketing boards and co-operative unions have increased pressure on monitoring systems. Bryceson (1993, p.77) notes how a Tanzanian Marketing Development Investigating Team found that 'if a staff member does not do what is asked of him, ... no actions seems to be taken. The system just grounds to a halt'. In Tanzania's NMC, in 1977/78, 9.3% grain stock losses were due to disappearance. Commodity distribution and financial irregularities were common in other marketing systems.

Zimbabwe's GMB has generally been regarded favourably with regard to administration and staffing. However, some reports highlighted failings in the Board's performance due to poor quality and, sometimes, corrupt officials (CSM (1986)).

4. Liberalisation of Staple Marketing Boards

As marketing agency losses mounted, the financial burden placed on the governments by their marketing boards spurred reform of the marketing systems. In both countries, the reform of the marketing system occurred in a climate of wider reform. Tanzania began the process of structural adjustment in the mid-1980s reforming other sectors in parallel to agriculture. Zimbabwe underwent economic liberalisation a decade later. As Jayne and Jones (1997) note, the number of reforms that countries underwent concurrently make it difficult to isolate the effects of food marketing reforms. Further, there were reversals in some of the policies as government commitments changed. This section describes the reforms in Tanzania and Zimbabwe. Table 1 gives some of the key parts of the reform process and the progress made by 1997.

4.1 Zimbabwe

The miss-management of the Grain Marketing Board in its handling of the 1990-91 drought left the GMB considerably weakened. The effect of the drought on the wider economy had been significant with tobacco yields, and so the revenue from Zimbabwe's main export, very low. The first casualty of the economic downturn was the refined maize flour subsidy, which, as noted above, had risen to unsustainable levels. This subsidy for the production of highly refined maize flour by the 'big five' commercial millers had been in existence since 1979. It was removed in 1993.

Table 1

The Reform Process in Five African Countries by 1997

Country	Zimbabwe	Tanzania
Institution(s) involved in Maize Trading	Grain Marketing Board (GMB)	National Milling Corporation (NMC) and Co-operative Union
Buying/Selling Monopoly	Abolished 1993	Abolished 1986
Producer Price Setting	Not abolished	Pan-territorial pricing abolished 1988
Consumer Price Setting	Not abolished	Pan-territorial pricing abolished 1988
Maintenance of Strategic Reserve	Yes - since 1997	Yes - 150,000 tonnes since 1987

At the same time, there was an easing on the controls over informal grain trading. This meant that maize grain could be traded in large amounts for the first time. Apart from allowing more trading opportunities for farmers, the freeing up of the informal market has led to changes in the processing sector.

Small-scale hammer mills are a lower cost alternative to the commercial millers' super refined. Since this reform, surveys have indicated that poorer households especially have shifted to maize flour milled by hammer mills (Jayne and Jones (1996)). By 1996, a number of new companies had been set up which specialised in 'roller-meal' maize flour production at a large-scale so that new brands have begun to appear in markets competing with the big five. Last year (1998) even saw the GMB introducing its own brand of maize meal (Herald (1998)).

The GMB's institutional structure has not been changed in the reforms. It has not been commercialised in the manner of Zimbabwe's other four crop marketing boards (which were commercialised in 1995). The GMB has continued to set producer and consumer prices. However, the need for financial viability has meant that the Board has begun to vary prices during the year as information regarding harvest has become available. The government has also begun to tackle the GMB's debt. In the 1994/95 drought, the government initiated several schemes to avoid the huge losses of the earlier drought. A drought levy was added to income tax creating a Z$1 billion drought levy fund (EIU (1997)). This was channelled to the Board to meet the financial costs of the 1994/95 drought, and also to begin to pay off the debts accrued during the 1991/92 drought.

At the same time, the GMB has started to rationalise its operations. The GMB has begun closing some unviable depots. Other GMB depots operate only at certain times of the season. The parastatal's 3500 staff have been reduced by a third since 1996. However, the government has indicated that the social roles of the GMB - maintaining depots in remote areas and a stockpile of grain for food security - will be subsidised by the government through the drought levy fund.

4.2 Tanzania

As part of the structural adjustment programme begun in 1983, Tanzania's food marketing system was reformed. Inter-regional private movements of grain were *de facto* legalised in the following year when the amount that could be transported was raised to half a tonne from the previous 30kg. All restrictions on grain movements were lifted three years later, though traders were only allowed to purchase from the local co-operatives and not directly from the producers. The effect has been very significant. Whereas in 1980/81 the volume of sales handled by the private sector was 43% of total maize sales, this number had become 83% by 1987/88 (Dercon (1992)). By 1990, traders were allowed to buy grain directly from farmers, though local governments had some say in when and where purchases could be made. This confused the situation, but in most parts of the country the traders had, by 1990, already been significant players in rural food markets for half a decade.

This longer post-reform period, in comparison to Zimbabwe, has meant some of the results of research on the effects of market liberalisation can be detailed. Santorum and Tibaijuka (1992) have analysed whether the private sector is taking advantage of the considerable benefits of operating at a large scale. Their evidence suggests that the trader does not invest in either large fleets of vehicles or sophisticated storage systems. Thus, the wholesaler usually trades only a truckload of grain and has a fast turnover in grain stocks. Small size in physical capital is mirrored by weak market information amongst traders. Gordon (1988) has noted that this remains a problem due to the large distances between markets and the poor communication system. Radio stations and newspapers have been used to communicate the price levels in the main cities, but information about the state of smaller markets remains more difficult to ascertain[2]. While trader entry at a large-scale of operation remains low,

[2] MDB (1992) find that 80% of their surveyed traders listened to the radio bulletins giving the price levels in Dar es Salaam.

indicators of market performance show a favourable picture. Coulter and Golob (1992) suggest that there is evidence of improvement in both resource allocation and of entrepreneurship. They cite evidence of prices in different markets converging and the difference between consumer and producers prices reflecting processing costs more closely.

At the start of the reform process, the National Milling Corporation and the co-operatives were financially weak. One reason for the improvement in the NMC's financial position has been the lower level of grains going through the system as private markets deal in more grain. A second reason was the abandonment of pan-territorial pricing in 1988. The NMC was then allowed to vary prices so that they better reflect marketing costs. In the more remote areas, producer prices have fallen as the high transport costs have been factored into the price the farmer receives. However, in some areas, the new pricing regime has led to producer price levels rising and the last two seasons of the 1980s saw large production surpluses sold to the NMC. The government has continued to announce purchase prices for maize. However, by 1987, these prices were quite low and were mainly used by the co-operative sector as a minimum price for purchase of grain with NMC prices higher than government determined prices.

As noted above, the reintroduction of the co-operatives in 1986 meant the National Milling Corporation became more concerned with the processing of maize into flour. However, some of its role as a parastatal trader remained as the NMC was charged with maintaining the country's strategic grain reserves (SGR). This was achieved through open-market purchase and sale of grains. As the SGR was set at a high level, this role meant the operations had a significant impact on the market (Coulter and Golob (1992)). In a move towards commercialisation of the NMC, this role was itself transferred to the Ministry of Agriculture in 1990.

The finances of the various agencies involved in food marketing gradually became more transparent in the later 1980s. Financial pressures combined with poor working relations between the NMC and co-operatives to cause long delays in the payment of farmers for grains. By 1991, the co-operatives were recognised as private institutions granting them a degree of autonomy they had not had for almost three decades.

5. Issues for Modern Grain Marketing: Interest Rates, Storage Problems and Trader Entry

A reasoning offered for the state intervention into food markets was the underdevelopment of financial markets linked to the food system. Surveys have indicated how, post-reform, the provision of inputs and capital at planting remain an area of concern (MDB (1992)). The marketing and processing of grain has a high degree of seasonality in sub-Saharan agriculture. There is a single harvest in the year and there is high demand for capital in the months leading to harvest. There is a marked reluctance from the formal sector to lend to farmers as the average producer possesses very little security (in particular, the traditional tenure system of much of sub-Saharan agriculture does not give the farmer exclusive and transferable rights to land). Also, credit relationships between individual farmers prove difficult as risks are highly covariate with poor rains affecting the harvest of neighbouring farmers in a similar manner. Thus, funds borrowed at the planting time are usually sourced from informal lenders.

Bagachwa (1995) studies the development of informal finance in Tanzania. Monthly nominal interest rates of ten per cent were over double the rate of inflation suggesting that annual real interest rates approached 100%. Further, there has been a marked increase in the importance of the various forms of money lender and this has been associated with the liberalisation of the grain trading system. The exorbitant rates of interest charged force farmers to sell harvested crops as soon as possible once crops are harvested (Coulter and Golob (1992), p.422). Thus, the problems of a poor credit system are often exacerbated by a supply glut at harvest time pushing prices down when the farmers would be selling. The poorest farmers have least access to capital and are most likely to sell early.

The effect on traders of the underdeveloped nature of credit markets has been primarily on the storage behaviour of the private trader in grains. Many recent studies of the private trade in grains indicates the low levels of inter-year storage especially. A first reason for trader reluctance to store grain into another agricultural season has been poor access to long-term credit (Lele (1971); Southworth et al. (1979); Sahn and Delgado (1987)). However, even where traders have access to the required capital, many of them do not believe that governments would allow them to profit from such stored grains if a drought causes large upward movements in grain prices. Governments have a history of intervening in the market to avert such movements in the price of staples (Kinsey (1992); Steffen (1995)). This means that the ability of the private market to smooth inter-year fluctuations in crop yield - and possibly the worst effects of a year of drought - are greatly diminished.

Entry into grain trading has been used as a barometer of the short-term success of the reform process. Where studies have been conducted, the evidence indicates that entry into grain retailing and processing has been high. These two activities have very little need for capital. Grain retailing sees the trader purchasing grain in small quantities for rapid sale, while entry into the processing sector has been concentrated in the small-scale hammer mill technology. The hammer mills are relatively inexpensive and the millers usually grind grains provided by a household for a fee.

Entry into the capital intensive activities has been low. Barrett (1997) notes the proportion of his sample of traders who began their activity since Madagascar liberalised its marketing system. While there has been healthy entry into the marketing activities requiring little capital, entry has been negligible in wholesaling, storage and long-distance transportation, activities where substantial capital investment is essential. Such findings are reflected in other studies on entry into marketing such as Kaluwa (1992) in Malawi and Bryceson (1993) in Tanzania.

As Jayne and Jones (1996) note: 'the experimental nature of food market liberalisation in Eastern and Southern Africa is apparent from the fact that, prior to the recent reforms, almost no one in the region has experienced a market-oriented food system in his/her lifetime' (p.29). The reformed marketing systems in place in many countries have thus had to face a severe test of credibility. Further, the reform process has never engendered much support amongst the population at large. The World Bank has had to use conditionality of loans as a carrot during discussions with governments and few of the large agricultural interest groups view the process as anything other than an imposed and foreign policy regime. Some reintroduction of market controls could occur if the finances of the countries improve.

A common reason for a future intervention into grain marketing would be food security. The heavily controlled marketing systems were geared towards coping with localised production failures through timely movements of grain as shortages occurred. The marketing systems succeeded in averting the worst consequences of drought with the governments always prioritising food for consumers and so averting famine conditions. Both Tanzania and Zimbabwe organised food distribution in the 1992 drought, a drought which affected all countries in the region, including South Africa. The marketing boards were always the main actor in the purchase of staples from international markets. As the state's role has declined in the food markets, some of these roles will not be taken by even the private sector. Coulter (1994) argues for public buffer stocks.

Excessive price instability could affect food security and Smith (1997) argues for some role for state agencies in insuring the adequate stability.

Post-reform, in Zimbabwe, the marketing board has been charged with maintaining strategic reserves to mitigate against drought. This role has largely been met through the purchase and sale of grains at market prices. However, as strategic reserves have involved large quantities of grain, the board's intervention in the marketing system to maintain reserve levels has usually been significant. Often, the intervention has involved government set purchase/sale prices. It appears that the habits of the controlled marketing system will persist for some time.

Many of the issues raised in this chapter will be discussed in the thesis. Chapter 4 will present a model of a food system which assumes a high level of discounting and poor transport system. The model also allows for the presence of a pan-territorial, pan-seasonal pricing regime operating in parallel with private movements of grain. The model will then be empirically investigated using survey data from Zimbabwe. In chapter 5, issues such as the entry of traders into the liberalised market will be discussed further in the context of what was observed in rural Zimbabwe. The pivotal role of the Grain Marketing Board of Zimbabwe post-liberalisation will be shown to be of great importance in shaping the way a local food marketing system operates.

CHAPTER 3:

Testing Market Integration: Motivation for Research

1. Liberalisation and Tests for Market Integration

The logic behind testing for market efficiency in food markets of developing countries has been uncontested. Various agencies have pressed developing countries to liberalise food markets so that productive and allocative efficiency can be attained. There has been a need for tests on whether the policy has delivered its goals. Such tests have usually tried to establish if there are impediments to regional trade through analysing time series data of regional prices. Since the early work in the 1970s using simple price correlations (Jones (1968)), methodology has improved considerably. Advances in the analysis of time series have been adopted by market analysts. Two particular techniques of time series analysis have proven highly popular: error correction models and cointegration. However, more recent analysts have attempted to specify tests based on a more detailed understanding of the economic models of the marketing systems (Baulch (1994) for the Philippines). Correlation of prices between pairs of markets is only one result of market integration. Recent work has nested the alternative results of economic models of regional markets.

The next section will describe the most commonly used model of regional markets - the Takayama and Judge spatial price equilibrium model. It will highlight the main results of the model. Takayama and Judge (1971) derive the arbitrage conditions for spatially dispersed markets. At any particular point in time, two possible states are described. In the first state, the commodity is being traded between the two regions so that the prices of the commodity in a pair of trading markets are determined jointly. The price difference between the two markets would be equal to the cost of transfer between the market. In the second state, there is no trade flows and the regional markets clear independently. Takayama and Judge highlight that this state is only consistent with regional price levels which differ by less than the cost of transfer between the market pairs.

The third section describes the empirical tests of market performance that stem from the spatial price equilibrium model. The section begins with Ravallion's seminal use of the error correction model on Bangladesh rice markets (Ravallion (1986)). The methodology uses the market price in the pair of markets. It assumes one of the markets is exogenous and then proceeds to determine whether the co-movement of the food price in the second market gives evidence of long-run integration. If this is the case, then Ravallion suggests tests for measuring the speed of the price transfer from the exogenous to the other market. This indicates whether the market pairs are integrated in the short-run.

However, more recent analysis of market integration questions whether the use of Ravallion's method is always warranted without some empirical evidence in support of Ravallion's assumption about exogeneity. This is where cointegration analysis has suggested methodological refinements. Palaskas and Harriss-White (1993) first noted that two price series have to be significantly cointegrated before an error correction model can be used citing the literature in econometrics on the Granger Representation Theory as evidence. Finally, Alexander and Wyeth (1994) noted that Ravallion's particular choice of error correction model needed evidence of one market being exogenous. They then provided empirical tests of this assertion as a pre-cursor to Ravallion style models.

The fourth section uses price data from Tanzania to analyse market integration. The techniques described in the chapter are used.

2. Economic Models of Spatial Economies

2.1 Regional market models

In models of regional markets, all transactions within a region occur at a point; that is, the effect on access to the marketed commodity of intraregional transport costs is not modelled. All buyers and sellers converge to a single point in the region. Trade then is modelled between these points, with transfer between the points incurring transport costs. The problem addressed by such models is been posed by Enke (1951, cited in Takayama and Judge(1971)):

> 'There are two (originally three) or more regions trading a homogenous good. Each region constitutes a single and distinct market. The regions of each possible pairs of regions are separated, but not isolated, by a transportation cost per physical unit which is independent of volume. There are no legal limitations to the actions of the profit-seeking traders in each region. For each region, the functions which relate local production and local use to local price are known, and consequently, the magnitude of difference which will be exported or imported at each local price is known. Given these trade functions and transportation costs, we wish to ascertain: (1) the net price in each region; (2) the quantity of exports and imports for each region; (3) which regions export, import or do neither; (4) the volume and direction of trade between each possible pairs of regions' (p. 40).

The interest in this spatial analysis of commodity flows has stemmed firstly from the theories of Ricardo justifying trade due to comparative advantage. In these, there is mutual benefit for participants through specialisation and trade. These models readily accepted that the cost of transfer between the producers and the consumers would temper the extent of this gain. The cost to transfer has to be off-set through economies due to differing supply and demand conditions in the separated markets.

A second reason for the interest in regional markets has been the close similarity between the theorised model and actual marketing systems. Regional food markets have been a feature of developing economies. In the rural areas, a regional market, perhaps periodic, acts or has acted as the main conduit for agricultural production to be transferred from a surplus area to regions where there is excess demand. Participants in the market are expected to meet at a point and so bear the cost of transfer to the regional market. The net price of the purchase for any consumer/seller then necessarily is identical in a regional market and the pricing regime become non-discriminatory (Phlips, 1983, p. 6).

2.2 Takayama and Judge and the law of one price

The primary in-sights into models for inter-regional trade have been shown by Takayama and Judge (1971) who build a set of models in line with the specification of Enke (above). This single-period model investigates the behaviour of prices and flows of the commodity when trade is competitive so that an optimal outcome results. Thus, Takayama and Judge extend the findings of competitive equilibrium - that under the regularly assumed restrictions on continuity, slope, curvature and domain of production and utility functions, and with a complete set of markets, an efficient, in the Paretian sense, outcome will result - to an economy with spatially segmented but not separated economy.

The simplified demand and supply conditions used here fall within the more general set of functional forms which Takayama and Judge investigate. However, the main conclusions would remain identical. A linear inverse demand function has the properties of being continuous, differentiable and monotonically decreasing in terms of the consumption quantity y_i. Similarly, the linear inverse supply function is an example of a continuous, differentiable and monotonically increasing function in terms of production quantity x_i.

In a two-country model, with regions 1 and 2, let the cost of transport between the regions be m per physical unit of the homogenous commodity. Assuming linear inverse demand and supply functions, the demand price in region i, p_i, is given by:

$$p_i = a_i + b_i y_i \qquad \text{for i = 1, 2} \qquad (1)$$

where the quantity demanded is y_i and a_i, $b_i > 0$, for i = 1, 2.

Similarly, the supply price, q_i, is assumed to be a linear function of the quantity produced, x_i:

$$q_i = c_i + d_i x_i \qquad \text{for i = 1, 2} \qquad (2)$$

where c_i, $d_i > 0$ for all i.

The quantity consumed by each region cannot exceed the total amount shipped into the region. Thus,

$$y_i \leq x_{ji} + x_{ii} \qquad \text{for i,j = 1, 2 (i}\neq\text{j)} \qquad (3)$$

where $x_{ij} \geq 0$ is the quantity shipped into region j from the region i, and x_{ii} is that part of region i's production which is supplied to region i. Thus, x_{ii} cannot be greater than the total amount produced in region i less the quantity shipped to region j, i.e.:

$$x_i \geq x_{ij} + x_{ii} \qquad \text{for i,j = 1, 2 (i}\neq\text{j).} \qquad (4)$$

Takayama and Judge proceed by defining a 'quasi-welfare function' for each region. This function calculates the area under the demand curve up to the consumed amount and subtracts the area under the supply curve up to the produced amount. The amount supplied by j may differ from that demanded in region i as the quantity x_{ii} + x_{ji} - x_{ij} may not be zero due to trade (e.g. some production may leave the region). This gives a measure of consumers' utility less producers' cost. Then, as transport is considered as exogenous to this economy, the total cost of transport is deducted. This function is assumed to be additive, or Pigovian, and a community quasi-welfare function, W, can be defined as:

$$W = \sum_{i=1}^{2}\left[\int_{0}^{y_i} a_i + b_i k_i dk - \int_{0}^{x_i} c_i + d_i k_i dk\right] - m \cdot \sum_{i=1}^{2}\sum_{j=1}^{2} x_{ij} \tag{5}$$

The first summation calculates the consumer and producer surplus of each of the two regions. The inverse demand function is integrated over quantity consumed; the inverse supply over quantity produced. The final term is the total cost of shipping the commodity between the two regions - a loss to total welfare. The optimisation program can then be defined as maximising equation (5) subject to the four conditions given in (3) and (4). The necessary conditions for an optimal solution would be derived by solving a Lagrangean formed by combining (5) with (3) and (2) with appropriate multipliers. By solving the Kuhn-Tucker conditions of the optimisation programme, Takayama and Judge establish a 'law of one price' for inter-regional trade:

- if trade takes place at all between any two regions, then price in the importing region equals price in the exporting region plus the unit transport cost incurred by moving between the two; the markets are said to be spatially integrated in this case;
- if trade does not take place between two markets, then the difference in price levels in the two markets cannot exceed the cost of transfer between the two markets.

Circumstances where market integration may not lead to Pareto optimality are investigated by Newbery and Stiglitz (1984). In a model of two competitive but risky economies, with no insurance markets, they show that free trade may diminish the self-insurance possibilities a situation of autarky allows. In particular, if the same event, say, bad climate, is common across the entire region but that event's occurrence in one region is not correlated with occurrence in the other, trade diminishes self-insurance opportunities.

3. Conventional Tests of Market Integration

The performance of food markets in developing countries have increasingly been scrutinised. Liberalisation of markets has prompted an explosion of interest in tests of market behaviour and this section details some of the main tests. The Takayama and Judge model of the last section forms the basis of the tests. When regional trade is occurring, the price of food in a pair of trading markets should differ by the cost of transfer. As the price levels are jointly determined, movements in time series data of markets prices would be highly correlated. The tests of market performance use this property to test market performance. Price co-movements are viewed as evidence of no impediments to trade with private traders profiting through arbitrage if there are any discrepancies. Where the price of food in a pair of markets persistently move in different directions, this is taken as evidence for low market integration and, potentially, some barriers to trading between the markets pairs.

3.1 Ravallion model

A common test for market integration was devised by Martin Ravallion in his work on markets in Bangladesh (Ravallion, 1986). Its application has been widespread (Nigeria: Heytens (1986); Ghana: Alderman (1993); Tanzania: Gordon (1988)). Timmer (1986) has added some details to the model but the underlying principles have been applied extensively with little modifications. The Ravallion approach assumes that there is a dominant reference market which trades with *N* outlying markets. Due to the dominance of the central market, the price formation in the outlying markets is a function of the central market and exogenous variables that affect that market:

$$P_i = f_i (R, X_i) \qquad \text{for } i = 1, \ldots, N \qquad (6)$$

where P_i is the level of price in the outlying market at time t, R the price in the reference market and X_j a vector of exogenous variables for the local market. At the same time, the price of the reference market is determined by all the other markets and factors that affect that local market:

$$R = f(P_1, .., P_N, X) \tag{7}$$

where X is a vector of exogenous variables affecting the reference market.

Equations (6) and (7) generalise the functional form of market pricing but model a static system. Ravallion proceeds by giving a dynamic structure to these equations by including several lags, given here as n. The model thus allows an assessment of price changes across time. To simplify the model, f is assumed linear. For the outlying markets the resulting equation becomes:

$$P_{it} = \sum_{j=1}^{n} a_{ij} P_{i,t-j} + \sum_{j=0}^{n} b_{ij} R_{t-j} + \gamma_i X_{it} + e_{it} \qquad \text{for i = 1,..., N.} \tag{8}$$

and for the reference market:

$$R_t = \sum_{j=1}^{n} a_j R_{t-i} + \sum_{i=1}^{N} \sum_{j=0}^{n} b_j^i P_{i,t-j} + \gamma X_t + e_t \tag{9}$$

where the errors, e_{it} and e_t, are normally distributed with zero mean. For the present analysis, only one lag is given, but as many should be included as is necessary to capture all of the significant effects. Often when the model is applied only the equation of the outlying markets is estimated and so the relationship takes the form of the autoregressive-distributed (ADL) lag model of order (1, 1). The order reflects the single lag utilised. Thus the price in the outlying market can be written as:

$$P_t = a_0 + a_1 P_{t-1} + b_0 R_{it} + b_1 R_{i,t-1} + X_{it} + e_{it} \tag{10}$$

where the disturbance is normally distributed and has mean zero.

The exogenous variables represented in the above equations usually take the form of a vector of variables such as dummies for trend (assumed to consist mainly of inflation) and seasonal variables.

Several error correction specifications can be derived (see Banarjee et al. (1993), pp. 48-49) from this specification. Each nests within it a variety of tests of market integration and a series of tests of coefficients can be undertaken to establish three categories of market integration. The particular derivation used by Ravallion was:

$$\Delta p_t = a_0 + (a_1 - 1)(P_{i,t-1} - R_{t-1}) + b_0 \Delta R_t + (b_0 + b_1 + a_1 - 1) R_{t-1} + X_{i,t} + e_t \qquad (11)$$

where the term R_{t-1}-$P_{i,t-1}$ is the error correction term.

This form offers some useful tests for the level of market integration. Firstly, there is evidence of long-run integration between the outlying and reference market if the coefficient on the lagged prices in the reference market is not significantly different from zero. This is testing whether the sum of the coefficients on all prices in the ADL equation is one; that is current price in the outlying market is some average of its past price and the past and present price in the reference market. If the coefficient is insignificantly different from zero, there is a long-run relationship. Due to this finding, the unrestricted dynamic specification is also inefficient and can be reduced in size. Such a procedure - termed general to specific modelling - is discussed in Charemza and Deadman (1992). In this case, Ravallion proceeds by re-estimating with the lagged reference market prices, R_{t-1}, omitted.

Given long-run integration exists in the pair of markets, short-run integration can be tested through analysing this restricted equation. In particular, if the coefficient on the error correction term equals minus 1 and the coefficient on the current change in the reference market price is equal to one, then there is evidence for strong short-run integration. This merely tests that the price in the outlying market is equal to the instantaneous price in the reference market (If a number of lags were employed in the estimation, then the coefficients on these should equal zero.)

If this strong short-run integration is rejected, there may be evidence for weak short-run integration. This is tested by a further reduction in the model. If there is a significant linear relationship (without a constant) between changes in the outlying market's price and changes in the reference market's price, then a weak form of short-run integration is supported; this would be non-instantaneous price transmission.

Reservations about the Ravallion model have stemmed from the assumption of the exogeneity of the reference market. Price analysts usually provide some qualitative assessment about the validity of the assumptions regarding the marketing system when the Ravallion method has been used. A common marketing structure that has fulfilled the criterion needed for central market exogeneity has been the radial economy. Here, it is assumed that the rural hinterland services the food needs of a large city. The rural areas are surplus in grains with the city necessarily being deficit. The one-way flow of grain is therefore from each rural market to the main city. The flow would be continuous throughout the year. Further, trade between rural markets is assumed away as such areas would be self-sufficient.

Later, direct tests regarding this aspect will be detailed but initially it is worth considering the implications of the reference market not being exogenous with respect to the outlying market. One such scenario would be when prices in the outlying market are determined by the reference market, but the reverse is also true resulting in a correlation between the reference market and the error term of the estimated equation. Here, another error correction model may be formulated for the reference market prices and then integrated into the model for the outlying market. The positive covariance between the two estimated error correction models would mean two stage least squares techniques would have to be used.

A further critique of the Ravallion type models is the assumption that trade would be continuous throughout the year. Again, the assumption that the market has a radial nature centring on a city which requires year-round supplies is a market structure which would deliver this continuous trading. However, changes in the transfer costs between the city and its rural supply markets may mean intermittent breaks in supply. The high degree of seasonality in supply has been cited as a main reason why transfer costs could be expected to vary. When seasons do not coincide across regions, reverses of food flows may result.

3.2 Cointegration techniques

The use of cointegration techniques in the analysis of price time-series data has been a solution to some of the problems of the Ravallion methodology. One interesting result of this later work has been the finding that the Ravallion approach is sometimes the correct estimation procedure, but only after tests have verified the market structure the Ravallion model assumes. This section will discuss the cointegration procedure and some of the drawbacks of the techniques.

Firstly, it is necessary to define two terms - stationarity and integration - associated with a discrete time series. A time series is stationary if it has no trends in it of any sort. More technically, a stochastic process is said to be stationary (in the more commonly used weak sense), if its expected value and variance is constant over time and the covariance of an observation and a lagged observation is dependent only on the length of the lag and not when in time the observation is made.

Stationarity leads to the second important concept of integration. If a time series, $\{p_t\}$, has to be differenced n times to give a stationary series, then $\{p_t\}$is integrated of order n, denoted I(n). Most price time series are I(1). Thus, while generally the levels of prices are not stationary with the variance tending to rise in time as a result of inflation, the first difference in price does not display this property.

To investigate the order of integration in a series, the Dickey-Fuller (DF) test or the augmented Dickey-Fuller (ADF) test is employed. Both these tests regress the change in the time series, Δp_t, against the lag of the level of p_{t-1}. Such a regression, which derives the DF statistic, often has the problem of serial correlation in the error term so that several lags of Δp_t may also be added until this problem is addressed[3]. The test then becomes the ADF test. The test statistic is the t-ratio of the coefficient of p_t. Rejection of the hypothesis provides evidence that the series is stationary. Thus, if the hypothesis is not rejected, the series null hypothesis, that the series is $I(1)$ or higher, must be tested. This is achieved by differencing the series, estimating another Dickey-Fuller equation. This time the regression involves estimating $\Delta^2 p_t$ using its lags and Δp_{t-1}. If the t-ratio on the Δp_{t-1} coefficient proves significant this time, there is evidence that Δp_t is stationary so that p_t is $I(1)$. Otherwise, the process must be repeated for the second difference.

The test statistic is not distributed as a standard student t-ratio. It is generally known as a DF or an ADF statistic (depending on any use of lags) and is always negative. The statistic is larger than the standard t-values. Dickey and Fuller (1981) provide a table of critical values for the DF and ADF statistics.

If two price series are both integrated of the same order, then they may be co-integrated. Two series, $\{p_{it}\}$, $\{p_{jt}\}$, which are both I(n), n>0, are cointegrated if some linear combination of the two series is stationary. If two series are cointegrated, it implies that while the series may in the short-run diverge, in the long-run this divergence is not sustained. This constraint on the behaviour of

[3]Lags of Δp_t are added until the coefficient is insignificant.

one series in relation to the other is taken as evidence that there is an equilibrium relationship between the two series as there is empirical evidence that the two variables converge. The standard means to test for cointegration is the Engle Granger Two Step Procedure.

Firstly, the linear combination of the two series is established. This is achieved through ordinary least squares regression of p_{it} on p_{jt} and a constant. Whether p_{it} or p_{jt} is used as the dependent variable is not important as it is the behaviour of the residuals in this cointegration equation which is investigated in the second stage. The residuals $\{e_t\}$ are subjected to the test for stationarity detailed above. A regression of Δe_t on e_{t-1} is performed with enough lags of the Δe_t term to absorb serial correlation in this regressions error term. If the t-ratio of the coefficient on e_{t-1} is higher than the critical ADF statistic then the two series are cointegrated order n, n (sometimes written as $I(n, n)$). If the test statistic is low then the critical value, no further action is taken as there is no evidence of cointegration in the series.

If two markets' price series are both integrated to the same order and they are both cointegrated, then the economic interpretation in terms of market integration is of some importance. The existence of cointegration is evidence that large differences between the prices in the two markets do not persist and there is a long-term equilibrium relationship between the prices in the two markets. This is prima facie evidence for the presence of some equilibrating force between the two markets and suggests there is market integration in the long-run.

Therefore, as a tool to determine market integration, the cointegration procedure can be used to determine long-run integration. In this, the method has some advantages over the Ravallion methodology. There has been no asserting of one market being a reference with the others outlying markets. Rather, the test can be used on all pairs of markets. Markets which show no cointegration can be determined and these would be poorly integrated as there would be significant persistent deviations in price spread.

3.3 Causality and exogeneity

The cointegration model can be extended using the Granger Representation Theorem. This states that the correct form of model to use for investigating causality between the two series is an error correction model. An error correction model allows the price analyst to determine the causality between market pairs which have a long-term relationship. The causality tested for is usually Granger causality. This essentially tests to see whether changes in one market precede changes in another. If there is evidence that changes in market i precede changes in market j then this is taken as evidence that market i causes market j. Causality can be in both directions and this is called a feedback relationship.

Several alternative forms have been specified for an error correction model. In all of these models an error correction term enters the model. This term is usually of the form

$$p_{i,t-1} - \beta p_{j,t-1} - \gamma \qquad (12)$$

where β is the coefficient of the long-run equilibrium relationship discovered in the cointegration analysis. The error correction properties of various specifications take different forms. In the Ravallion model detailed above, the coefficients on the terms P_{t-1} - R_{t-1} and the term R_{t-1} combine to give the coefficient on the lagged price in the second market.

The error correction model can take a ‘structural’ form by assuming some structure to the system generating the data. Assuming some structure allows additional *a prior* models specifications. The Ravallion model, noted above, is a structural form in that it assumes the exogeneity of the reference market and then proceeds to identify the dynamics of how the reference market causes the outlying market. As Wyeth (1992) observes, this market structure assumption allows the contemporaneous price in the reference market to be an independent variable in the estimated equation. Thus, Δr_t is a regressor in (11) which would be inadmissible unless the reference market is exogenous.

When no assumptions are made regarding the structure of the market and cointegration exists between two price series, the commonest form of error correction model is the reduced form model. This is an autoregression with two disequilibrium terms, i.e. change in price in market i is regressed on several lags of $\Delta p_{i,t}$, several lags of $\Delta p_{j,t}$, $p_{i,t-1}$ and $p_{j,t-1}$. Note how no contemporaneous variables are included. The long-run equilibrium condition of the model can be inferred from the coefficients on the two final terms which, one would hope, would have different signs and jointly form the error correction mechanism (hence these terms are described as disequilibrium). Causality can also be determined in this model due to its autoregressive nature by testing the joint significance of the coefficients of the lagged price series of market *j*. If there is evidence that these coefficients are non-zero, then market *j* Granger causes market *i*.

Exogeneity of a time series from a second time series can also be determined within this specification. Exogeneity of a variable $\{p_i\}$from another variable $\{p_j\}$ is when adding information from $\{p_j\}$does not help in explaining the behaviour of $\{p_i\}$. Weak exogeneity is determined by testing for a zero coefficient on the disequilibrium terms. If the coefficient proves to be negative then there is evidence against the error correction mechanism, thus questioning the existence of a long-term relationship. Clearly, this test may counter the previous results of the cointegration analysis. Under these circumstances questions regarding the specification of the model must be raised. Strong exogeneity is shown when $\{p_i\}$ is weakly exogenous to $\{p_j\}$ and also $\{p_j\}$ does not Granger cause $\{p_i\}$.

A second error correction specification utilises a two stage estimation procedure. In the first stage, the long-run relationship is estimated. If cointegration is observed between the two series, there is evidence that an error correction mechanism should be employed. Further, the cointegrating relationship can also give more information about the form this error correction term takes. That is the cointegration relationship can then used to generate estimates of the error correction term. A regression is then performed on lagged differences in the two time series and this error correction term:

$$\Delta p_{j,t} = \alpha_0 \Delta p_{j,t-1} + \alpha_1 \Delta p_{j,t-2} + \beta_0 \Delta p_{i,t-1} + \beta_1 \Delta p_{i,t-2} + \gamma(p_{t-1} - bp_{t-1} - c) + \delta + \varepsilon_t \quad (13)$$

Granger causality can be tested through the same testing procedure as above, i.e. $\{p_{it}\}$ Granger causes $\{p_{jt}\}$ if the coefficients on the lagged Δp_{it} are significantly not all zero. Weak exogeneity can be tested by looking at the significance of the error correction term. As noted above, the presence of strong exogeneity is confirmed when there is no Granger causality and weak exogeneity.

Looking again at the structural form of Ravallion, one can immediately see an alternative way of proceeding. Rather than assuming the exogeneity of the reference market, this can be tested first. It is only after a price series has proven to be exogenous to the other market that the Ravallion model can be employed. Rather than assuming the exogeneity of the reference market, the tests detailed in this section can be used to determine whether there are empirical grounds for this assertion.

4. Empirical Tests of Market Integration

4.1 Tanzanian grain price data

Tanzanian data regarding monthly maize prices in six markets - Arusha, Dar es Salaam, Iringa, Mbeya, Shinyanga and Songea - covering the period January 1986 to December 1990 will be analysed in this section. The price was noted in Tanzanian Shillings for a 20 litre tin of maize. This is the volume equivalent of approximately 17 kg of maize. The period covered was a period of change in the marketing system. Until 1985, the marketing boards had a monopoly in transporting and storing grains. Almost all large-scale movements of grain had to be directed through the marketing board. However, as part of the IMF's structural adjustment programme the later part of the decade saw liberalisation in the market for staples including maize.

Maize consumption is high in Tanzania - maize is one of the two main staples - and access to this crop has important impact on household food security. The freeing up of the market saw a burgeoning of small and medium-scale enterprises in the trading and distributing of grains. This was greatly facilitated by a history of grain trading activities before liberalisation. There had been a strong parallel, illegal market in grains which had expanded considerably in the 1980s.

Bryceson (1993) describes the changes the Tanzanian marketing system underwent during the late 1980s. She also gives a simple and useful typography of the country and the six markets analysed here which provides an assessment of the likely maize demand in the markets. Dar es Salaam is a large city and as such is highly maize deficit. It is also a major port and links Tanzania's agricultural producers to export markets. The other main urbanised area is in the north-west by the shores of Lake Victoria. The market Shinyanga is in this region. The region is not as populated as Dar es Salaam and so regional production in rice makes the area self-sufficient or surplus in rice. However, maize production is not high and so Shinyanga is also maize deficit. The northern region of Arusha and the more central Iringa are both maize surplus areas. These areas concentrate on maize production in preference to rice. It is only in the south that both crops are grown. Songea and Mbeya markets serve regions which are often surplus in both main staples.

The map of Tanzania indicates the transport infrastructure of the country. Only a few main highways are covered with tarmac and large distances are involved in most inter-market trading.

4.2 Ravallion's test of market integration

Table 1 indicates the results of estimating equation (11) for the Tanzanian price data. The exogenous market is assumed to be the large port city of Dar es Salaam so that the reference price series, R_t, is the logarithm of the price of a 20 litre tin of maize in the Dar es Salaam market. The other five markets are then the dependent markets. The radial structure of the market has support in the literature. Bryceson (1993) studies the flows of grain around Tanzania through private traders and finds that the main purchasing area of the country is Dar es Salaam. It is a much larger city than any other in the country and is also one of the largest ports in the region.

The estimation of (11) allows a test of the long-run integration of the market. This is performed by testing whether the co-efficient on the lagged price of the error term is significantly different from zero. As the last section indicates, a zero co-efficient indicates that the price in the regional market is a weighted average of its lagged value, and the current and lagged price level of the reference market. The *t*-statistic indicates that the hypothesis of long-run integration is rejected only in the case of Shinyanga market. All other markets have insignificant co-efficients (at 5%). The bottom half of the table indicates an F-test which was performed and bears out this finding. In the long-run, four of the five markets are integrated with the central Dar es Salaam market.

For these four markets, restricted models were estimated to test for short-run integration. In the first test - which Ravallion indicates is a 'strong' short-run integration - the R_{t-1} term is dropped and the co-efficient on P_{t-1}-R_{t-1} equalling -1 and the co-efficient on R_t-R_{t-1} equalling +1 is jointly tested. Table 1 indicates that the statistic is highly significant so that short-run integration is rejected. There is no evidence to reject the hypothesis of short-run separation. This is Ravallion's weaker test for short-run integration and considers whether there is any relationship between the change in the regional market price change and the reference market price change. A simple regression of the first variable on the second with no intercept term indicates that this reduced form is not a good explanator of the data in any of the markets.

The Ravallion-type model provides a simple set of results. Long-run integration is observed between Dar es Salaam and all but one of the regional markets. Short-run integration is rejected for all market pairs.

4.3 Testing for stationarity

Table 2 indicates the results of the augmented Dickey-Fuller test performed on the price series for the six markets and the consumer price index (CPI). All series were logged prior to all analyses. The standard Dickey-Fuller regression was performed on the series to be tested. Where serial correlation was observed in the error term, a lagged difference in the time series being tested was added. Such a process was repeated until no correlation was observed in the error term and the t-statistic noted.

The size of the statistics should be checked against the critical values provided in Fuller (1976). It can be seen that when the test was performed on the levels of prices, there was no clear evidence of stationarity. At 5 per cent significance, Iringa market does provide evidence of stationarity but the power of the ADF test is considered quite low so that cautious analysis would support differencing of this series. Thus, in all the series the tests were performed on the first difference. The first difference in prices in the six markets is stationary. Thus, the six markets are I(1). This concurs with many other analysis of price time series data. The CPI was differenced twice before stationarity was observed suggesting this series was I(2). This is a slightly surprising result, but allows us to disregard inflation as causing the change in prices in the markets.

4.4 Engle-Granger two-step procedure

The next stage is to test for cointegration between price time series using the Engle-Granger Two-Step Procedure. The results of the OLS regression between the pairs of markets where cointegration was observed is provided in Table 3. The test statistic from the second stage of the procedure for all pairs of markets is presented in table 3. This is the ADF test to test for stationarity in the residuals of the OLS regressions. Again, the ADF statistics must be compared with the critical values provided in Fuller (1976). Critical values for the three standard levels of significance are provided at the bottom of table 3. It must be noted that these results merely indicate cointegration. The strength of these test statistics can give no light to the nature of causality.

The results indicate that Songea and Arusha - two regions which are generally grain surplus - are cointegrated with all of the other markets apart from Mbeya. Though the significance of the cointegration varies considerably, the long-run integration of these grain supplying markets with the rest of the country is in line with expectations. Two other maize surplus areas, Arusha and Iringa, are cointegrated with Dar es Salaam and Shinyanga respectively. Dar es Salaam is clearly maize deficit being a large capital city, so that the integration with a proximate surplus area is unsurprising. Similarly, Shinyanga is a rice growing region which is maize deficit. The long-run integration of this market with Iringa is therefore not unexpected.

Mbeya, a central surplus area, is not integrated with any of the markets. Mbeya is in the grain belt of southern Tanzania. It is well serviced by road and rail lying the main routes heading south into Zambia. It is certainly far closer to the deficit areas around Shinyanga than Songea. However, whereas there is evidence of long-run market integration between Songea and Shinyanga, there is no evidence for Mbeya's integration with Shinyanga.

4.5 Causality and exogeneity

Next, a dynamic model is designed for the markets that are cointegrated. The results are indicated for the five markets (Mbeya can now be excluded) in table 5. The series of tables show the reduced form estimated for each of the five markets against the markets that are cointegrated with it. Results regarding goodness-of-fit are indicated. The final statistic, F(Causality) indicates whether market i Granger causes market j. Thus, in table 5A, in the first column, the low F-value of 0.758 indicates that there is no evidence that Arusha Granger causes Dar es Salaam. In all cases, there are 56 observations.

Estimates of the error correction term were a regressor in the reduced form of the model. Table 4 gives the series of equations (one for each pair of market which showed cointegration) used to estimate this series. The coefficient on this term, if significant, provides evidence against weak exogeneity.

A general observation is that a high causality statistics improves the goodness-of-fit, but that the converse need not be the case. This is because the specified reduced form model can be seen as a very general model wherein Granger causality is a dynamic specification which is tested. A goodness-of-fit then necessarily follows. However, as the general specification does include other possible models, the converse need not necessarily be the case.

Looking at the individual markets, it is clear that Granger causality is strongest from the deficit markets to the surplus markets. This is shown in tables 5B and 5C which cover the estimates of the reduced form models for Dar es Salaam and Shinyanga respectively. This suggests that Dar es Salaam Granger causes Arusha, Iringa and Songea, while Shinyanga Granger causes Arusha and Songea. The results support the main thesis of radial market models that deficit, urbanised areas determine the price levels in the rural hinterland. Ravallion's model of Bangladesh put Dacca firmly in the centre of the system of markets he considered. Similarly, Dar es Salaam and Shinyanga determine the food marketing system of Tanzania.

The next step is to check whether the two deficit markets are exogenous to the other markets. A series is weakly exogenous if the coefficient in the error correction term is insignificant. It is strongly exogenous if there is no evidence of Granger causality as well. Consider table 5A. In the estimation of Arusha's price change on the behaviour of Dar es Salaam, the t-ratio on the error correction term does prove insignificant. Dar es Salaam is weakly exogenous to Arusha. This exogeneity can be shown to be strong as the F(Causality) statistic is insignificant too. Shinyanga also proves strongly exogenous to Arusha. In the case of Songea, these results are repeated for Shinyanga which proves to be exogenous. However, Dar es Salaam is neither exogenous to Iringa nor Songea. This indicates that the Ravallion-type model would be a miss-specification for Dar es Salaam in two of the three markets it Granger causes as the causation is two-way. The use of a contemporaneous Dar es Salaam price in the estimation of prices in Iringa or Songea would not be correct.

The tables indicate one pair of rural markets interact. There is evidence that Songea and Iringa Granger cause each other. Again, this counters the use of the radial market where trade is unidirectional to the reference market.

5. The Motivation of the Present Research

A debate has recently emerged regarding the applicability of the tests most commonly used by market analysts. Barrett (1996) questioned whether the methodologies applied have lost touch with the phenomenon being analysed. An understanding of the way markets for staples in a particular countries should be used to back up the empirical findings of price analysis. The assumption by Ravallion of a radial marketing structure was based on that researcher's extensive work in Bangladesh with traders and other market participants. The assumptions underpinning the Ravallion (1986)'s application have since been empirically tested and proven to be appropriate (Palaskas and Harriss-White, 1996). However, the wholesale application of the methodology has sometimes been the result of only a cursory understanding of the actual marketing system that exists.

A second feature of recent market analysis has been the use of tests with very little power. Baulch (1996) empirically compares the reliability of the standard tests of the market analyst. He uses simulation data from a model which has transfer costs and highly variable supply and demand conditions. In the artificial economy, there are discontinuities in trade flows caused by transport bottlenecks segmenting markets despite arbitrage opportunities. Also, in his model discontinuities in trade flows arise due to there being no incentive for arbitrage because inter-market spread is exceeded by the cost of transfer. The price data that was generated also had an inflationary component so was I(1). When tests of market integration were run on the data, the Ravallion type tests performed poorly while the co-integration and causality tests indicated market integration. Baulch notes this result depends more on the restrictiveness of the tests than on the ability of the tests to identify the discontinuities in the actual trading patterns. His preferred test - the parity bounds model - is robust to such trade flow behaviour and picks out the breaks in flow.

As market liberalisation has gathered pace the reliability of tests has become of some importance. The dramatic changes in the way markets are organised in poorer countries has been unprecedented and measurement of the policy success is an important issue. Market integration tests do not appear to be portable and the refining of tests to local circumstances has been seen as a means to make up for this shortcoming. For this to be done, modelling the marketing system being analysed appears a more sound basis for empirical research (as in Baulch, 1996). This thesis will develop a model of food marketing taking into account the agricultural and institutional context of the market for food in southern and eastern Africa. It will highlight the importance of stored grains. Consumption of stored grain is a substitute for inter-regional trade. The model will indicate that periods of time where no trade is taking place may not be the result of market failure, but of an optimal allocation of resources between storage and transport. The fifth and sixth chapters of the thesis will then test the model empirically using survey data from Zimbabwe. It will be shown that the grain trading behaviour of households can be explained in terms of storage. At times, storage of grain acts as a substitute to the purchase of grain from the local market. Finally, the Tanzanian price data already employed in the present chapter will be used to see the effect of storage on the food market prices.

Table 1

Ravallion Analysis of Tanzanian Markets

		Regional Market				
Co-efficient Estimate		Arusha	Iringa	Mbeya	Shiny'ga	Songea
Intercept		-0.859	0.977	0.695	1.750	-0.184
		(0.440)	(0.581)	(0.646)	(0.617)	(0.535)
$P_{i,t-1}$-R_{t-1}		-0.442	-0.562	-0.377	-0.262	-0.634
		(0.081)	(0.113)	(0.109)	(0.102)	(0.120)
R_t-R_{t-1}		0.419	0.092	0.405	0.099	0.560
		(0.115)	(0.153)	(0.166)	(0.152)	(0.140)
R_{t-1}		0.123	-0.175	-0.129	-0.277	-0.047
		(0.069)	(0.091)	(0.102)	(0.097)	(0.086)
R^2		0.46	0.32	0.23	0.16	0.42
Adj-R^2		0.43	0.28	0.19	0.11	0.38
Null Hypothesis		Test Statistic (Probability value)				
Coefficients	F(3,55)	15.79	8.46	5.55	3.44	13.08
Zero		(.00)	(.00	(.00)	(.02)	(.00)
Long-run	F(1,55)	3.21	3.67	1.59	8.20	0.30
Separation		(.08)	(.06)	(.21)	(.01)	(.59)
Short-run	F(2,56)	39.47	18.82	21.59	n/a	8.62
Integration		(.00)	(.00)	(.00)		(.00)
Short-run	F(1,58)	0.01	0.01	0.02	n/a	0.00
Separation		(.94)	(.93)	(.87)		(1.0)

The bottom half of the table indicates the F-value (Probability value) of the Ravallion tests of market integration. E.g. Short-run intergration is rejected in four cases.

Table 2

Augmented Dickey-Fuller Tests for Tanzanian Markets

CITY	I(1) v I(0)	I(2) v I(1)
Arusha	-2.90	-5.31
Dar es Salaam	-3.03	-8.20
Shinyanga	-2.93	-7.84
Mbeya	-3.13	-8.79
Iringa	-3.88	-9.85
Songea	-2.85	-7.55
Consumer Price Index	-2.50	-2.86

Critical value for the ADF statistic is -3.45 at 5%

Table 3

Significance level of cointegration tests

Market	DSM	Shiny'ga	Mbeya	Iringa	Songea
Arusha	-4.55***	-3.05*	-2.99	-3.17	-4.08***
DSM	-	-2.63	-2.27	-3.34*	-5.13***
Shinyanga		-	-2.71	-2.72	-3.59**
Mbeya			-	-2.56	-2.70
Iringa				-	-3.07*

Critical ADF value on residuals of cointegrating equation is -3.03 (10%), -3.37 (5%) and -4.07 (1%).

Table 4

Cointegrating regression for pairs of markets with significant cointegration (at 10 per cent)

Dependent Variable	Arusha	Arusha	Arusha	Arusha
Independent Variable	DSM	Shinyanga	Iringa	Songea
Constant	0.131	-1.614	-0.507	-1.008
Coefficient on Independent Variable	-0.996 (-7.363)	-0.707 (-7.674)	-0.926 (-4.81)	-0.923 (-9.220)

Dependent Variable	Iringa	DSM	Shinyanga	Iringa
Independent Variable	DSM	Songea	Songea	Songea
Constant	0.296	-1.013	0.698	-0.699
Coefficient on Independent Variable	-1.01 (-7.520)	-0.953 (-15.201)	-1.27 (-8.988)	-0.97 (-6.140)

Note: t-statistics in parenthesis.

Table 5A

Reduced form dynamic model for Arusha

Dependent Variable: $\Delta p_{i,t}$ where p_i = Arusha price at time t

Independent Variables	$p_{j,t}$ Dar es Salaam	Shinyanga	Iringa	Songea
Constant	0.015 (0.874)	0.027 (1.327)	0.022 (1.026)	0.021 (0.978)
Error Correction Term	0.067 (0.490)	0.012 (0.081)	0.118 (0.828)	0.069 (0.322)
$\Delta p_{i,t-1}$	-0.130 (-0.755)	0.048 (0.273)	0.193 (0.964)	0.312 (1.371)
$\Delta p_{i,t-2}$	-0.179 (-1.313)	-0.146 (-0.912)	-0.087 (-0.508)	-0.366 (-1.628)
$\Delta p_{j,t-1}$	0.008 (0.042)	-0.072 (-0.409)	-0.280 (-1.562)	-0.099 (-0.437)
$\Delta p_{j,t-2}$	0.414 (2.486)	-0.106 (-0.640)	-0.002 (-0.013)	0.333 (1.641)
R-squared	0.141	0.028	0.133	0.120
Adj R-squared	0.057	-0.067	0.048	0.033
F(Causality)	0.758	0.293	0.829	0.565

Note: t-statistics in parenthesis.

Table 5B

Reduced form dynamic model for Dar es Salaam

Dependent Variable: $\Delta p_{i,t}$ where p_i = Dar es Salaam price at time t

Independent Variables	$p_{j,t}$ Arusha	Iringa	Songea
Constant	0.014	0.0173	0.018
	(0.929)	(0.903)	(0.889)
Error Correction Term	-0.364	-0.357	0.568
	(-3.046)	(-2.504)	(2.777)
$\Delta p_{i,t-1}$	0.078	0.193	-0.088
	(0.473)	(1.079)	(-0.416)
$\Delta p_{i,t-2}$	0.102	-0.084	0.010
	(0.704)	(-0.499)	(0.054)
$\Delta p_{j,t-1}$	0.128	-0.059	0.133
	(0.852)	(-0.352)	(0.740)
$\Delta p_{j,t-2}$	0.031	0.049	0.231
	(0.258)	(0.349)	(1.613)
R-squared	0.328	0.292	0.212
Adj R-squared	0.263	0.222	0.135
F(Causality)	7.408	4.816	7.556

Note: t-statistics in parenthesis.

Table 5C

Reduced form dynamic model for Shinyanga

Dependent Variable: $\Delta p_{i,t}$ where p_i = Shinyanga price at time t

Independent Variables	$p_{j,t}$ Arusha	$p_{j,t}$ Songea
Constant	0.015 (0.968)	0.022 (1.026)
Error Correction Term	-0.443 (-4.078)	0.447 (3.41)
$\Delta p_{i,t-1}$	-0.133 (-1.010)	-0.027 (-0.147)
$\Delta p_{i,t-2}$	-0.009 (-0.069)	-0.007 (-0.046)
$\Delta p_{j,t-1}$	0.287 (2.213)	0.110 (0.715)
$\Delta p_{j,t-2}$	0.163 (1.375)	0.271 (2.22)
R-squared	0.342	0.133
Adj R-squared	0.278	0.048
F(Causality)	7.919	7.720

Note: t-statistics in parenthesis.

Table 5D

Reduced form dynamic model for Iringa

Dependent Variable: $\Delta p_{i,t}$ where p_i = Iringa price at time t

Independent Variables	$p_{j,t}$		
	Arusha	DSM	Songea
Constant	0.013	0.010	0.017
	(0.798)	(0.628)	(0.829)
Error Correction Term	-0.253	0.313	0.215
	(-2.258)	(2.649)	(1.284)
$\Delta p_{i,t-1}$	0.057	-0.002	0.168
	(0.404)	(-0.017)	(0.922)
$\Delta p_{i,t-2}$	0.064	0.104	0.218
	(0.517)	(0.901)	(1.437)
$\Delta p_{j,t-1}$	0.242	0.097	-0.015
	(1.542)	(0.657)	(-0.082)
$\Delta p_{j,t-2}$	0.062	0.374	0.143
	(0.462)	(2.70)	(0.975)
R-squared	0.178	0.272	0.143
Adj R-squared	0.097	0.201	0.059
F(Causality)	2.937	3.984	2.374

Note: t-statistics in parenthesis.

Table 5E

Reduced form dynamic model for Songea

Dependent Variable: $\Delta p_{i,t}$ where p_i = Songea price at time t

Independent Variables	$p_{j,t}$ Arusha	DSM	Shinyanga	Iringa
Constant	0.014	0.013	0.025	0.018
	(0.917)	(0.790)	(1.244)	(0.887)
Error Correction Term	-0.402	-0.453	-0.000	-0.299
	(-2.516)	(-2.645)	(-0.001)	(-1.825)
$\Delta p_{i,t-1}$	-0.186	-0.218	-0.028	0.086
	(-1.094)	(-1.450)	(-0.163)	(0.487)
$\Delta p_{i,t-2}$	0.215	-0.080	-0.009	0.097
	(1.416)	(-0.670)	(-0.064)	(0.678)
$\Delta p_{j,t-1}$	0.340	0.210	-0.076	-0.219
	(1.990)	(1.184)	(-0.439)	(-1.224)
$\Delta p_{j,t-2}$	-0.123	0.474	-0.077	0.007
	(-0.728)	(3.085)	(-0.439)	(0.050)
R-squared	0.273	0.212	0.178	0.217
Adj R-squared	0.202	0.135	0.097	0.140
F(Causality)	2.632	2.456	0.013	2.726

Note: t-statistics in parenthesis.

CHAPTER 4:

A Spatial and Temporal Model of Grain Markets

1. Introduction

In chapter 3, the Takayama-Judge model of spatial equilibrium was discussed. This model underpins many of the tests of food market integration that economists have used. The Takayama-Judge results indicate that spatial arbitrage across regional food markets should restrict regional price differentials to the cost of transfer between the regions. At times where transfer takes place, the price differential should equal the cost of transfer. Analysts have then proceeded by testing this spatial arbitrage rule. When market prices are integrated (in the econometric co-integration sense), this is taken as a sign that the markets are trading and therefore, rather confusingly, integrated (in the food marketing sense). This has generally been judged as 'good'. When market prices diverge, there may be short or long-term impediments to trade and the markets would not be integrated. This would be detrimental to welfare and the removal of the obstacles to trade would be suggested.

In this chapter, a more complex structure to regional food markets is hypothesised. While the Takayama-Judge model allows the spatial aspects of food markets to be explored, the temporal features of food markets are not modelled. This chapter integrates this aspect through more explicit reference to the dynamics of market trade. In particular, the departure from conventional modelling is the inclusion of commodity storage into a model of inter-regional trade. Empirical work on storage in commodity markets, mainly using North American data, highlights that arbitrage conditions are broken when models take explicit account of spatial-temporal interaction. This chapter will widen such results and show that they have a significant effect on Takayama-Judge spatial arbitrage results. Food market tests which neglect the issue of storage may wrongly suggest there are impediments to trade.

One phenomenon observed in commodity pricing when there are futures markets in the commodity is 'backwardation'. This occurs when the spread between the spot and futures price of a commodity does not fully reflect the carrying charges. The storage of substantial quantities of a commodity in such circumstances would be irrational as a forward purchase on the futures market will be cheaper than storing. Thus, there is prima facie evidence of profitable arbitrage opportunities - selling in the spot market and buying in the futures market - which would continue until there is no backwardation. However, these appear not to be undertaken and the storing of the commodity despite backwardation persists. A popular explanation for this behaviour has been that the stored commodity offers some benefit to the stockholder over the increase in its capital value - a convenience yield. Kaldor (1939) reflected that the stocks enabled 'producers to lay hands on them the moment they are wanted and thus saving the cost and trouble of ordering frequent deliveries or of waiting for deliveries' (p. 3-4).

Working (Working (1948), Working (1949a), Working (1949b)) first documented the firm's use of storage and provided empirical evidence supporting Kaldor's view. Storage was most commonly viewed by firms as an adjunct to the main business and a means to avoid the large losses if the main function of the business was disrupted. The convenience yield of the stored commodity would then reflect the lower cost with which firms could maintain a steady output and the speed with which a firm could meet upward changes in product demand (Telser (1958)). Others have suggested further factors in determining the convenience yield and so the extent of backwardation in commodity markets noting the importance of reliability in delivery when securing repeat business. The convenience of possessing stocks would increase reliability and so yield a further benefit to the firm in terms of a good reputation for meeting demand. However, the applicability of many of these explanations to a homogenous and heavily traded good such as a staple grain can be questioned. The multi-stage processes involving several different inputs common in manufacturing would not be mirrored in agricultural processing.

Wright and Williams (1989) propose a theory explaining backwardation which does not rely on concepts of convenience yield. They argue that the observation of negative prices for storage is a result of inappropriate aggregation. If the price of commodities are disaggregated properly, the price difference between the spot and future prices of the disaggregates would fully reflect the carrying costs so that the negative price of storage vanishes. Grain, where backwardation was first observed, provides an example of the mistaken aggregation of economically meaningful subaggregates. Working (Working (1948), Working (1949a), Working (1949b)) observed that the spot price for wheat was lower than the futures price, but by an amount insufficient to cover storage costs. It must be noted, however, that while the futures and spot contracts specify delivery in a certain location (e.g. Chicago), the storage of the grain prior to honouring the futures contract is at locations other than the point of future sale. Thus, the price that clears the futures market is based on the costs of processes in addition to storage, for example the Iowa-Chicago transfer costs. Wright and Williams (1989) suggest that by choosing a more meaningful subaggregate - the spot and futures prices in Iowa - the backwardation in the presence of significant storage would disappear.

This chapter will consider a model of grain stocks across space which is influenced by the work on backwardation. The model will differ from previous work by focusing on the timing of grain trading in an economy where storage is significant. The general results of the backwardation model - futures and spot grain prices not fully reflecting storage costs in the presence of significant storage - will still be present when market prices are inappropriately aggregated. However, the issue of when markets are integrated will be the focus of this thesis and the chapter will extend the Wright-Williams type model in this direction.

The advantage of the present formulation of the model will be its ability to generalise to complex market structures. The previous chapter highlighted the radial system where all sales are to a single port of export. This has been the most common form since Ravallion (1986). Here, a model will be presented which investigates behaviour when there is significant trade between locations which produce grain and not just trade to a single central market. Trade between rural regions is a particular feature of rural poor economies.

In the next section, Wright and Williams's 1989 model of backwardation in commodity markets will be presented. This explains backwardation as a problem of aggregation. The third section will give a simple graphical illustration of the model that forms the basis of the thesis. Sections 4 and 5 will then provide a more rigorous mathematical treatment. There, the main results will be generalised by using optimal control analysis to the modelled economy. Finally the results will be discussed.

2. Wright and Williams Model of Backwardation

Backwardation has been observed in the commodity markets by economists for many years - Kaldor (1939) being an early reference. Backwardation is when a commodity's price for future delivery is below the price for immediate delivery. In simple models of storage, when there is significant stockholding, temporal arbitrage will equate futures prices to the current price plus costs of storage. Backwardation is an empirical example of the breakdown of this temporal arbitrage rule. Early explanations of the phenomenon have identified some benefit of storage to the storer. For example, the storing of a commodity allows supply variations to be smoothed. This would justify the observed backwardation and the implicit negative price for storage as storers will effectively be paying for the additional benefit they gain through storage.

Wright and Williams (1989) propose an alternative explanation. They consider storage under backwardation as an aggregation phenomenon. In their model, there are two commodities, here denoted 1 and 2, with the transformation of a quantity, y, of the first into the second incurring a cost, $c(y)$; $c'(y) > 0$ and $c''(y) \leq 0$. Wright and Williams (1989) note that the most obvious example of a transformation is the transfer of the grain from region 1 to region 2 so that the transformation cost becomes the transport cost. In the model, there are no physical costs to storage. Rather, a positive constant rate of interest, r, insures that there is an opportunity cost to tying up capital in storing the commodity. The variables in the model that Wright and Williams (1989) consider are:

- $s_i(t)$ the amount of grain stored in each region from period t to period $t+1$, i=1,2.
- $h_i(t)$ the additions to the stock due to new supplies in each period, which is assumed to be a random variable with a time-invariant mean, $\mu_1^h = E_{t-1}[h_1(t)]$ and $\mu_2^h = E_{t-1}[h_2(t)]$ for the two regions i=1,2.
- $p_i[q_i]$ the inverse demand function in each region, i=1,2.
- $y(t)$ quantity transferred between regions.
- $c(y)$ cost of transferring quantity, y, with $c'(y) > 0$ and $c''(y) \leq 0$.
- $q_i(t)$ quantity consumed, which is equivalent to the change in the stock.

The maximisation is from the view of the first period looking into the future, i.e. time t=1, 2, ... ∞. The model is an application of the partial equilibrium theory of investment under uncertainty (Schienkman and Schechtman (1983)) and is solved by treating the two regions as one firm seeking to maximise the value of the future profit stream, i.e.:

$$\max E_1\left[\sum_{t=1}^{\infty}(1+r)^{-t}\{p_1[q_1(t)]+p_2[q_2(t)]-c(y)\}\right] \tag{1}$$

where

$q_1(t)=h_1(t)+s_1(t-1)-s_1(t)-y(t)$ and $q_2(t)=h_2(t)+s_2(t-1)-s_2(t)+y(t)$.

The maximand essentially calculates the present value of the profits of the firm. The firm is assumed to be competitive and have rational expectations. The inverse demand function gives the price, p_i, at which the amount consumed in each region is sold. The level of consumption, q_i, is the remainder after changes in the level of stocks. This is positive in relation to new supply and negative with respect to the drawing down of stocks. The level of inter-regional transfer affects profitability in region 1 negatively while increasing supplies in region 2. The model assumes that this uni-directional flow incurs a cost, the final term $c(y)$ in (1).

The maximisation yields first-order conditions similar to Takayama-Judge conditions detailed in the previous chapter. These are, with p^e denoting the expected value of p for the next period:

$$\begin{aligned}-p_1+(1+r)^{-1}\cdot p_1^e &= 0, \text{ when } s_1>0\\ &\leq 0, \text{ when } s_1=0\end{aligned} \tag{2}$$

$$\begin{aligned}-p_2+(1+r)^{-1}\cdot p_2^e &= 0, \text{ when } s_2>0\\ &\leq 0, \text{ when } s_2=0\end{aligned} \tag{3}$$

$$-p_1+p_2-c'[y(t)]=0, \text{ when } y>0 \tag{4}$$

Conditions (2) and (3) state that, where the expected price in the next period exceeds the present price by exactly the cost of storage, storage takes place. If expected future price exceed present price by more than the cost of storage then temporal arbitrage will take place with storage increasing until the present and future value of grain is equalised. When the temporal price difference is less than the costs of storage, no storage takes place. Condition (4) is the spatial equilibrium condition. Transfer occurs until the marginal cost of transporting an additional unit equals the price differential across the regions.

These conditions set up a richer pricing and storage model. There are two sets of spot and futures prices associated with the storing behaviour of two different region. Wright and Williams (1989) continue by considering aggregation of commodity price and the storage levels across the regions. If spot and futures prices are quoted with delivery in some central market, as with Telser's (1958) use of grain prices, it is clear that only when both regions are storing would there be no backwardation. If there is no storage in one of the regions, the future price will be below the current level. If the stock levels are aggregated and the price levels averaged, backwardation would be observed in the presence of non-zero storage. In aggregate, the fact that there is no storage in one of the regions is hidden.

Algebraic manipulation of the conditions reveals the conditions when this will be occur. Assume that region 2 has no grain stored so that the first part of (3) becomes a strict inequality. Further, assume that region 1 has grain in store so that (2) is an equality. Combining with (4) gives:

$$-p_1 - p'[y(t)] + (1+r)^{-1}\{p_1^e + c'^e[y(t+1)]\} < 0 \tag{5}$$

and substituting P_2 for its expected value in (2.5) gives:

$$c'[y(t)] > (1+r)^{-1} c'^e[y(t+1)]\,. \tag{6}$$

Wright and Williams (1989) state this as the fundamental necessary condition for backwardation. Inequality (6) states that the current marginal cost of transfer from the region with grain (in this case region 1) to the region without (region 2) must be above the expected cost in the next period. When this is the case, price measures which average over the two regions could provide evidence of backwardation. Wright and Williams (1989) can therefore explain futures prices not differing from spot prices by the cost of storage through recourse to two assumptions about commodity markets: the current marginal cost of transformation exceeds the expected future cost and the price measure mistakenly aggregates regional indices of stocks and prices.

Empirical evidence supporting the model has been provided by Thompson (1986) who found that as the definition of coffee stocks and prices became more precise, observation of significant stockholding in times of backwardation diminish. This behaviour would be consistent with the model indicating the importance of the aggregation assumption.

These views of backwardation as an aggregation problem have been recently applied to agricultural markets. Benirschka and Binkley (1995) consider the storage of grains across space and model the changing behaviour of storers of grain as distance to the port of sale increases. Brennan et al. (1997) consider the market for wheat in Western Australia and highlight that backwardation is observed in prices at the port of export. However, storage occurs at locations distant from the port. As the transfer costs are significant, the delaying of grain sales from distant grain stores becomes a means to postpone transfer costs and the future delivery price will reflect this saving. However, as long as the futures price is not disaggregated by the location of the grain stores, significant storage and simultaneous backwardation will be observed.

3. A model of trading when regions store grain

3.1 Overview

To analyse the grain marketing behaviour of two regions with stores of the commodity, this section presents an optimal control analysis. The section gives the necessary and sufficient conditions for an optimal program as detailed in Seierstad and Sydsaeter (1977). In the model, there are two regions which each have an initial harvest of grain. The regions must maintain non-negative grain stocks while using grain to meet their regional consumption needs. The regions can trade with each other and there is also an external market which buys and sells grain at a constant price throughout the program. However, this external market is some distance from the regions and purchases from and sales to it incur transfer costs.

In the optimisation, a revenue function is maximised over time with the revenues of the two regions added together. Combining revenue across regions in this manner means that the value of grains transferred between the regions is netted out. Only the costs associated with transfer are deducted from the total revenue. Storage of grains also incurs an opportunity cost. A positive discount rate, constant over the program, implies that storage of grain is at the expense of the earnings of some interest-bearing asset. Variables are as follows:

- t time;
- h_i harvested production of commodity in region i;
- r rate of interest;
- m cost of transport between markets;
- $p_i(t)$ price of commodity at t in market i;
- $y(t)$ quantity of commodity transferred from market 2 to market 1;
- $x_i(t)$ grain sales by region i to the external market;
- $z_i(t)$ grain purchases by region i from the external market;
- p the price of grain in the external market;
- d_i the cost of transfer from the external market;
- * initial value of a variable, i.e. at time, t=0.

3.2 Two-region model as a dynamic optimisation

Assume there are two regions, i=1,2, which each produce an initial harvest at time t=0 of grain, h_i. The regions must each then maintain non-negative stocks of grain, s_i, until the following harvest at the end of the program at t=T. For simplicity, grain consumption is modelled as a constant out-flow of one unit from the grain stock.

One source for grain is an external market which buys and sells grain at a price p. This price is constant throughout the program. The external market may be an international market for grain or may be some super-regional marketing institution, such as a grain marketing board. The regions procure grain, z_i, from this external market and such purchases will reduce total revenue. Apart from the price p charged, there is a cost of transfer, d_i. Thus, a unit of grain purchased from the external market will reduce revenue by $p+d_i$. When region i is selling x_i to the external market, the cost of transfer means that the revenue raised would be $p-d_i$ per unit sold.

Inter-regional trade can also occur. Without loss of generality, it is assumed that transfer only takes place from region 2 to region 1[4]. Transfer of an amount of grain will reduce revenue by the transfer cost, m, per unit multiplied by the amount which is transferred, y. Assumptions regarding the parameters and the initial level of regional harvests are as follows:

(A1) Transfers are costly, i.e. $d_1 > 0$, $d_2 > 0$, $m > 0$.

(A2) Transfer costs are less than the external market price, $d_1, d_2, m < p$.

(A3) The opportunity cost of storage, r, is a positive constant.

(A4) Transfer costs are such that $d_2 + m > d_1$.

(A5) Transfer costs are such that $d_1 + m > d_2$.

(A6) Regional harvests are such that $h_2 > h_1 - \frac{1}{r}\ln\frac{p+d_1}{p+d_2-m}$.

Assumptions A1 to A5 are used later to show that various onward sales by markets are not cost-effective. In appendix 1, it is shown that assumption A6 guarantees the direction of trade is from region 2 to region 1 and will later be relaxed to indicate how the model can be generalised for trade in both

[4] In situations where the direction of the inequality is reversed, the region 1 would become region 2 and vice versa and the same analysis can be applied.

directions. Essentially, it indicates that while region 1's harvest level may be slightly greater than region 2, trade will occur from region 1 to region 2 if this disparity is too large. This would mean that the problem as set up would be inappropriate as the variable y only considers flows from 2 to region 1.

The optimal control problem is one of maximising the revenue from selling grain to the external market, less the costs of any purchases from it, for each of the regions and then deducting the costs associated with inter-regional trade:

$$\max \int_{t=0}^{T} e^{-rt}\left[(p-d_1)\cdot x_1 + (p-d_2)\cdot x_2 - (p+d_1)\cdot z_1 - (p+d_2)\cdot z_2 - my\right]dt \tag{7}$$

The maximisation will be subject to the change in grain stock being equal to the various in-flows and out-flows:

$$\dot{s}_1 = z_1 - x_1 + y - 1 \tag{8}$$

$$\dot{s}_2 = z_2 - x_2 - y - 1. \tag{9}$$

At the end of the program, there is a new harvest and it is assumed that households use all grain by this time. Further, non-negativity is imposed on the level of stocks and flows:

$$s_i \geq 0; \qquad i=1,2 \tag{10}$$

$$s_i(T) = 0; \qquad i=1,2 \tag{11}$$

$$z_i, x_i, y \geq 0; \qquad i=1,2. \tag{12}$$

Combining (6) with (8) and (9) gives an autonomous dynamic optimisation problem (Leonard and Van Long (1992)) so that a current value Hamiltonian can be used. This has five control variables - x_1, x_2, z_1, z_2 and y - and two current value costate variables associated with equation (6) and (7), ψ_1 and ψ_2 respectively:

$$L = (p - d_1)x_1 + (p - d_2)x_2 - (p + d_1)z_1 - (p + d_2)z_2 - my + \psi_1(z_1 - x_1 + y - 1) + \psi_2(z_2 - x_2 - y - 1) + \mu_1 s_1 + \mu_2 s_2 \quad (13)$$

The variable $\mu_i(.)$ is the Langrange multiplier associated with the non-negativity constraint on the stock of grain, equation (10). The necessary and sufficient conditions for the optimal dynamic program are detailed in Seierstad and Sydsaeter (1977). Conditions (12) regarding the non-negativity of grain flows are integrated into the first order conditions for this problem[5]:

$$\frac{\partial L}{\partial x_i}.x_i = ((p - d_i) - \psi_i).x_i = 0;\; x_i \geq 0;\; \frac{\partial L}{\partial x_i} \leq 0 \qquad i=1,2 \quad (14)$$

$$\frac{\partial L}{\partial y}.y = (-m + \psi_1 - \psi_2).y = 0;\; z_i \geq 0;\; \frac{\partial L}{\partial z_i} \leq 0 \qquad i=1,2 \quad (15)$$

$$\frac{\partial L}{\partial z_i}.z_i = (-(p + d_i) + \psi_i).z_i = 0;\; y \geq 0;\; \frac{\partial L}{\partial y} \leq 0 \quad (16)$$

The non-negativity of the grain stocks imply that:

$$s_i.\mu_i = 0 \qquad i=1,2 \quad (17)$$

The dynamics of the two regional stocks of grain, given in equations (8) and (9), combines with the constraint that the grain stocks cannot be negative to complicate the dynamics of the costate variables. At most times, the following condition holds:

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[5] The first order conditions include the non-negativity constraint on the flow variables. An alternative means to include this would be to add five additional terms to the Lagrangean - of the form $\lambda_y y$ for the variable y - for each of the control variables. For example, condition (15) would then become:

$$\frac{\partial L}{\partial y} = -m + \psi_1 - \psi_2 + \lambda_y = 0\;;\; \lambda_y \geq 0\;;\; \lambda_y \cdot y = 0$$

The non-negativity of the Langrangean multiplier, λ_y implies the third part of condition (15). The first part rewrites the standard Lagrangean condition $\lambda_y y = 0$.

$$\dot{\psi}_i = -\frac{\partial L}{\partial s_i} = -\mu_i + r\psi_i \qquad i=1,2 \qquad (18)$$

However, as observed by Jacobsen et al. (1971) (theorem 6), there can be jumps in the costate variable if the level of the state variable - grain stocks in this case - reaches the lower bound (zero). Such times in the optimal programme are called junction points. Defining t_j (j=1,2,...,k) as the values taken by t at the junction points in the particular program, additional conditions for the optimal solution are derived. The condition is, where $^-$ and $^+$ imply the instants before and after the jump:

$$\psi_i(t_j^-) - \psi_i(t_j^+) = \beta_i(t_j) \text{ with } \beta_i(t_j) \geq 0 \text{ and } \beta_i(t_j).s_i = 0 \qquad (19)$$

Finally, the terminal level of grain stocks must be zero (11), so there are no terminal conditions on the value taken by the costate variables at the end of the program. The transversality conditions are hence 'free'.

3.3 Preliminary model results

As with many optimal control programs, the essence of the model rests in the dynamics of the costate variables. The behaviour of the costates in this case are determined jointly by the level of the state variable (the stocks of grain in each of the regions) and which of the control variables takes a non-zero value. Consider the behaviour of the costate variable ψ_i when the region has grain stocks, i.e. $s_i > 0$. Condition (17) implies that the Lagrangean multiplier μ_i(.) takes the value zero so that (18) can be solved giving lemma 1. (Note that a superscript asterix refers to the value of a variable at the start of the program, i.e. $\psi_i^* = \psi_i(0)$).

Lemma 1. *When there are stocks of grain in region i* (=1,2), $s_i > 0$, *the costate variable is given by the function:*

$$\psi_i = \psi_i^* e^{rt} \qquad i=1,2. \qquad (20)$$

It is common to interpret the costate variable as the shadow price of the state variable, i.e. the price of a unit of grain in store. Therefore, this result can be viewed as a reiteration of the Hotelling *r*-percent rule (see Neher (1990)) which states that the value of stock of a resource must appreciate at the rate of discount. Any lower rate of appreciation would prompt storers to sell grain in favour of the interest-bearing asset while a higher rate would cause movement of funds in the opposite direction.

Some conditions on the control variables can also be derived easily using (13) to (19) and the assumptions of the model. Clearly, as $d_i > 0$ (A1), $p + d_i > p - d_i$. Therefore, using (14) and (15), the costate variable for a region cannot satisfy both $L_{x_i} = 0$ and $L_{z_i} = 0$. This implies that $z_i > 0$ and $x_i > 0$ cannot both be true simultaneously and leads to a second result.

Lemma 2. *A region will not buy from the external market at the same time as it is selling grain to the external market.*

The assumptions regarding the cost of transfers relative to the cost of accessing the external market - A4 and A5 - preclude other control variables from being positive contemporaneously. If inter-regional trade is occurring, $y > 0$, condition (16) implies that $\psi_1 - \psi_2 = m$. Firstly, consider whether region 2 could be buying from the external market, i.e. $z_2 > 0$, when this takes place. In such a case both conditions (15) and (16) would be equalities, that is both $\psi_1 - \psi_2 = m$ and $\psi_2 = p + d_2$ hold. The two are not consistent as, from A4, $\psi_1 = p + m + d_2 > p + d_1$. This contradicts the condition that $L_{z_1} \leq 0$, condition (15). Secondly, given $y > 0$, consider whether region 1 would be simultaneously selling to the external market, $x_1 > 0$. For this to occur, (14) indicates that $\psi_1 - \psi_2 = m$ and $\psi_1 = p - d_1$ must hold. This cannot hold at the same time as $\psi_2 = p - m - d_1 < p - d_2$. This contradicts the condition that $L_{x_2} \leq 0$, condition (14). These two results are combined to give lemma 3.

Lemma 3. *If inter-regional trade is occurring - region 2 selling grain to region 1 - then:*

i) *Region 2 is not buying from the external market;*

ii) *Region 1 is not selling to the external market.*

These general results would be present in models which do not jointly consider spatial and temporal aspects of grain markets. The first result, that the price in a region with grain stocks would obey the Hotelling *r*-percent rule, would be true for models where inter-regional trade did not take place, but storage was allowed. The second two results follow directly from the assumptions of the model and would be the case in a static, spatial model. Onward selling of grain is not cost-effective as assumptions A4 and A5 make the total cost of two transfers greater than that of a single transfer. The following propositions will indicate how the interaction of time and space in grain markets adds to these results. A first proposition of the dynamic model concerns the timing of any grain sales made by the regions. The external market purchases grain from the regions at a price fixed for the entire program. The positive rate of discount implies that if sales are to occur at all, it would be optimal to make the sales as early in the program as possible and then invest the revenue earned. This is proven as proposition 1.

Proposition 1. *In the model of inter-regional grain marketing described by A1 to A6 and (7) to (12), if grain sales to the external market occur, they will take place at time t=0.*

Proof. Conditions (8) to (11) indicate that for sales to the external market to take place, i.e. $x_i > 0$, either region i possesses grain stocks, $s_i > 0$, or it purchases grain from the external source, $z_i > 0$. Lemma 2 (above) rules this latter possibility out. In region 1, in addition to these possibilities, region 2 could supply grain, i.e. $y > 0$, to be sold to the external market, $x_2 > 0$. This is ruled out by lemma 3.

Consider then the case where $s_i > 0$. Lemma 1 indicates that, denoting the initial values of ψ_i with an asterix, $\psi_i = \psi^*_i e^{rt}$. The exponential growth in the costate means that its initial value is the lowest value taken during the entire period while there are positive grain stocks. For positive grain sales, (14) indicates that $\psi_i = p - d_i$. Also, from (14), $\frac{\partial L}{\partial x_i} \leq 0$ implies that $p - d_i - \psi_i \leq 0$. The value of the costate at times of grain sales must be the lowest value ψ_i takes. It therefore follows that this can only occur at t=0. ❑

Corollary 1. *If sales occur in region i, $x_i > 0$, then $\psi_i^* = p - d_i$.*

Proposition 1 greatly simplifies the discussion of the marketing system. Essentially, the selling of grain allows the region to earn revenue from any harvested grain which will be excess to the optimal program. Due to the positive rate of discount, storage of grains is costly and so any excess grain should be sold as early as possible.

Proposition 2. *In the model of inter-regional grain marketing described by A1 to A6 and (7) to (12), inter-regional trade occurs after region 1 runs out of grain.*

Proof. By contradiction. Taking equation (10) and condition (11) (i.e. $s_2 \geq 0$), grain sold to region 1 by region 2 must come from either: a) region 2's grain stock ($s_2 > 0$); or b) purchases from the external market ($z_2 > 0$). Lemma 2 precludes (b).

In the former case, $s_2 > 0 \Rightarrow \mu_2 = 0 \Rightarrow \psi_2 = \psi_2^* \cdot e^{rt}$. For inter-regional trade, $y > 0$ so that for condition (16) to be true, $\psi_1 - \psi_2 = m$. Combining, $\psi_1 = \psi_2^* \cdot e^{rt} + m$ when region 2 has grain stocks and inter-regional trade is occurring. This behaviour of the costate variable, ψ_1, is not consistent with $s_1 > 0$. Lemma 1 indicates that the presence of stocks in region 1 would mean that the costate rises exponentially, i.e. $\psi_1 = \psi_1^* \cdot e^{rt}$. Thus, $s_2 > 0$ and $z_2 > 0$ is not consistent with $s_1 > 0$.❑

Corollary 2. *Region 2 must possess own stocks of grain for the entire period of inter-regional trade.*

Proposition 3. *In the model of inter-regional grain marketing described by A1 to A6 and (7) to (12), purchases from the external market occur from some time (here, t=T_2) until the end of the program, if at all.*

Proof. While region 2 has grain, lemma 1 gives $s_2 > 0 \Rightarrow \mu_2 = 0 \Rightarrow \psi_2 = \psi_2^* \cdot e^{rt}$. After this, with no stocks in region 2, condition (10) indicates that the region can only purchase from the external market. (15) gives the condition $\psi_2 = p + d_2$ on the costate when these purchases take place and the condition $\psi_2 < p + d_2$ when no purchases are taking place. The exponential growth of the costate when stocks exist in the region is consistent with the latter strict inequality and so must precede the equality on the costate. Consumption of own stocks must precede purchases from the external market.

For region 1, conditions (8) and (9) indicates that once own stocks are exhausted, consumption could be met through purchases from the region 2 or from the external market. When inter-regional trade is taking place, proposition 2 demonstrates that $\psi_1 = \psi_2^* \cdot e^{rt} + m$. This is a strictly increasing function and so the limit imposed on the costate variable of region 1 by (15, for region 1) would be a strict inequality, i.e. $\psi_1 < p + d_1$. Only after the exhaustion of stocks and any inter-regional trade can the equality hold, $\psi_1 = p + d_1$ and so $z_1 > 0$.❑

Propositions 1 to 3 order the regions' actions. Grain sales to the external market occur at the start of the program, at t=0, and there follows a period of time when the regions consume their own stocks of grain. When region 1 runs out of grain, inter-regional trade may occur. The corollary to proposition 2 states that region 2's grain stocks must outlast this period of inter-regional trade. At the end of the program purchases will occur. The entire period of time can therefore be split into four periods. From t=0 to T_1, both regions are consuming own stocks. After this to T_m, inter-regional trade occurs. After this, until T_2, region 1 is purchasing from the external market while region 2 still has own stocks remaining. After T_2, both regions have exhausted their stocks of grain so that the external market is the only source of grain.

Proposition 4. *In the model of inter-regional grain marketing described by A1 to A6 and (7) to (12), the costate variable is continuous.*

Proof. The number of junction points where the Jacobson-Lele-Speyer conditions (19) may be satisfied is two in the present model, j=1 when t = T_1 (region 1 exhausts its stock of grain) and j=2 when t = T_2 (when region 2 exhausts its grain). Consider region 2. At time t = T_2, a discontinuity would imply that the costate will decrease at that instant. However, as observed in proposition 3, during the period prior to the junction point, $\psi_2 \leq p + d_2$. After the junction point, the region purchases from the external market so that $\psi_2 = p + d_2$ which is greater than any value the ψ_1 could take prior to T_1. The costate variable cannot instantaneously fall as (19) so $\beta_2(T_2) = 0$.

For region 1, if no inter-regional trade occurs, $\beta_1(T_1) = 0$ by an analogous argument to region 2. Otherwise, at time $t = T_1$, inter-regional trade will begin so that $\psi_1 - \psi_2 \leq m$ (condition 16) will actually bind. Corollary 2 notes that during and before trade, region 2 has stocks of grain so that $\psi_2 = \psi_2^* \cdot e^{rt}$ for the period before and after trade begins. The condition $\psi_1 \leq m + \psi_2^* \cdot e^{rt}$ prior to trade means that ψ_1 cannot fall after trade begins and the condition binds, i.e. $\psi_1 = m + \psi_2^* \cdot e^{rt}$. Again, the costate variable cannot instantaneously fall as (19) so $\beta_1(T_1) = 0$. ❑

3.4 Complete specification of the model of regional trade

The four propositions allows the optimal program to be completely solved. The first three propositions allow the ordering of the various grain flows to be characterised. The order after harvest is grain sales at t=0, followed by a period of consumption of harvested grain. When region 1 exhausts its grain stocks, there may follow a period of inter-regional trade with region 2 consuming its own stock of grain as well as selling grain to meet region 1's consumption needs. After grain trading, region 2 consumes any remaining own grain while region 1 sources all consumption from the external market. Both regions purchasing from the external market are the concluding flows. Some of the control variables may remain at zero throughout the program with the control variable associated quantifying inter-regional trade requiring particular attention. When a particular control variables takes a non-zero value, the associated function of the costate variable becomes an equality. Table 1 indicates the regional costate's functional form which results due to this for the entire program when there is trade between the two regions. Table 2 details the behaviour of the costate when there is no trade between the regions and the costates are independent.

Proposition 4 indicates what happens at the points in the program where there are switches between control variables. According to the maximum principle, the costate variable is continuous at all times except when the state variable reaches a bound, zero grain stocks being the case in this program. At such junction points, proposition 4 proves that the costate functions would be continuous. The continuity of the costate throughout the program allows the points in the program when costate switching occurs to be written in terms of costate equalities, i.e. an equality sign can be placed between the functional forms before and after the point in time when a switch occurs. This allows a set of conditions to be derived. When there is trade between the two regions, the conditions are:

$$\text{At } t = T_1,\ \psi_1^* \cdot e^{rT_1} = \psi_2^* \cdot e^{rT_1} + m; \tag{21}$$

$$\text{At } t = T_m,\ p + d_1 = \psi_2^* \cdot e^{rT_m} + m; \tag{22}$$

$$\text{At } t = T_2,\ p + d_2 = \psi_2^* \cdot e^{rT_2}. \tag{23}$$

When there is no trade between the two regions, the continuity of the costate implies that:

$$\text{For } \psi_i \text{ at } t=T_i,\ \psi_i^* e^{rT_i} = p + d_i \qquad i=1,2. \tag{24}$$

Further, the lack of trade implies that y =0 throughout the optimal program. From condition (16) - the spatial arbitrage condition - a further relationship can be noted. The lack of inter-regional trade implies that, at the time when inter-regional trade could begin (at the exhaustion of region 1's grain stocks (see proposition 2)) the difference between regional costates is less than the cost of transfer:

$$\psi_1^* \cdot e^{rT_1} - \psi_2^* \cdot e^{rT_1} < m. \tag{25}$$

This states that when region 1 has exhausted its grain supply, inter-regional trade would not be initiated as the difference in the costate variables is less than the cost of transfer.

Table 1

Costate Variable Functional Forms during the Optimal Program when Trade Occurs

$t=$	0	T_1	T_m	T_2	1
	NO TRADE	TRADE	NO TRADE	NO TRADE	
ψ_1	$\psi_1^* \cdot e^{rt}$	$\psi_2^* \cdot e^{rt} + m$	$p + d_1$	$p + d_1$	
ψ_2	$\psi_2^* \cdot e^{rt}$	$\psi_2^* \cdot e^{rt}$	$\psi_2^* \cdot e^{rt}$	$p + d_2$	

Table 2

Costate Variable Functional Forms without Trade

$t=$	0	T_1	T_2	1
ψ_1	$\psi_1^* \cdot e^{rt}$	$p + d_1$	$p + d_1$	
ψ_2	$\psi_2^* \cdot e^{rt}$	$\psi_2^* \cdot e^{rt}$	$p + d_2$	

Having derived the dynamics of the costates after harvest, the initial values taken by the costates can be considered. This depends on whether there are grain sales to the external market. Corollary 1 can be used to give the combination of values of the costate and the level of grain stocks at t=0. When

Figure 1

Regional Grain Prices over Time

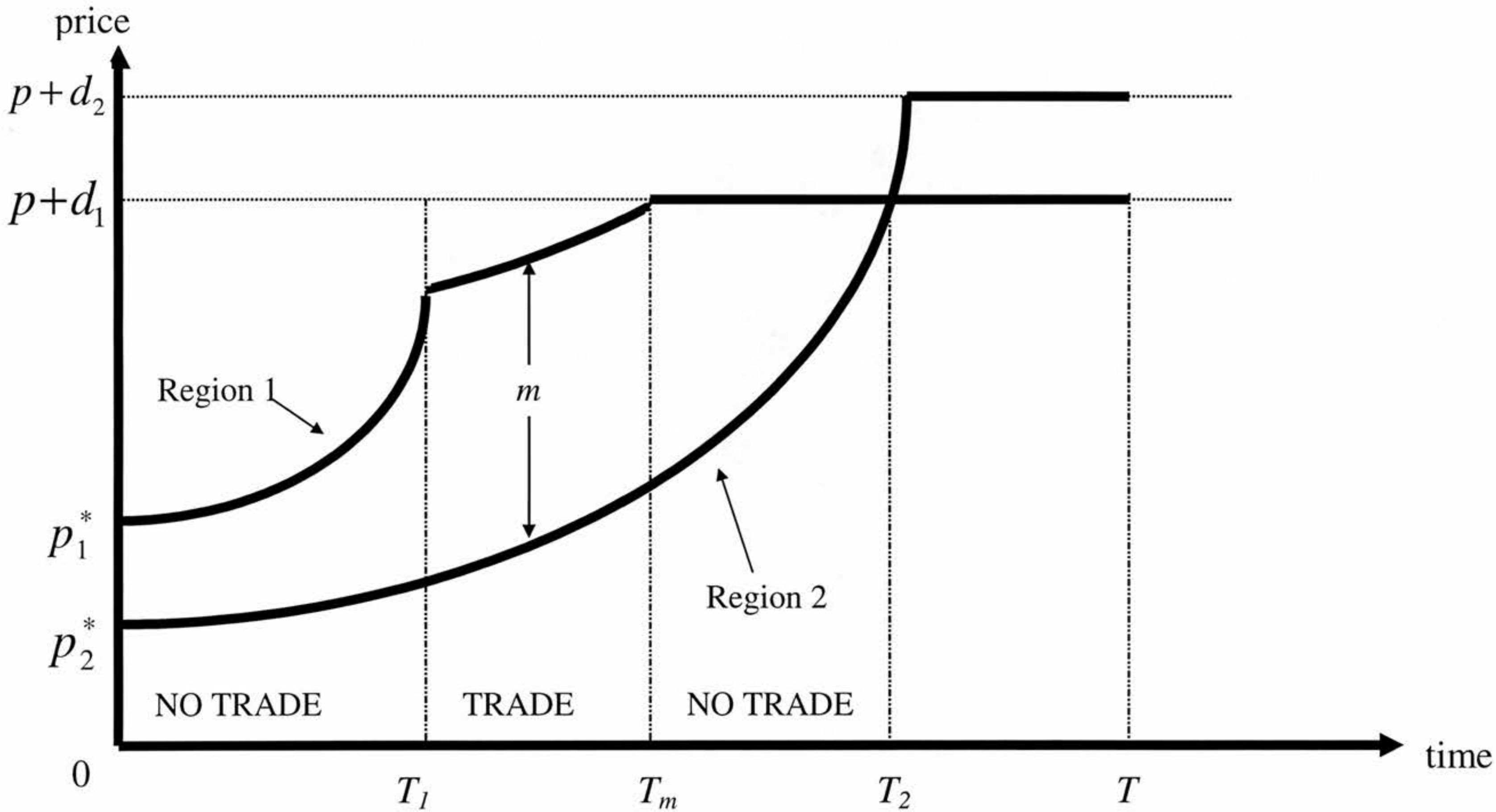


Table 3

Initial Values of Costate and State Variables

Initial Scenario	ψ_1^*	ψ_2^*	s_1^*	s_2^*
Both regions sell grain	$p-d_1$	$p-d_2$	h_1-x_1	h_2-x_2
Only region 1 sells grain	$p-d_1$	$\geq p-d_2$	h_1-x_1	h_2
Only region 2 sells grain	$\geq p-d_1$	$p-d_2$	h_1	h_2-x_2
Neither region sell grain	$\geq p-d_1$	$\geq p-d_2$	h_1	h_2

one of the regions sells grain at the start of the program, the initial value the costate takes in that region is its minimum value, $p-d_i$. Also, the sales of grain by the region implies that the initial stocks of grain are some value less than the harvested level. The initial values taken be regional costate variables and stock levels differ when regions do not sell any grain to the external market. In such regions, the initial value the costate variable takes is greater that $p-d_i$. However, as no sales are made, initial grain stock levels must equal the harvested level of grains. Table 3 summarises the four possibilities.

Figure 1 indicates the behaviour of the costate variables in one of the four cases. In figure 1, initial harvest levels and parameter values are such that neither region sells grain but there is inter-regional trade. Region 1 is consuming it harvested grain until the period T_1. As there are stocks of grain in both region during this period, both regional costates rise exponentially. After this, region 1 begins purchasing grain from region 2. Until time T_m, region 1's costate differs from region 2's by the cost of transfer. During this period, price correlation may be expected as shocks in either region which affect the market clearing price would be transferred. Inter-regional trade ends when the external market becomes a cheaper source of grain for region 1 than region 2 so that region 1 purchases from the external market. From this point until T_2, region 2 is consuming its own grain and the costate continues its exponential rise. The external market becomes the sole supplier of grain after region 2 exhausts its stocks.

The total grain harvested at the start of the program provides regional constraints on the total level of flows out of, into and between the regions. As consumption of grain is identical in both regions at one per unit time, the times at which the various flows of grain switch off and on are equal to the quantity of grain transferred from a particular source. For example, in region 1, the quantity of grain available in the harvest must equal the sum of the amount region 1 sells to the external market and the length of time before the region exhausts its own supply (i.e. T_1):

$$h_1 = x_1^* + T_1. \tag{26}$$

For region 2, the picture is complicated by the region's supplying of region 1 if there is a period of inter-regional trade. In the present model, due to the simple way in which consumption is specified, the amount of grain transferred is equal to the length of time trade occurs, that is T_m - T_1:

$$h_2 = x_2^* + T_2 + T_m - T_1. \tag{27}$$

If inter-regional trade does not take place, then the constraint on region 2 is similar to that of region 1:

$$h_2 = x_2^* + T_2. \tag{28}$$

Equations (20)-(28) and the various combinations of costate and grain stock initial values provide systems of solvable equations for each of the four initial scenarios set out in table 2. However, the exact scenario which will occur depends on the levels of harvest in relation to the parameters of the model. These relationships are investigated further in the following section.

4. Behaviour of spatial commodity markets

4.1 Overview

This section considers the behaviour of regional markets when there is an external market and the possibility of inter-regional trade. The section focuses on the whether the two regions would trade in a particular season so that market integration would be observed. It will also consider how long such inter-regional trade will last. As might be expected, the parameters of the model and the level of harvest in the two regions jointly determine the extent of market integration.

An assumption of the previous section will be relaxed. Inter-regional trade was previously considered to be unidirectional - from region 2 to region 1. Appendix 1 indicates the conditions on the parameters and the level of the two regions' harvest when this assumption will be unsatisfactory. However, it also shows that in such circumstances, the model may be respecified with the regions exchanging places. This intuitively appealing property of the model allows the results of the following analysis to be generalised to inter-regional trade in either direction through a transformation of variables and parameters. In the two figures 2 and 3, figure 2 considers the combination of regional harvests which would yield trade from region 2 to 1. However, by reformulating the problem with the two regions switching places, figure 3 gives a more complete picture allowing trade to occur both from 2 to 1 and, in the upper left side of the diagram, from 1 to 2. It is worth noting that figure 3 is not symmetrical about the $h_1=h_2$ line unless the two regions are equidistant from the external market, i.e. $d_1=d_2$.

4.2 The occurrence of inter-regional trade

The conditions when trade does not take place provide an initial insight into the parameter relationships which determine the nature of regional grain stock management. If, after harvest, the regions do not trade with each other, the harvested grain is either consumed within the region or sold to the external market. Thus, constraints (26) and (28) are relevant to the program (i.e.

harvested grain equals the sum of grain sales and the time before exhaustion of regional grain stocks). With regard to the conditions at the start of the program, the four potential scenarios detailed in table 2 need to be considered: neither region selling grain to the external market, region 1 selling, region 2 selling and both regions making sales to the external market.

A start in analysing these various situations is to note the conditions on regional harvests for positive grain sales in both regions. Using (26) and (28), it is clear that when sales occur in regions i=1,2, and there is no inter-regional trade:

$$h_i > T_i \qquad i=1,2. \qquad (29)$$

Further, positive grain sales constrain the initial value of a region's costate variable as given by table 1b:

$$\psi_i^* = p - d_i \qquad i=1,2. \qquad (30)$$

Conditions (29) and (30) can be combined with equation (24):

$$\text{For } \psi_i \text{ at } t=T_i\text{, } \psi_i^* e^{rT_i} = p + d_i \qquad i=1,2. \qquad (24)$$

For a region, this gives a minimum harvest level for grain sales to the external market from that region to occur when the two regions do not trade:

$$h_i > \frac{1}{r}\ln\frac{p+d_i}{p-d_i} \qquad i=1,2. \qquad (31)$$

These two inequalities partition the (h_1, h_2) space into distinct areas. However, as shown in figure 2, only in the situation where both regions are selling to the external markets are conditions (31) for regions i=1,2 sufficient to guarantee no inter-regional trade. This is area B in figure 2 and occurs when both areas have very high harvest levels. For this to be a sufficient condition, equation (25) needs to be considered:

$$\psi_1^* \cdot e^{rT_1} - \psi_2^* \cdot e^{rT_1} < m. \qquad (25)$$

(In appendix 2, this condition is explored further.)

Area C gives combinations of regional harvest levels where sales to the external market are made by region 2 and there is no inter-regional trade. Inter-regional trade does not occur only if region 2's sales to the external market could not be cheaply transferred to the other market. This is the case if condition (25) is met throughout the program. By noting that the maximum value the difference between regional costates can take will be at time, $t=T_1$, and, as there are no grain sales by region 1, this occurs at $t=h_1$, (25) can be re-written. Substituting into (23) using $t=h_1$, for region 1:

$$\psi_1^* \cdot e^{rh_1} = p + d_1 \tag{24}$$

and the results from table 2:

$$\psi_2^* \cdot e^{rh_1} = (p - d_2) \cdot e^{rh_1} \tag{32}$$

and solving gives the condition:

$$h_1 > \frac{1}{r} \ln \frac{(p + d_1 - m)}{(p - d_2)}. \tag{33}$$

Figure 2

Regional Harvest Levels and Inter-Regional Trade

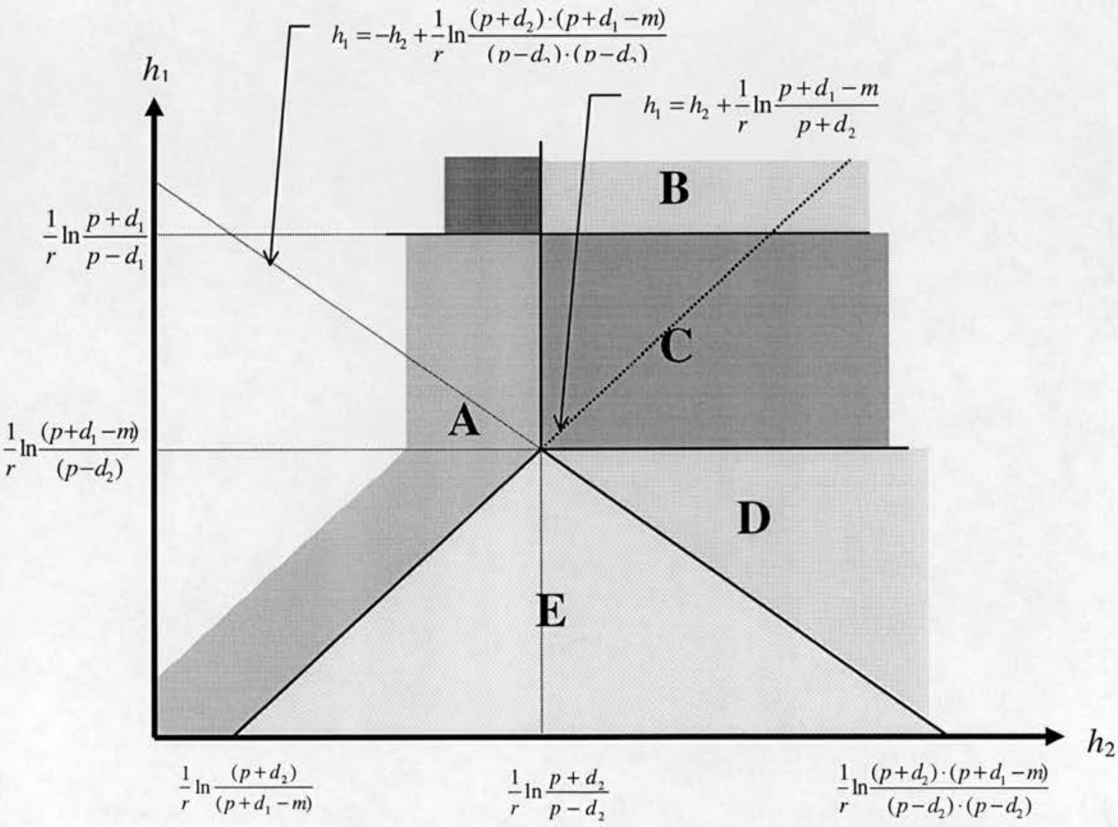
A No Inter-regional Trade or Grain Sales to the External Market

B No Inter-regional Trade; Both Regions sell to the External Market

C No-Inter-regional Trade; Region 2 sells to the External Market

D Trade from Region 2 to 1 with Region 2 also selling to the External Market

E Trade from Region 2 to 1 with Neither Region selling to the External Market



The diagram indicates the nature of regional trade for various combinations of harvest levels for the two regions. This figure considers the case where trade occurs from region 2 to region 1 but not the other way. Full derivation is in the text.

Figure 3

Regional Harvest Levels and Inter-Regional Trade

A No Inter-regional Trade or Grain Sales to the External Market

B No Inter-regional Trade; Both Regions sell to the External Market

C No-Inter-regional Trade; Region 2 sells to the External Market

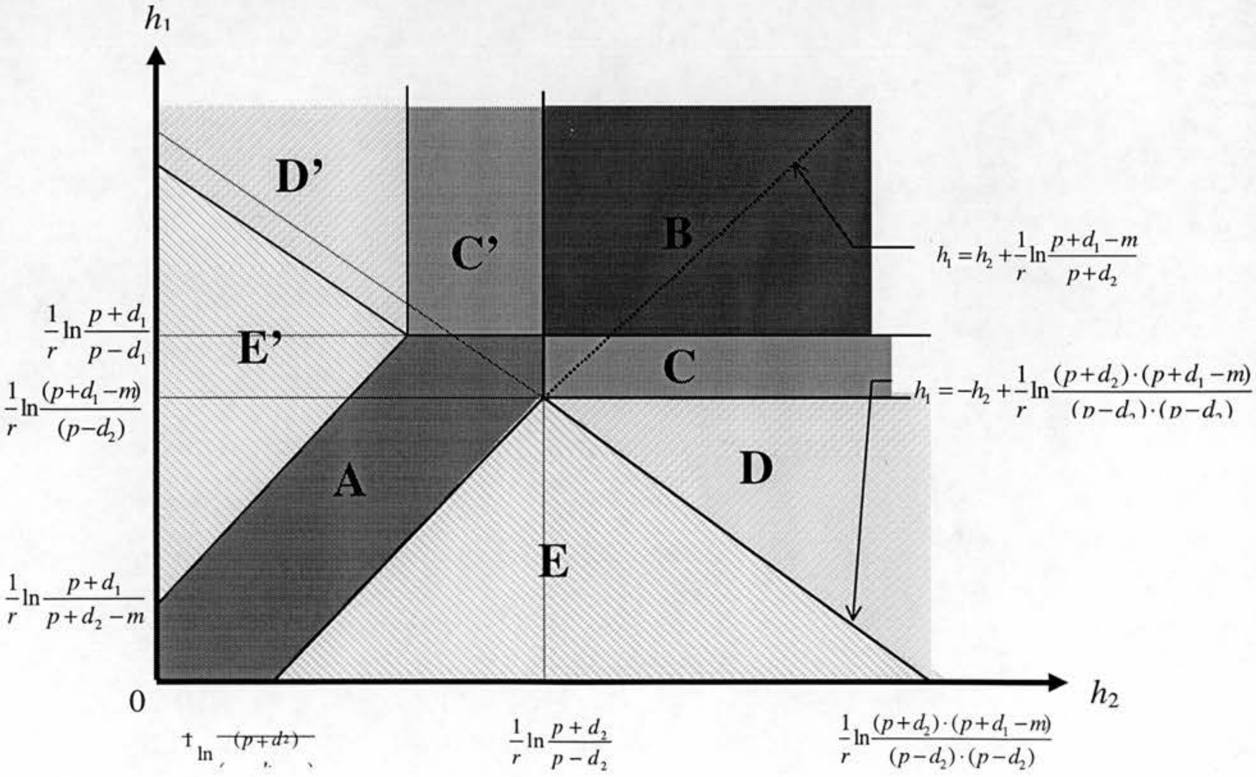
C' No-Inter-regional Trade; Region 1 sells to the External Market

D Trade from Region 2 to 1 with Region 2 also selling to the External Market

D' Trade from Region 1 to 2 with Region 1 also selling to the External Market

E Trade from Region 2 to 1 with Neither Region selling to the External Market

E' Trade from Region 1 to 2 with Neither Region selling to the External Market



The diagram indicates the nature of regional trade for various combinations of harvest levels for the two regions. This figure considers the case where trade occurs in both directions. Full derivation

This is indicated as region C in figure 2. The reflection of this is indicated as region C' in figure 3.

Area A indicates combinations of harvest which result in no inter-regional trade and no sales to the external market. This area shows that equal or nearly equal harvests give rise to regional autarky. This is not surprising and can be explained by noting the identical consumption needs of the regions. When harvests are similar, both regions exhaust their grain stocks at a similar time and so it is unlikely that a region will sell to its neighbour. Appendix 1 indicates the derivation of the region. It is shown there that if inter-regional trade is only allowed in the direction of region 2 to 1, then the conditions on the harvest are:

$$h_1 \geq h_2 \tag{34}$$

$$h_1 \leq h_2 + \frac{1}{r}\ln\frac{p+d_2-m}{p+d_1} \tag{35}$$

The first condition notes that the distribution of harvests favours region 1. In such circumstances, there would be not trade in the direction of 2 to 1. The second condition is the bound put on the extent to which region 1's harvest can exceed 2's without causing price divergence to be great enough for trade *from* region 1 *to* region 2.

The dark area made up from A, B and C indicates combinations of regional harvest which would make regional trade unnecessary as own stocks and the external market would be adequate to meet the needs of the regions. Area A indicates that equal or near equal harvest levels would also make trade unlikely. The likelihood of falling into the regions C and D can be proxied by considering the two inequalities:

$$h_1 \geq \frac{1}{r}\ln\frac{(p+d_1-m)}{(p-d_2)}; \tag{36}$$

$$h_2 \geq \frac{1}{r}\ln\frac{(p+d_2-m)}{(p-d_1)}. \tag{37}$$

If both are true, then inter-regional trade does not occur as the harvest combination would be in the dark area of figure 2. From (36) and (37), it is apparent that the higher the rate of discount, the less likely trade is. Trade, however, is more likely to occur when regions are distant from the external market and the transfer costs between the regions is small.

Appendix 2 qualifies conditions (36) and (37) somewhat. Under certain parameter values, only one of the two conditions can be used to differentiate harvest levels where trading takes place from harvest levels without trading. When parameters take these values one of (36) and (37) will be replaced by one of the conditions (31).

4.3 The timing of trade

When there is inter-regional trade, figure 2 distinguishes between two possible scenarios. Inter-regional trade from region 2 to region 1 can take place in the presence of region 2 selling to the external market, indicated as area D. However, when region 2's harvest is low, such inter-regional trade can occur with no grain sales to the external market by either region. In figure 2, this is indicated as E. Trade from region 1 to region 2 is indicated by areas D' (with region 1 selling to the external market) and E' (no sales) in figure 3. The conditions on the harvest levels in the two regions to differentiate between the two can be derived by looking at the length of time that trade occurs and then comparing these results with the conditions for grain sales, that is, the pair of equations (31).

Consider firstly the situation where only region 2 sells grain both to the external market and the other region. Clearly, the lack of sales to the external market from region 1 means that its harvested grain is exhausted through consumption and the time taken by this is equal to the level of harvest, i.e.:

$$T_1 = h_1. \tag{38}$$

Trade begins at time T_1. Region 2's sale of grain indicates that the initial value of the costate can be derived from equation (24) as $p - d_2$. This combines with (16) to give:

$$p - d_1 = (p - d_2) \cdot e^{rT_m} + m. \tag{39}$$

The time when trading ends can then be easily derived:

$$T_m = \frac{1}{r} \ln \frac{p + d_1 - m}{p - d_2}. \tag{40}$$

The time when region 2 exhausts its own supply of grain, T_2, is derived by combining (38) with (23) to give:

$$p + d_2 = (p - d_2) \cdot e^{rT_2}. \tag{41}$$

This solves to provide:

$$T_2 = \frac{1}{r} \ln \frac{p + d_1}{p - d_2}. \tag{42}$$

Now, consider the constraints (20) and (21) which, when combined, state that the total harvest must equal total grain sales, grain consumption and the amount of grain traded between the regions:

$$h_1 + h_2 = x_1^* + x_2^* + T_m + T_2. \tag{43}$$

Noting that for grain sales from region 2 to occur, $x_2^* > 0$, and that $x_1^* = 0$:

$$h_1 > -h_2 + \frac{1}{r} \ln \frac{(p + d_2) \cdot (p + d_1 - m)}{(p - d_2) \cdot (p - d_2)}. \tag{44}$$

The inequality (44) splits the region D from E - combinations of regional harvests which combine inter-regional trade with and without region 2 selling grain respectively.

The timing of trading derived can provide some indication of the length of time that markets trade. Trade occurs during the period T_m - T_1 and, when sales are made to the external market by region 2, this is equal to:

$$T_m - T_1 = \frac{1}{r}\ln\frac{p+d_1-m}{p-d_2} - h_1 . \tag{45}$$

When there is no grain sales to the external market, the length of time that trade takes place becomes:

$$T_m - T_1 = \frac{1}{2r}\ln\frac{p+d_1-m}{p+d_2} + \frac{h_2-h_1}{2} . \tag{46}$$

Equations (45) and (46) both indicate that the more expensive it is for region 1 to buy grain from the external market, the value $p+d_1$, the longer the trade. Cheapness in procuring grain from the neighbouring region, low m, and a low rate of discount, r, has a similar effect. The denominator in the logged fraction indicates the impact of grain sales on the level of trade. When region 2 is selling grain to the external market, the revenue gained through selling grain, p - d_2, is negatively related to the duration of inter-regional trade. When no grain sales occur, the opportunity cost of selling grain to region 1 becomes the cost of grain purchases from the external market, $p + d_2$.

5. Concluding Remarks

In this chapter, the Takayama-Judge spatial arbitrage model has been extended to consider the situation where there is storage of the commodity. A model presented by Williams and Wright (1989) highlights how commodity storage leads to breakdowns in temporal arbitrage rules. This chapter extends this result into a dynamic seasonal model of storage. Previous models have assumed that inter-regional trade would occur throughout a year and then proceeded to test for price co-movements. Here, it is suggested that periods of time where there is no trade may be the result of storage substituting for trade as an efficient means to offset transportation costs. This substitutability depends crucially on the cost of transfer between the regions and the rate of discount.

The optimal control model and figures 2 and 3 highlight how likely it is that trade takes place in a particular year with a particular distribution of harvest. The lighter shaded parts of figure 3 give combinations of regional harvests where trade would take place and the Takayama-Judge condition on inter-regional could be expected to bind for some part of the year. Further as trade is taking place, market clearing prices in the two regions would be interdependent so that price correlation would be expected. However, the model presented here would only expect regional trade to occur for some portion of a year. Inter-regional trade throughout a year would not be optimal in the model so that periods where regional market prices are not correlated would be expected.

In years where harvest levels are in the dark area of figure 3, there is no inter-regional trade in the optimal program. In such years, there would be no reason to expect correlation between market prices in the two regions and market integration tests would be inappropriate. Because there would be no reason to suppose price changes would be transferred between markets, such an analysis of the price data may erroneously suggest market trade is in some way obstructed. The diagrams indicate that this is most likely to be the case when two regions have similar initial stocks levels (harvests). Trade would not be beneficial in such circumstances.

The results of this chapter highlight the effect of spatial and temporal interaction on food market behaviour. In areas where storage of grain is significant, the market integration tests must be used with some caution. The primary result of the present analysis is that trade cannot be assumed to be a constant feature of food markets.

Appendix to Chapter 4

Part 1

In this appendix, the conditions under which inter-regional flows of grain will be from region 2 to region 1 is discussed. A situation is considered where there is no trade and the inter-regional difference in costate variable is less than the cost of transfer. However, as $\psi_2 > \psi_1$, if trade were to occur, it would be *towards* region 2. Inter-regional trade does not occur as long as:

$$\psi_2^* \cdot e^{rt} - \psi_1^* \cdot e^{rt} < m \tag{1.1}$$

is guaranteed throughout the program. If both regions do not trade, and assuming no grain sales to the external market, so that $h_i = T_i$, and using equation (24):

$$\psi_i^* = (p + d_i) \cdot e^{-rh_i} \tag{1.2}$$

Combining (1.1) and (1.2) gives:

$$(p + d_2) \cdot e^{r(t-h_2)} - (p + d_1) \cdot e^{r(t-h_1)} < m \tag{1.3}$$

Inter-regional trading from region 1 to 2 would occur when region 2 exhausts its grain stock if at all. Thus, if (1.3) holds at $t = h_2$ then it will have held during the entire program. This gives the condition (which is assumption 6):

$$h_2 > h_1 - \frac{1}{r} \ln \frac{p + d_1}{p + d_2 - m}. \tag{A6}$$

Note that A6 can be rewritten so that region 1 and region 2 exchange places. This can then be rearranged so that h_2 appears on the left-hand side:

$$h_2 < h_1 + \frac{1}{r} \ln \frac{p + d_2}{p + d_1 - m} \tag{1.4}$$

The areas given by (A6) and (1.4) overlap. This indicates that there is no pair of harvest levels which will not fall in one of the two areas. Some harvest pairs will lie in both. The direction of inter-regional trade - region 2 to 1 if A6 holds, region 1 to 2 if (1.4) holds, either direction is both are satisfied - can then be decided on this basis. This means that the present model can be applied to all harvest combinations.

Part 2

Figures 1 and 2 have been drawn assuming that:

$$\frac{p+d_i}{p-p_i} > \frac{p+d_i-m}{p-d_j} \qquad (i,j)=(1,2),(2,1) \qquad (2.1)$$

It can readily be derived that this will be the case, if:

$$d_1 \cdot (d_2 - d_1 + m) < p \cdot (d_1 - d_2 + m) \qquad (2.2)$$

in the case where $(i,j)=(1,2)$ and:

$$d_2 \cdot (d_1 - d_2 + m) < p \cdot (d_2 - d_1 + m)\,. \qquad (2.3)$$

in the case where $(i,j)=(2,1)$.

It can readily be seen that if the two regions are the same distance from the external market, then conditions (2.2) and (2.3) will be satisfied because assumption 2 states that $d_1, d_2 < p$. The extent to which p exceeds the transfer costs for regions to the external market determines whether (2.2) and (2.3) are satisfied. For a wide range of parameter values, the two conditions are satisfied so that diagrams 2 and 3 can be viewed as representing the most likely scenario. However, when one of the two conditions is not satisfied, e.g. the sign of (2.2) is reversed:

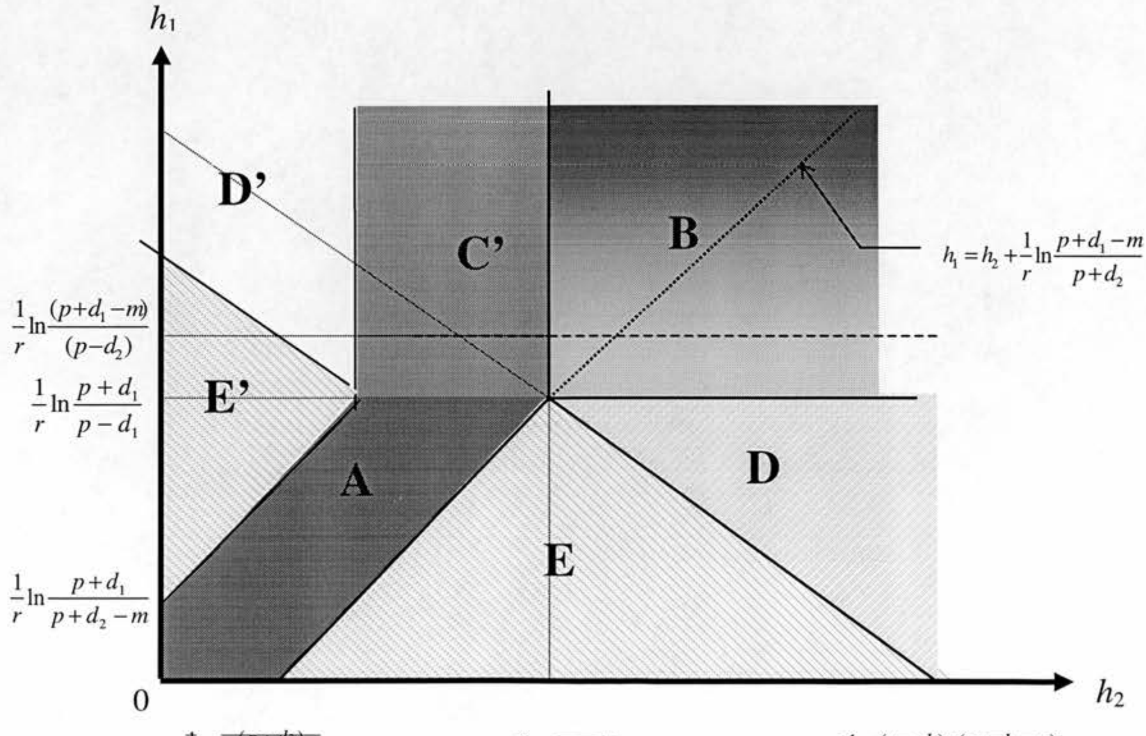
$$d_1 \cdot (d_2 - d_1 + m) > p \cdot (d_1 - d_2 + m)\,. \qquad (2.4)$$

The fact that $p > d_1$ and $p > d_2$ necessarily implies that (2.3) must hold. Thus, at least one of (2.2) and (2.3) is always true. Figure 4 indicates what the effect of (2.4) is on the extent of market trading. It indicates that region C in figure 4 no longer exists. That is, region 2 selling to the external market is no longer consistent with no inter-regional trade. The intuition behind this is that the parameters of the model are such that region 1 is more integrated with region 2 than with the external market. If region 2 has sufficient grain to sell to the external market, then some part of those sales would be firstly claimed by region 1. Note that the region C' still indicates: region 2 can sell grain to the external market and to the other region.

Figure 4

Regional Harvest Levels and Inter-Regional Trade

- A No Inter-regional Trade or Grain Sales to the External Market
- B No Inter-regional Trade; Both Regions sell to the External Market
- C' No-Inter-regional Trade; Region 1 sells to the External Market
- D Trade from Region 2 to 1 with Region 2 also selling to the External Market
- D' Trade from Region 1 to 2 with Region 1 also selling to the External Market
- E Trade from Region 2 to 1 with Neither Region selling to the External Market
- E' Trade from Region 1 to 2 with Neither Region selling to the External Market



The diagram indicates the nature of regional trade for various

CHAPTER 5:

Spatial Aspects of a Rural Grain Market

1. Introduction

Chapter 1 indicates how many countries in Sub-Saharan Africa have liberalised grain markets in the last decade. Restraints on the private marketing of grains have been relaxed so that the large parastatal marketing boards no longer have a monopoly in the market for staples. It is hoped that the policy will deliver allocative and productive efficiency in the food production and delivery system (Elz (1987)). However, a common worry is that the policy would merely replace a public monopoly with a private monopoly. Commentators have noted the considerable economies of scale that are a feature of many levels in the food distribution system (Bagachwa (1992); Rubey (1995)). Economic theory warns that such a market structure could lead to concentration and potentially to welfare losses associated with monopoly. Thus, as liberalisation has begun to gather speed, there has been an interest in the conduct of the markets identifying changes in the level of competition.

The present chapter focuses on the role of Zimbabwe's Grain Marketing Board (GMB) after liberalisation. The similarity between the market structure in Zimbabwe and other marketing systems in the southern African region has been noted in the research leading to liberalisation (see articles in Valdes and Muir-Leresche (1993)). The findings in this chapter therefore should have wider relevance. In the period considered, the marketing system of Zimbabwe was still dominated by the presence of the parastatal marketing board. The opportunities for private marketing in food markets however had been greatly increased with private traders being allowed to transport foodgrains in parallel with the GMB. Further, the GMB became a wholesaler of foodgrains selling grains to traders for onward sale to consumers.

The analysis here is based on a survey conducted in 1994-95. The area surveyed is a drought-prone rural district and the season when the data was gathered was particularly poor. One of the main criticisms of the pre-liberalisation marketing system was that it served food insecure regions badly at times of grain deficit such as the 1994-95 season (Jayne and Chisvo (1991)). The state-controlled marketing system was oriented towards moving grain to the urban population. In good years, the GMB was active in purchasing rural surpluses to sell on to meet needs of urban consumers. However, this orientation meant that the marketing system could not meet the needs of rural deficit households at a low cost. The results here thus give the first indications of the effects of the new marketing regulations on the semi-arid parts of Zimbabwe at a time of food distress.

The next section will give some background to the research. The survey of households from across Buhera District was conducted in the 1994-95 agricultural season. Due to the poor season, a substantial number of those households were purchasers of grain. Private traders and the GMB were significant suppliers of grain. In the third section, the channels through which grain was sold to the households will be further investigated. Small-scale traders are found to act as intermediaries between the households and the GMB, exploiting the scale returns in transferring grain to the areas distant from the Board's depot. Larger traders are trading in grain purchased directly from surplus farmers in areas which had better rains, thus completely by-passing the GMB. Some evidence is provided suggesting that the market is competitive and this is further substantiated through an empirical analysis of the price at which household are purchasing grains. The chapter ends with a discussion of the main findings and a conclusion.

2. Background

2.1 Survey details

2.1.1 Study area and survey design

Buhera District lies a hundred kilometres south of Harare in the province of Manicaland. It straddles the three least productive of the five agroecological zones of Zimbabwe. Map 1 indicates the position of the district and some of its features. The southern part of Buhera falls under zone V where rainfall levels are low and the lands unproductive. The quality of land improves northwards so that the northern third of the district, falling under zone III, is generally food self-sufficient in aggregate. Two tarmac roads skirt the district: one minor road across the north-western end (linking the GMB depot in Buhera town to the marketing network); the other, a more busy road, just crossing the southern most tip of the district. There is no rail service. The interior of the District is served by a poorly maintained road system. The main north-south road is heavily rutted by the buses plying the route while, off this highway, there is a high degree of variation in quality.

As part of a survey of Buhera District, 354 households in ten wards were interviewed regularly during 1995. The ten wards selected are marked on map 1. A sampling strategy was designed to cover the whole district and to include both remote and accessible areas. Data about the district was stored on a geographical information system (GIS). A first stratification was based on the agroecological conditions of the district. Ten wards were selected in proportion to the number of the thirty wards of the district which fell in the three agroecological zones. The transport infrastructure, terrain and location of markets was combined to create a map of market access. The average value of the village clusters from this map was calculated and village clusters were selected through stratifying the village clusters by good or poor access to markets.

The households were randomly selected from the twenty village clusters which emerged from the final stratification. In March 1995, just prior to the harvest, these households were asked about their grain purchases over the previous four months. This was repeated four months later in July and again in November. As harvest begins in March, the results utilised here cover the periods in the year when the households were most and least likely to be purchasing grains. The 1994/95 season was very poor - the first drought since liberalisation. As a consequence, the new marketing channels were of importance for the first time in allowing the large number of deficit households access to food.

In September, a qualitative follow-up on this survey was made. The significant markets utilised by the households were identified and the sources of grain for these markets were elicited through discussions with 'key informants' (a sub-sample of seven households, six traders and 2 government officials).

2.1.2 Variables employed and summary statistics

The variables used in this analysis are derived from the household survey. Table 1 provides some descriptive statistics about the variables which were selected for analysis. The same variables were drawn from the data for the three rounds of surveying. There were 885 individual purchases by the households in the four months from November 1994 (round 1). In the next four months, March to June 1995, the households made 489 purchase transactions. The fall reflects the fact that households also harvested grains in this round and so were less reliant on the market. In the final round of surveying, July to October 1995, the number of purchases had risen again to 681.

Households were asked the price at which they purchased grain. This is the dependent variable in the econometric analysis in section 4. From table 1a, the first round saw the lowest mean purchase price, z$22.91 for a 17kg tin of maize. This rose by about z$2 for the two following rounds. The determinants of price will be analysed later in the chapter. The distance from the Grain Marketing Board to the centre of the ward where the household resided has also been utilised in the later analysis to quantify the spatial aspects of the marketing system in Buhera District. The slightly higher mean in the second round reflects the fact that the households more distant from the GMB depot were more likely to be grain purchasers in the second round that the other two rounds. The quantity of grain purchased in an individual transaction is also detailed. The average level rises over the three rounds.

Table 1b indicates the summary statistics of the three dummy variables used in the empirical analysis. The first variable, h, takes the value of one if the source from which the household purchased grain was another household. The proportion of purchases where another household was the source remains similar across the rounds. The proportion of households purchasing grains directly from the GMB g, however, falls over the survey rounds. Initially, just under 10% of household purchases were sourced from the depot. This falls to nearly 3% in the other two rounds. The third main source, which may be seen as the remainder of purchases, was the private trader. Approximately two-thirds of all purchases were from the trader showing the dominance of the grain trader in meeting the food needs of the rural household.

Figure 1

Price of Grain and Location with a GMB Depot

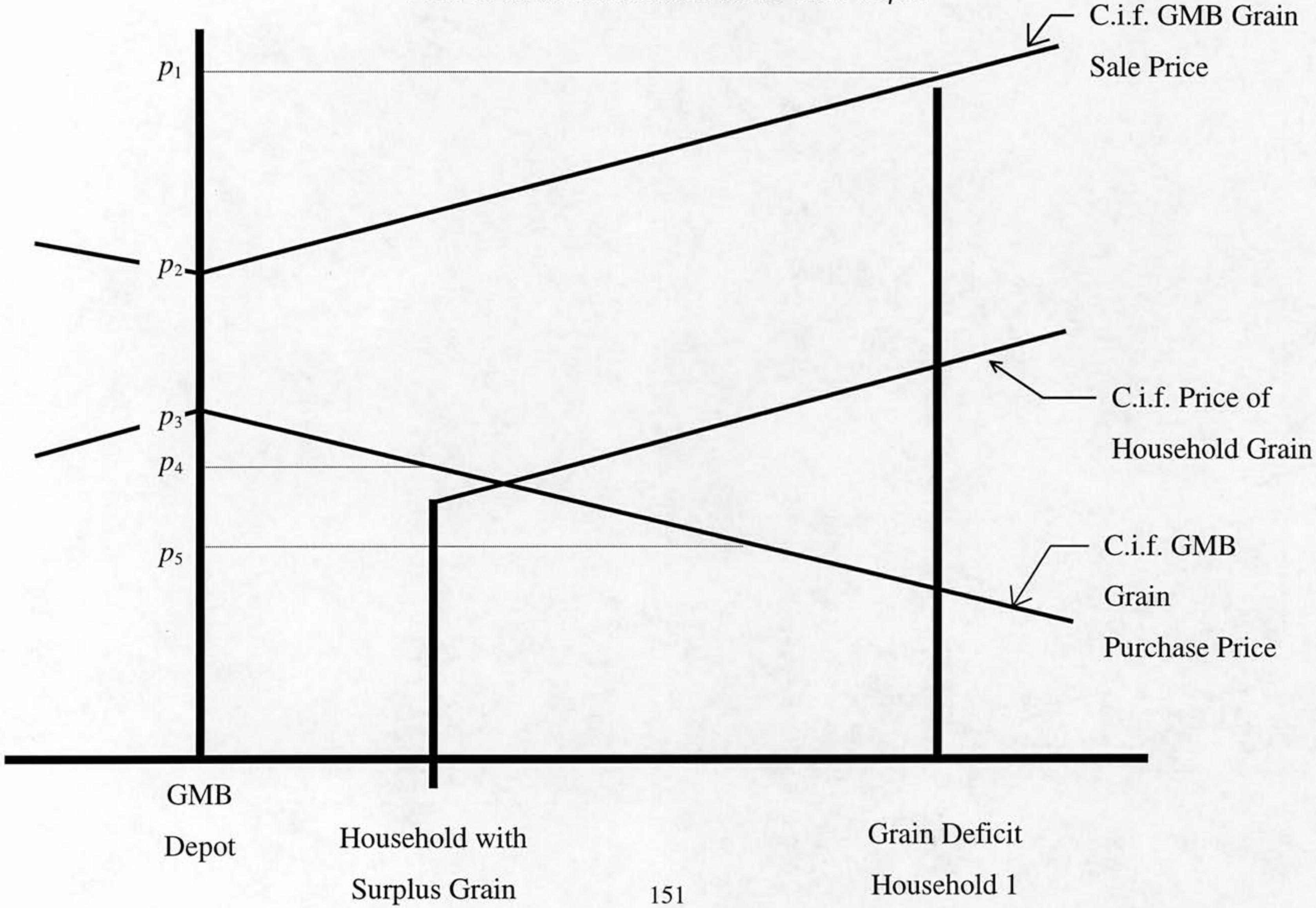


Table 1a

Descriptive Statistics for Continuous Variables

Variable		Mean	Standard Dev	Skew	Kurt	Min	Max	Obs
			Round 1: November 1994 to February 1995					
Price[1]	p	22.91	3.64	-0.7	7.8	10	50	854
Distance[2]	d	0.93	0.42	0.2	2.4	0.09	1.68	885
Quantity[3]	q	0.50	0.40	2.6	13.9	0.04	3.64	878
			Round 2: March to June 1995					
Price	p	24.30	2.88	0.0	19.3	10.4	50	485
Distance	d	0.97	0.38	0.0	2.8	0.09	1.68	489
Quantity	q	0.59	0.56	6.4	74.2	0.04	8.19	484
			Round 3: July to October 1995					
Price	p	24.87	3.12	-0.6	6.6	10	36	665
Distance	d	0.93	0.43	0.3	2.2	0.09	1.68	681
Quantity	q	0.70	0.97	6.4	59	0.09	12.5	669

Notes: [1]Price measured in Zimbabwe dollars per 17kg tin of maize; [2]Distance measured in `00km from Buhera GMB depot, adjusted for ease of travel (see data appendix); [3]Quantity in kilograms.

The mode of transport employed by the household in transferring the grain home is summarised by the variable *t*. This takes the value one if motorised transport - almost always a bus - was used. From table 1b, across the three rounds, 11, 8 and 16 per cent of the purchases involved some form of motorised transport.

Table 2 gives a breakdown of the maize transactions by source. It can be seen that the three main sources of grain - the GMB, private traders and other households - dominated the food purchases by households. Only 3.4% of grain purchases by quantity came from the other two sources. The table also gives some indication of the typical size of purchases. Purchases from the GMB were on average 120kg. This is much greater than the purchases from the other two main sources: 48kg was the size of average purchase from private traders; 68kg for purchases from other households. Table 2 also indicates number of locations from which purchases were made. The difficulty of accurately identifying the different markets was one problem. Identifying households was very difficult too. This makes this data harder to analyse as presented (a later section will use maps to analyse the locational data). However, there is some evidence that the households tended to use less markets in the third round than in the first, despite purchasing a similar amount to the first round. Summing the number of locations is not appropriate with the data as many of the locations had both households and private traders selling grain to households. However, the fact that the 22 tonnes purchased from private traders was bought from 101 different traders in the first round can be contrasted with the 21 tonnes bought from only 68 locations in the third round.

Table 1b

Descriptive Statistics for Binary Variables

Variable		Proportion	Obs
	Round 1: November 1994 to February 1995		
Takes value 1 if			
Source household	h	0.295	884
Source GMB	g	0.093	884
Motorised transport	t	0.108	878
	Round 2: March to June 1995		
Takes value 1 if			
Source household	h	0.301	489
Source GMB	g	0.033	489
Motorised transport	t	0.084	465
	Round 3: July to October 1995		
Takes value 1 if			
Source household	h	0.336	681
Source GMB	g	0.036	681
Motorised transport	t	0.164	679

Table 2

Household Sources of Grain, Buhera District 1994-95

	Round 1 November 1994-February 1995			Round 2 March 1995-June 1995			Round 3 July 1995-October 1995		
Source	No. of Locations	Quan (kg)	No. of Transactions	No. of Locations	Quan (kg)	No. of Transactions	No. of Locations	Quan (kg)	No. of Transaction
GMB	6	6458	70	2	1834	16	1	4950	24
Private Traders	53	22499	552	41	16616	295	52	21303	410
Other Households	101	16919	318	66	9268	147	68	18161	228
Local Miller	4	459	8	3	1036	25	1	153	3
Urban Miller	6	811	17	3	353	6	2	1273	16
Total		44037	885		29107	489		45840	681

2.2 Liberalisation of food markets

2.2.1 Liberalisation and the role of traders

Liberalisation has prompted an explosion of research interest in the private trading of foodgrains. Market liberalisation policies have enlarged the activities that the private individual can undertake and so an increase in the number of entrants has been anticipated. Research has focused in measuring the extent and determinants of this phenomenon. A general finding of such studies has been a skewed distribution regarding which marketing activities are undertaken by new entrants. Barrett (1997) notes the proportion of his interviewed sample who began their activity since Madagascar liberalised its marketing system in 1985. He finds the proportion to be much greater in the activities which require very little initial capital, such as sub-collectors (agents procuring grain from farmers for larger traders), small scale grain millers and casual retailers. Capital intensive activities - wholesaling, long-distance transporting and interseasonal storage of grain - were much less likely to attract entry since liberalisation.

Table 3 indicates some of his results. The table orders the types of private market agents by the average sunk costs for the sample. The percentage of agents who entered after 1985 is clearly correlated to the amount of costs that have to be sunk upon entry. Such results are observed in other studies such as Kaluwa (1992) in Malawi, Bryceson (1993) in Tanzania etc..

In Zimbabwe, entry has been relatively unobstructed. Registration of traders wishing to sell grains is compulsory. However, as with other countries, only the largest traders have taken the trouble to register as unregistered small traders have generally been tolerated. Traders have rarely indicated government regulation as a constraint on entry (Kinsey (1992)). The lack of bureaucracy combines with the lower start-up costs of the small-scale activities to make entry much more likely in retailing, grain collecting and small-scale grain processing. The sample of traders in the present survey was small, but it is noticeable that all four of the wholesalers/long-distance transporters had been in existence for some years as GMB registered buyers (this is discussed later). All four had their own trucks and storage facilities and in conversation agreed that the large initial costs for an entrant would be the main deterrence to entry. Meanwhile, the sample of smaller traders had a much higher proportion of recent entrants. Of the twelve small-scale vendors, four had entered in the season in which the survey took place (one was also going to exit at the end of the season).

Table 3
Trader Entry in Madagascar

	Mean Equipment Sunk Cost (FMG)	% entered since 1985	Number Surveyed
Long-haul transporters	197.1	27.8	18
Inter-seasonal storers	56.6	30.0	10
Millers	34.3	75.0	12
Wholesale collectors	10.5	33.3	15
Wholesale retailers	1.9	40.5	37
Short-haul transporters	0.5	50.0	66
Subcollectors	0.4	71.4	21
Casual retailers	0.02	57.6	144

From Barrett (1997) Table 1

A question that must be asked is whether entry is an appropriate measure of the success of market liberalisation. Models of perfect competition suggest that a large number of participants is a necessary condition for the welfare maximising impacts of a free market. A small number of participants then gives rise to worries of monopolisation with the monopolist earning monopoly rents at the expense of the consumer. However, this view neglects the large literature on industrial organisation analysing markets with few participants. One particular literature which ties in with the empirical work on returns to scale is the that of market contestability (Baumol (1982)). Many industries have large economies of scale and a small number of firms are better able to exploit the size advantages. A contestable market occurs when there are potential entrants which would be attracted into the market should monopoly pricing occur and this constrains the incumbent from over-pricing. The analysis indicates that for the replication of the competitive equilibrium, entry into the industry should be costless and quick. Thus, there should be the potential for over-pricing to quickly attract competitors to the market. The incumbent would then take into account the possibility of a 'hit-and-run' entrant when setting prices. Clearly, costless entry and exit can rarely be the case and some premium is extracted by the incumbent due to the existence of irretrievable sunk costs of entry.

2.2.2 Liberalisation and Zimbabwe's GMB

Studies have indicated the large sunk costs associated with three levels of the marketing system: interseasonal storage, long-haul transportation and wholesaling. The GMB has had a monopoly in these three roles for most of the century. Prior to liberalisation, a complex map of zones combined with restrictions on movements across zones by individuals or private companies to force surplus production to be sold to the local depot of the state controlled GMB (Jayne and Nuppenau (1993)). For grain sales, the GMB was tied to a subsidised urban-based processing sector and almost all grains not for export were sold on to these firms. The large economies of scale defined marketing as a natural monopoly and this was one of the reasons for the public monopoly.

While this system ensured adequate food supplies to consumers in the growing cities, it resulted in the anomaly that no production was directed to *rural deficit* households (Rukuni and Jayne (1995), p.20). The restrictions on grain movements stifled normal commercial mechanisms which would have moved grain to deficit households directly from surplus rural areas at times of need. Instead, these households were forced to buy milled flour produced in the cities. Studies indicated the extent of this phenomenon - in some areas, almost all households used purchased maize flour (Heddon-Dunkhorst (1990)). Apart from the high quality being inappropriate for these low income households, there were also unnecessary transport costs - moving grain to the cities and then moving flour back to the rural areas - which could not be off-set by scale returns in commercial processing. This effectively raised the cost of the staples, increasing food insecurity. The cost reduction by replacing the public marketing system maize flour with small-scale, local processing of local maize grain is estimated at 35 per cent by Jayne and Nuppenau (1993).

The poor food access in rural Zimbabwe was one of the main forces behind the government's relaxation of trading regulations in 1993. Private traders are now allowed to move grain across long distances in competition to the GMB. Thus, traders are now trading grain between surplus areas and deficit households. Further, traders can now purchase grain from the GMB and then sell these grains on to any buyers. The converse - supplying the GMB through purchases from farmers - is also allowed. The GMB continues to set annual buying and selling prices with a margin to compensate the Board for the transport and storage costs. These prices apply for food grains bought or sold at the GMB's depots regardless of depot location. Whereas prior to liberalisation, the deficit rural household could only purchase grain through two channels:

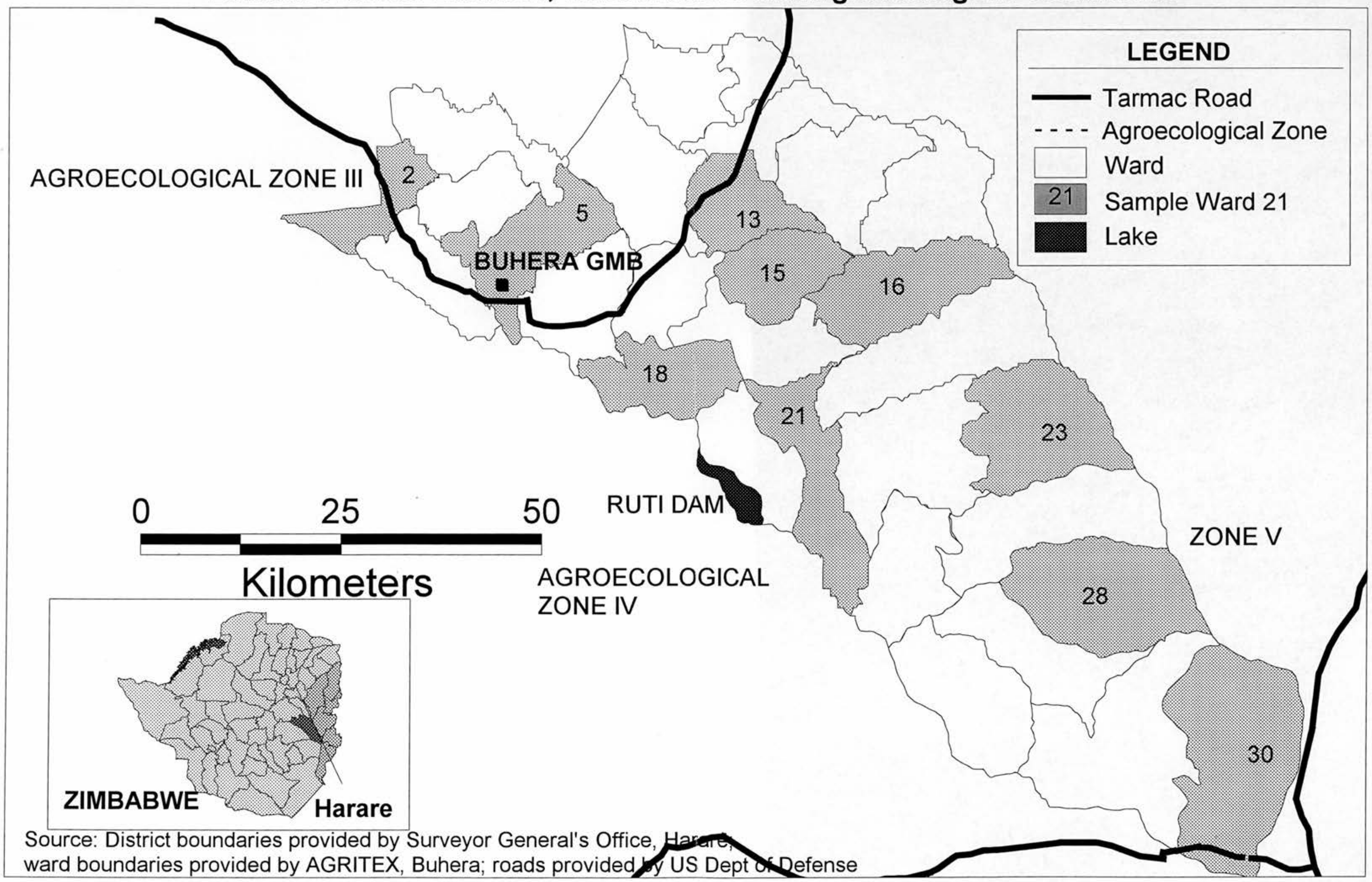
1. Grain Marketing Board to Urban Processor to Deficit household;
2. Surplus neighbouring farmer to Deficit household;

The increased freedom in grain trading now makes three new channels much easier (channel (3) was technically allowed but Chisvo et al. (1991) found few GMB depot managers were aware of it and so rarely allowed direct sales):

3. Grain Marketing Board to Deficit household;
4. Grain Marketing Board to Trader to Deficit household;
5. Surplus farmer to Trader to Deficit household.

The 1994-95 season was particularly poor with forty per cent of surveyed households purchasing grains. In the drier southern wards this figure rose to nearly seventy per cent (Vaze et al. (1996)). The liberalisation of the marketing system meant that the GMB depot in the north of the district could become a major source of grains for rural households at a time of drought for the first time. Post-liberalisation, the GMB depot could act as a retailer and a

MAP 1: Buhera District: Location, Infrastructure and Agroecological Conditions



Source: District boundaries provided by Surveyor General's Office, Harare; ward boundaries provided by AGRITEX, Buhera; roads provided by US Dept of Defense wholesaler of grains. The fixed price at which the Board sells grain suggests a simple model of grain pricing across the district can be employed. As the distance from the depot rises the market price level should rise. This is an application of a result which is much used in models of market integration across spatially dispersed markets. The Takayama-Judge model asserts that spatial arbitrage would lead to the price difference between two markets not exceeding the cost of transfer between the two markets (Takayama and Judge (1971)).

Figure 1 illustrates this arbitrage condition graphically. The horizontal axis is distance and the origin is assumed to be the location of the GMB depot. This determines the cost of grain for the deficit household indicated at the right of the diagram. The deficit household pays the price p_1 for GMB grain which would be purchased directly from the Board at the GMB sale price p_2, with the difference reflecting the cost of transportation. Consider a household located between the depot the deficit household which possesses surplus grains and wishes to sell this. If the household chose to sell the grain to the GMB, the household would receive the GMB's purchase price, p_3, which would be equivalent to p_4 when the cost of transfer are taken into account. Consider the potential sale price for the surplus household if it chose to sell to the grain deficit household. In the diagram, the household might be able to justify a price of p_5, on the basis that this would be the same as the c.i.f. GMB purchase price. However, viewing the alternative sources of grain available to the deficit household, namely the GMB depot, it is clear that the deficit household would be willing to pay a considerably higher price, up to p_1. Such reasoning suggests that marketing channels 2 and 5 (surplus household to deficit household, perhaps via a trader) would be more popular in the areas distant from the depot.

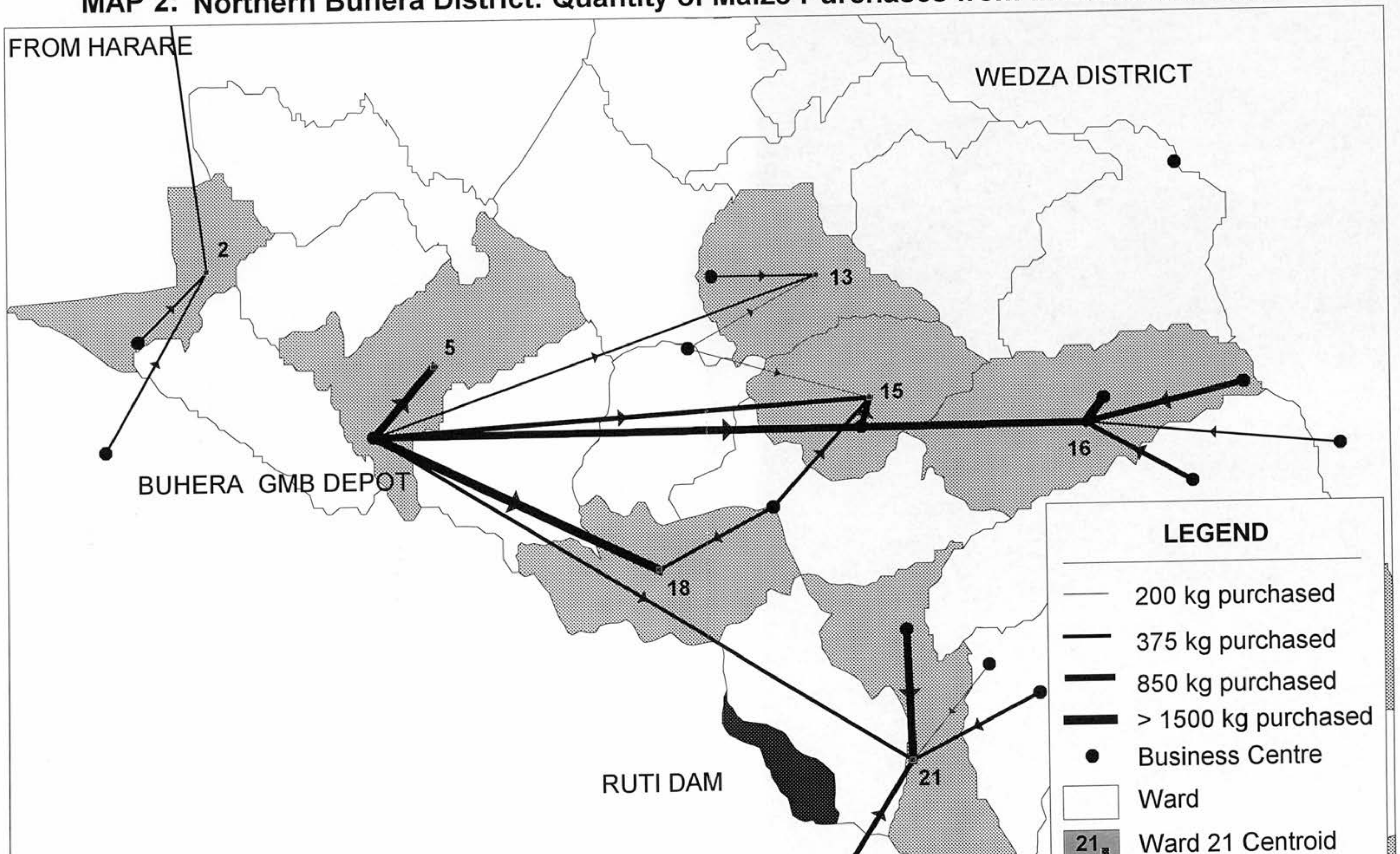
3. Spatial flows of grain

3.1 Market areas and grain sourcing

To analyse the spatial patterns, household food purchases were mapped using a Geographical Information System. This combined the survey data concerning purchase location with geographic information regarding the position of the markets. In maps 2 and 3, the grey lines link the centroid of the sampled wards to the source from which purchases were made by the households. Most sources were traders operating from shops in business centres near to the households. Buhera GMB depot was an additional source for grain purchases. The arrows indicate the direction of grain movement, i.e. from a trader or the GMB to the sampled households. The thickness of the line varies according to the total quantity purchased by the 35 sample households in the ward (see legend). Thus, each line represents an aggregate of several transactions, sometimes by the same household. Almost all grain purchases were of maize. To make the map easier to understand, the numerous small sources - below 100 kg in total ward purchases - were ignored in generating the map (but are included in the later econometric analysis).

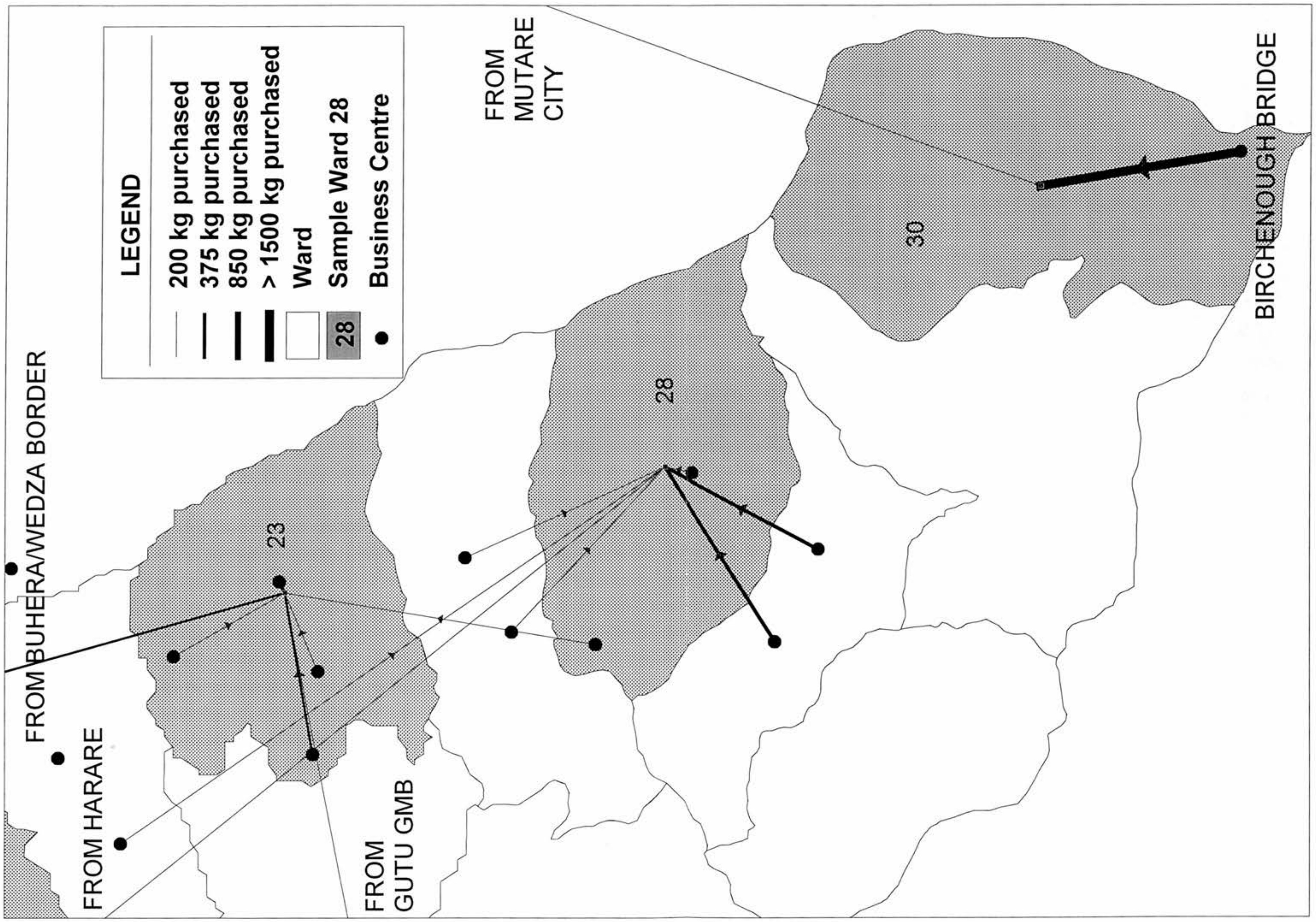
Looking at purchases from the GMB depot in Buhera town, the Board's new role as a retailer of grains can be seen. For more than two thirds of the district this depot is the nearest source of GMB grain. Further, two rivers that run along the eastern and western boundaries of the district make other closer depots by distance less accessible in practise. A comparison of maps 2 and 3 indicates the effect of the northern position of the depot. While in map 3, the three most southerly wards do not procure food from the GMB directly, in six of the seven northerly wards, households are purchasing significant amounts of grain directly from the GMB depot (see map 2). The importance of the position of the GMB depot is borne out further by looking at the changing sources of grain for the wards as distance from the GMB increases. Households in ward 5, which contains the depot, purchase almost exclusively from the GMB. Further away

MAP 2: Northern Buhera District: Quantity of Maize Purchases from Markets and GMB



Source: Ward boundaries provided by AGRITEX; business centre locations provided by District Development Fund, Buhera

MAP 3: Southern Buhera District: Quantity of Maize Purchases from Markets and GMB



from the depot, the number of non-GMB sources increases. Ward 18 only has one other source, while the more distant wards 13 and 15 purchase from two traders as well as the depot. Wards 16 and 21, the two furthest from the depot, purchase the least from the GMB directly as a proportion of total bought.

Much of the district relied on the GMB for grain indirectly. In Buhera, the private trader is acting as an intermediary. Many traders when asked about where they sourced grain confirmed the GMB as a supplier. In remote areas, there are obvious economic benefits of a private trader purchasing in bulk to sell to households. Traders purchasing in very large amounts can then exploit the returns to scale in bulking. Traders have the access to capital that such purchases would necessitate. They are also sometimes owners of transport. Thus, that traders are able to sell grains purchased from the GMB in the more distant wards is to be expected - they were common in the centres supplying wards 13, 15, 16 and particularly in the most distant ward 21.

The establishment of intermediaries between the households and the GMB to exploit bulk opportunities is a consequence of liberalisation. Prior to the lifting of restrictions, GMB depot managers were allowed to sell grain to individuals only if they were certain that this grain would not be sold on to others. This clearly runs counter to the needs of the more remote areas to bulk purchase and so minimise transport costs. Very few purchased from the GMB and many managers were found to be unaware that selling was allowed in any circumstances (Chisvo et al., 1991). Thus, traders acting as intermediaries between the GMB and the household suggests that new channels that the liberalisation offers are being utilised.

The three wards - 13, 15 and 16 - form a boundary between reaches of the GMB depot in Buhera and the northern Wedza district. Wedza falls entirely under good agroecological conditions, primarily zone III, and had been surplus in the 1993/4 and 1994/5 seasons. Some of ward 16's traders were being supplied by the surplus farmers of Wedza district. Similarly, households in ward 23 were using a trader on the Buhera-Wedza border to source grain. Thus, a third channel - surplus area to trader to household - was prominent in these wards. It must be noted that prior to liberalisation, some of these operations would not have been allowed as Wedza is partly a commercial area, that is in a different zone to Buhera. Thus, traders are establishing direct routes for surplus areas to provide maize to deficit rural areas.

This new channel is very much the preserve of the biggest four traders. The mechanics of such transactions owe much to their pre-liberalisation roles in the marketing system. Prior to liberalisation, the large traders were GMB registered buyers. Registered buyers were contracted by the GMB to buy grain from surplus regions at a price fixed by the GMB and then to sell the grains to the local depot. Registered buyers often employed 'agents' who procured grain through the markets in surplus areas such as Wedza, or, sometimes, directly from surplus households. When a full truckload had been purchased, the agent informed the trader and transport was arranged. A feature of the modern market is the widespread use of agents by large traders to source grain from more distant surplus areas. The registered buyers' network of agents and expertise in the logistics of moving large quantities of grains have thus been used to meet local needs. Prior to liberalisation this specialisation was used to channel grain out of the area even though there were food deficit households locally.

A difference between the two new channels involving private agents should be stated. In the first channel - GMB to trader to deficit household - the trader has none of the costs associated with sourcing of grains. Thus, this can be undertaken by small-scale traders. However, the need for contacts, an efficient transportation system, storage, both at the trader's and agent's location etc. means that the latter trading enterprise has high initial costs and this channel of grain marketing is most likely to be undertaken by the large-scale traders.

In passing, it is worth noting that the behaviour of ward 30 is somewhat different to the rest of Buhera. Birchenough Bridge, in the south, is an established trading point considerably busier than any of the other towns of Buhera. Consequently, the road is lined by traders at Birchenough. They have ready access to the grains that move along the highway between surplus areas and the GMB depots further east and west. The households in ward 30 are almost entirely serviced by this market (the one line to Mutare City marks a household with a relative working there).

3.2 Coping with monopolies in the hinterland

Across the district, the various channels described earlier have been established. However, with the presence of large initial, possibly sunk, costs, the worry of monopoly pricing must be addressed. Small-scale traders sourcing grain from the GMB act in competition with the large-scale traders. The small-scale traders begin trading with a little capital used mainly to purchase the grain. These costs are then recouped relatively quickly by under-cutting other operators in the market. Storage costs - mainly interest on borrowed capital - are thus kept to a minimum. However, the relatively small purchases mean that few of the transport returns to scale can be exploited so that it is the spreading of the initial fixed costs across several customers which makes the enterprise remunerative. Periodically, small-scale traders will be unable to supply grains. Their dependence on others for inputs such as capital and transport makes them vulnerable to changes in the market. In ward 21, intermittently, two small-scale traders would purchase grain from the GMB and, using public transport and a rented cart, move this grain to the ward (only one is large enough in volume to be represented as a line on map 3). These traders sell grain very quickly by undercutting the larger traders. This allows early repayment of the (usually) borrowed capital. Some households also suggested that the large trader in the area would become aware of the presence of the competitor and lower prices accordingly (this pricing behaviour was denied by the trader, however). This strategy of combating trader monopoly pricing was also followed in other more remote wards.

Wards 23 and 28 are particularly inaccessible. There is prima facie evidence to suggest that the wards are near the intersection of market boundaries. This means the wards are furthest from all sources of grain - the GMB depot in Buhera, and surplus areas in the south and north - and so in a particularly weak market position. The first evidence that this may be the case is the source of maize for the wards. Wards 28 and 30 (which is the most southernmost ward) are supplied largely by southern producers of grain, 23 by eastern areas and all the other wards are supplied by the GMB or northern surplus regions. Thus, supplies to ward 23 and 28 come from all directions which is only possible at the market boundary. Further, the price pattern confirms the unique nature of these two wards. Price of maize peaks in wards 23 and 28 and the decline in price in Birchenough Bridge - ward 30 (table 4). A final fact of the agroecological conditions of the district is also indicated by table 4. Grain sales were largely made by households in the two wards to the north-west of the district - wards 2 and 5. These two wards are some distance from the wards 23 and 28 which are described as 'remote'.

Table 4
Price of Maize in Sample Wards

Ward	2	5	13	15	16	18	21	23	28	30
Avg. Price of 20 litre tin[6] of Maize(Zim$)	25	23	25	26	25	n/a	27	29	29	27
Avg. Household Sales of Grain 1994-95 (kgs)	134	137	1	0	6	1	0	2	15	18

n/a = no price observations were recorded

The purchasing behaviour of households in both wards exhibit two consequences of poor access to the marketing system. Firstly, no household makes significant purchases directly from the GMB. Secondly, through

[6] A 20 litre tin of maize contains approximately 18 kg of grain.

discussions with market participants, it was established that there was only one supplier of transport, residing in ward 28, used by the various grain traders of both wards. The greater distances involved in bringing in maize to these more remote households make exploiting scale economies in transport a priority and there is only one individual possessing the necessary transport for both wards. The lack of purchases from the GMB and the marketing power in the hands of the single haulage agent must rouse worries of monopolisation.

How do these two wards cope with their poorer position? Poor access to the GMB means that the GMB's impact on market prices is blunted. In areas near the depot, prices would be set taking into account that the customer can purchase from the GMB, effectively placing a ceiling on the market price. Clearly, actual purchases from the GMB need not occur if both buyer and seller are aware of the cost of acquiring grain from alternative sources and the purchaser can credibly threaten to take trade away from the local market. That this may be the case is borne out by a small survey of price information undertaken. In wards 23 and 28, 47% of households surveyed at random could accurately give the GMB price of maize. In the other eight wards, only 27% were as accurate. While this is significantly higher only at ten per cent confidence levels, it must be seen in the context of the negligible volume of trade with the GMB undertaken by households in the two wards. Despite this small volume, the respondents had an in-sight into the costs of such transactions.

Direct action by villages in this area was also noted. Two incidents particularly stand out. In one village, the trader was cautioned by village leaders regarding pricing behaviour and the traders access to the village market was threatened. The threat was that the village would follow a neighbouring village where the traders business was by-passed altogether. In the second village, the headman began grain trading as a response to the high prices charged by the local trader using trips to both Buhera GMB and Wedza district to procure grains.

4. Empirical Analysis of Purchase Price

4.1 Multilevel analysis

4.1.1 Motivation for multilevel analysis

In section two the sample survey was described and it was indicated that the sampling strategy involved an initial stratification on the basis of a well-defined geographical unit - the ward. Such a sampling strategy is standard in surveys such as the one under consideration providing a relatively low cost means to gain variation in the sample. However, the sampling strategy results in clustering. Within wards, there will be geographical clustering in measures such as the access to price information or some attitudinal commonalties. Special procedures have been designed to produce valid statistical inferences when evaluating data which has this property (Skinner et al. (1989)).

In general, the effect of the sampling strategy on econometric analysis has not attracted much interest. Analysts proceed without explicitly modelling the sampling design preferring to consider it as a 'nuisance factor'. In areas of spatial econometrics, more elaborate techniques have been considered (Anselin and Bera (1997)). However, a recent survey of research where such methods would be appropriate has highlighted that these techniques have seldom been used (Anselin and Hudak (1992)). Methodological complexity combines with the high computational demand to make the spatial econometric techniques hard to apply unless using small datasets or investing in specially written software.

In the present case, there is already evidence that the spatial aspects of the dataset are of considerable importance. The previous analysis of food marketing used maps to highlight spatial patterns in the marketing of foodgrains. In a quantitative analysis of the consequences of these patterns, it seems necessary to control for the clustering that may result from the sampling strategy. It must be noted that in this case the population structure itself is not of interest. Multilevel modelling often seeks to identify the effects of the higher level. For example, students may be sampled with clustering on schools. Usually, an analyst will be interested in the variation in the performance of the schools as well as individual students. Here, however, few implications will be drawn about individual wards that form the basis of the clustering.

4.1.2 The two-level model

Goldstein (1995) presents the statistical theory behind the multilevel model. The methodology is exemplified in terms of a school and the score tests of the students of the schools. The level 1 unit in this example is the student. It could be hypothesised that explanatory variables for each of the students would combine with the school characteristics in determining the test scores. These school characteristics would form the second level of the model. Essentially, the multilevel models hypothesise a nested structure to a population with the sub-sample within level 2's clusters having some intra-cluster covariance. Estimation techniques which take this into account will improve efficiency of estimates.

In the present example, a three-level structure could be envisaged where the household which purchases the grain is introduced as a level in-between the individual purchases and the wards. However, here the level 1 unit is a household purchase of grain; the level 2 unit is the ward. Each of the purchases within a ward are assumed to have some intra-cluster covariance. Thus, an initial approach would be to treat each of the wards separately, fitting a relationship for the purchase price paid in the transactions within one ward. Within a ward j then, the price paid by household i, p_{ij}, is related to a vector of explanatory variables $\mathbf{x}_{ij}$:

$$p_{ij}=\alpha_j+\beta_j\mathbf{x}_{ij}+e_{ij} \tag{1}$$

where α is a constant term, β_j a parameter vector and e_{ij} is a disturbance term with zero mean and variance σ_e^2. It can be seen that the parameter estimates are here defined for each of the wards. Further, it could be assumed that there is a common within ward residual variance. That is, the variance of the term is common across all j.

While this brings some of the issues of the multilevel modelling to the fore, the actual impact of the nested structure of the population can be analysed directly. This is achieved by allowing some of the parameter estimates to be random variables. Usually, the constant term is allowed to vary across the level 1 clusters. Also, some subset of the coefficients of the explanatory variables would be allowed to vary. That is, in the case where the constant term and a single explanatory variable is allowed a variable coefficient:

$$\alpha_j = \alpha + u_j; \quad \beta_{1j} = \beta_1 + u_{1j} \tag{2}$$

where u_j, u_{1j} are random variables with parameters:

$$E(u_j) = E(u_{1j}) = 0 \tag{3}$$

$$\text{var}(u_j) = \sigma_u^2,\ \text{var}(u_{1j}) = \sigma_{u_1}^2,\ \text{cov}(u_j, u_{1j}) = \sigma_{uu_1}^2 \tag{4}$$

This allows equation (1) to be rewritten:

$$p_{ij} = \alpha + \beta_1 x_{ij} + (u_j + u_{1j} x_{ij} + e_{ij}) \tag{5}$$

This expresses the response variable in terms of fixed effect and, in the brackets, a random effect. In the literature, the random effect is referred to as a residual. It can be seen that the single-level model forms a simplification of the 2-level model where only the e_{ij} is considered with the other error terms suppressed. This is the main difference in the multilevel modelling techniques. More than one residual term is included and special estimation techniques are required to estimate coefficients. A symmetry in the other components of the residuals can also be noted. If the constant term is viewed as a parameter estimate of a variable which takes the value one for all observations, the terms in u have a similarity to the parameter estimates.

Estimation can proceed to evaluate the coefficients, α and β, and the various variance and covariances, termed *random parameters*, σ_e^2, σ_u^2, $\sigma_{u_1}^2$ and $\sigma_{uu_1}^2$. Here, a simple model will be utilised. The variance components model (Goldstein (1995), p. 18) assumes that there is no residual term in x_{ij}. This reduces the number of estimated random parameters to two, σ_e^2 and σ_u^2,. The estimated regression becomes:

$$p_{ij} = \alpha + \beta_1 x_{ij} + (u_j + e_{ij}) \tag{6}$$

The model is called the variance components model because of the simple form the variance of the response variables takes. Equation (6) indicates that the price level varies about a fixed effect ($\alpha + \beta_1 x_{ij}$) by the sum of two disturbance term. The variance of ($u_j + e_{ij}$) is (Goldstein (1995), p.18):

$$\mathrm{var}(p_{ij} | \alpha, \beta_1, x_{ij}) = \mathrm{var}(u_j + e_{ij}) = \sigma_u^2 + \sigma_e^2 \tag{7}$$

This is the sum of the level 1 variance and the level 2 variance and indicates that the total variance for the price level of an individual purchase is constant. The covariance of the price level of two purchases in the same ward can also be elicited. Noting that the variation of the price of two individual purchases in one ward would be $u_j + e_{i_1 j}$ and $u_j + e_{i_2 j}$, where i_1 refers to the first purchase in ward j and i_2 to a second purchase, the covariance of these terms can readily seen be given by:

$$\mathrm{cov}(u_j + e_{i_1 j}, u_j + e_{i_2 j}) = \mathrm{cov}(u_j, u_j) = \sigma_u^2 \tag{8}$$

since the level 1 residuals are assumed to be independent. Equations (7) and equation (8) can be used to give the covariance matrix for the price level of purchases in the same ward. For a ward where three purchases were made this will be given by a (3x3) matrix such as **A**:

$$\mathbf{A} = \begin{pmatrix} \sigma_u^2 + \sigma_e^2 & \sigma_u^2 & \sigma_u^2 \\ \sigma_u^2 & \sigma_u^2 + \sigma_e^2 & \sigma_u^2 \\ \sigma_u^2 & \sigma_u^2 & \sigma_u^2 + \sigma_e^2 \end{pmatrix} \tag{9}$$

A similar form of matrix would apply to all wards and these can be combined across wards to give a covariance matrix for all of the multilevel sample. The covariance between the price of purchases made in two different wards is zero. This means that the covariance matrix of the response variable is block-diagonal:

$$\begin{pmatrix} \mathbf{A} & \mathbf{O} \\ \mathbf{O} & \mathbf{B} \end{pmatrix} \tag{10}$$

where **B** is similar to **A** except has as many rows and columns as there are purchases in the second ward.

The correlation of the price level between two purchases made in different wards can be seen to be zero from equation (10) as the covariance between the prices would be zero. However, the correlation of purchase price for two purchases in the same ward can be written down. The intra-cluster correlation, ρ, is given by:

$$\rho = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_e^2}. \tag{11}$$

4.2 An Analysis of the Price of Household Grain Purchases

4.2.1 Estimated model

In this section, results from the estimation of a multilevel model are presented. The model is applied to sample survey data from Buhera District regarding the individual grain purchase transactions of the household over the 1994-95 season. The dependent variable is the price paid by the household in a particular purchase transaction and the independent variables are as detailed in section 3.1: the distance of the household from the market anchor, the quantity of grain purchased, whether the source was another household, whether the source was the GMB and whether the household made use of motorised transport in the transaction.

The multilevel model assumes that the level 1 unit is the individual grain trade. These are clustered by the ward, j, in which the householdmaking purchase i resides. A variance components model is then used in this formulation so that the analysis of the random effects is limited to the constant term. Thus, the modelled equation takes the form:

$$p_{ij} = \alpha + \beta_1 d_j + \beta_2 d_j^2 + \beta_3 q_{ij} + \beta_4 t_{ij} + \beta_5 g_{ij} + \beta_6 h_{ij} + (u_j + e_{ij}) \qquad (12)$$

where variables are as in table 1.

Estimation of this multilevel model was performed using the proprietary software MIXREG. This is a program written to provide estimates for mixed-effects regression models for normally distributed response data. Here it is use for clustered data where the mixed effects model assumes a degree of dependency within the cluster and adjusts for this. The software uses marginal maximum likelihood estimation (EM algorithm with Fisher-scoring).

4.2.2 Empirical identification of the market anchor

One of the determinants of purchase price is hypothesised to be the market anchor. In the model elaborated in chapter 4, the external market behaved in the manner of an anchor market, constraining the price that would be allowed at a particular location to being the cost of purchasing from the anchor market plus any costs associated with transfer. As distance from the market anchor increased the model indicated that this effect would be blunted. Transfer costs caused a large spread between c.i.f. price for household purchases and the f.o.b. price for household sales to the external market. In this section the role of the GMB as an external market and so as an anchor to price over space is empirically investigated.

The inter-ward distance for the all pairs of sample wards was calculated. This was achieved through the use of a GIS routine called 'COST' in the proprietary geographical information system package Idrisi. The routine finds the shortest route between a particular point on a map and all other points on a map. A point actually is a pixel on a grid which represents a kilometre square. The length of the line between two points is not used because the algorithm selects a route taking into account different friction values for each pixel. A pixel may be relatively costly to cross, indicating an obstruction such as a mountain or a river. Tarmac roads were deemed the easiest to cross costing one fifth of a pixel of flat land. Thus the algorithm calculated the shortest distance taking transport and terrain into account.

The algorithm was applied ten times to calculate the cost of travel from each point in Buhera to the geographical centre of each of the ten wards. This gave ten maps indicating the distance to the wards. The inter-ward cost for a particular ward was then calculated as the average value of all the pixels within that ward. As these gave quite large numbers, the inter-ward costs were normalised in terms of hundreds of kilometres of tarmac road. The model given by equation (12) was then estimated ten times, l=1,2,...,10, assuming each time that a different ward was the anchor ward. Thus, d measures the distance from ward j to ward l. This was repeated across the three rounds of data.

Table 5 summarises the results of the estimation focusing on the first two parameters - the intercept term and the coefficient on the distance measure, d. Other parameter estimates and estimation results are included in the appendix to this chapter. These tables indicate that other parameter estimates stay constant across the regressions despite the market centre is assumed to be different. Thus, the summary results presented in table 5 will be focused on.

Table 5

Identification of Market Anchor

Ward	Round 1 Nov 1994 - Feb 1995		Round 2 March - June 1995		Round 3 July - October 1995	
	Intercept	Coefficient on *d*	Intercept	Coefficient on *d*	Intercept	Coefficient on *d*
2	19.71	6.00	20.88	4.61	24.88	0.96
	(0.90)	(1.43)	(0.76)	(1.11)	(1.08)	(2.15)
5	20.22	6.60	20.41	7.04	23.57	2.78
	(1.12)	(2.26)	(0.67)	(1.16)	(0.84)	(1.3)
13	25.01	-4.35	23.59	0.74	26.47	-2.55
	(1.36)	(3.41)	(1.14)	(2.88)	(0.98)	(2.49)
15	25.28	-5.15	24.10	-0.32	26.97	-4.06
	(1.37)	(4.00)	(1.21)	(3.55)	(1.02)	(3.01)
16	24.72	-3.59	22.18	4.66	27.73	-5.87
	(1.65)	(4.19)	(1.14)	(2.92)	(0.97)	(2.42)
18	24.17	0.86	22.63	3.21	25.97	0.91
	(1.78)	(5.18)	(1.25)	(3.15)	(1.54)	(4.48)
21	25.29	-1.26	25.30	-1.40	25.88	2.30
	(1.85)	(5.13)	(1.80)	(5.01)	(1.65)	(4.55)
23	24.43	1.74	26.80	-3.34	26.09	2.30
	(0.91)	(2.10)	(0.79)	(1.80)	(0.92)	(2.11)
28	24.20	2.28	26.11	-1.15	26.67	1.09
	(0.74)	(1.52)	(0.71)	(1.47)	(0.72)	(1.48)
30	24.18	2.37	25.62	0.52	27.55	-0.17
	(0.85)	(1.36)	(0.74)	(1.21)	(0.71)	(1.14)

Note: Results of estimating equation (12) only presenting parameter estimates for first two coefficients (full results in appendix to chapter 5); standard errors in parenthesis.

The intercept term is the cost of grain purchases assuming all the other variables are zero. Thus, it measures the price paid at the anchor market for a purchase from a trader using no motorised transport. (The quantity purchased is zero, also.) Table 5 highlights the lower intercept term found if the distance measure is centred on ward 5. This is also a feature when the analysis is centred on the close by ward 2. This gives some support to the argument that the anchor for the Buhera grain markets is located near the GMB depot which is located in the centre of ward 5.

A further result is the significance of the distance coefficient in the two wards. When the distance measure is centred on other wards, the estimate is rarely significant. This also lends support to the anchoring role performed by the location of the depot. As distance from ward 5 increases, the purchase price increases. This would be expected as costs of transfer would be positively related to distance. The following section will explore the other determinants of purchase price given the market anchor is ward 5, where the GMB depot is located.

4.2.3 Determinants of purchase price

Table 6 presents an empirical analysis of the spatial patterns in the price paid by households purchasing maize. Other grains have been ignored as they were not commonly traded. All prices were converted to Zimbabwean dollars per tin (the most common unit of measurement for transactions). The regressed equation was of the form given in equation (12). Summary statistics for each of the variables are presented in table 1.

The regression was run for each of the rounds. The results of the multilevel model for the first two periods are not significantly different in terms of the value of the coefficients at 5%, using a Chow test ($F(7,1321) = 3.1523$. However, the estimated coefficients are not identical in the third round at 5%. The bottom half of the table indicates the validity of the model employed. In the appendix, regression results for ordinary least squares is presented. These indicate a high goodness-of-fit suggesting the OLS model explains the data well.

The log-likelihood results at the foot of table 6 indicates how much the OLS results are improved by modelling the underlying process taking into account a two-level structure. In round the three rounds, the log likelihoods are improved by 22,1 and 12 respectively. A likelihood ratio test can be performed by multiplying this improvement by two. This statistic is distributed $\chi(2)$. Thus, in the first and third round estimation is significantly improved by allowing for covariance within clusters. In the second round this is not the case: a test statistic of 2 is not significant. However, the table presents the results of the multilevel model estimation rather than the OLS results for easier comparability. The other model statistics further evidence this result that there is a two-level structure in all but the second round. In the middle round, intra-cluster variance is insignificantly different from zero so that the intra-cluster correlation is a low 0.01. In the other rounds, these statistics are larger suggesting that there is significant within-ward covariance.

Table 6

Determinants of Purchase Price of Maize

Independent variable		Period Round 1 Nov 94 - Feb '95	Round 2 Mar '95 - Jun '95	Round 3 Jul '95 - Oct '95
Intercept	α	20.22	20.41	23.57
		(1.12)	(0.67)	(0.84)
d	β_1	6.60	7.04	2.78
		(2.26)	(1.16)	(1.30)
d^2	β_2	-2.18	-2.23	-0.466
		(0.97)	(0.46)	(0.48)
q	β_3	-0.646	-0.385	-0.442
		(0.30)	(0.21)	(0.12)
t	β_4	-3.16	-3.77	-3.10
		(0.41)	(0.46)	(0.30)
g	β_5	-0.618	-0.897	-0.031
		(0.50)	(0.72)	(0.63)
h	β_6	-1.49	0.166	-1.38
		(0.31)	(0.276)	(0.26)
σ_u^2		0.959	0.063	0.446
		(0.49)	(0.086)	(0.24)
σ_e^2		9.69	5.84	5.75
		(0.47)	(0.39)	(0.32)
ρ		0.09	0.011	0.07
N		850	460	664
Log Likelihood				
Multilevel		-2179	-1060	-1522
OLS		-2201	-1061	-1534

Note: Standard errors in parenthesis; σ_e^2 and σ_u^2 are always positive so *z*-score is one tailed.

The constant term, α, indicates the 'basic' price of grain, i.e. a household in Buhera town buying from Buhera depot/market. The constant term in the first round estimation is not significantly different to the z$18.79 price at which the GMB was selling during the entirety of the first round. Thus, in the first round, at least, the model confirms expectations that it is the GMB's depot which is anchoring the price level. In June, the GMB price rose to z$21.45. The impact of the GMB's price rise would not affect all transactions in the second period as the Board set the price in the middle of the period. It is impossible to differentiate the households who purchased before the price rise from those purchasing afterwards. The absolute value of the constant term, however, does indicate the importance of the Board's selling price as the intercept remains in the region of the GMB price.

There is evidence of a price rise between the second and third rounds. The constant term rose by 20%. This can explained by the 14% rise in the GMB selling price of May 1995. However, the constant term is significantly higher than the GMB price in round 3 (GMB price was then z$21.45).

Other factors in the model estimate the effect on price of distance from the depot and the channel which the purchaser used when buying. The first two variables, distance and distance-squared, investigates whether a simple model of price formation across space is compatible with the data. The model encapsulates a spatial equilibrium term (β_1) and a non-linear component, perhaps capturing transport bulking opportunities (β_2). Evidence of the importance of the GMB's pricing policy is further provided by these co-efficient on the distance from the GMB. The distance variable has a significant positive effect on all estimates. Thus, there appears to be evidence in support of the spatial arbitrage pricing rule. However, the magnitude of the effect is clearly diminished by round 3. The coefficients on distance are insignificantly different across the first two rounds. However, the third round sees a significant fall in the cost-distance ratio.

The distance-squared term has a significant negative impact on price. This implies that cost of transfer has a quadratic relationship with distance. It is difficult to make firm conclusions about this parameter estimate as the term is insignificant in the third round and in size is less than a third the size of the coefficient of distance. Thus, only at large distances, in the first two rounds, does the distance-squared term affect the price level.

The coefficient on q indicates the impact of the quantity of maize purchased in a transaction. Buying grain in larger quantities has the expected negative effect in two of the periods. Large purchases would expect a discount, both because of the added leverage for the purchaser over the seller and because the purchaser has a greater incentive to shop around and get the lowest price.

The equation also considers the cost difference of three alternatives to the private local market: purchasing from a neighbouring household (the term β_6 measures the price effect of this), purchasing from the GMB (the term β_5 measures the price effect of this) and of travelling to a distant market (the term β_4 measures the price effect of this). The source of purchase is perhaps the most interesting result. Buying directly from the Board's depot does not affect the price paid. Thus, though price will be determined by the distance of the purchaser from the depot, the purchaser actually visiting the depot personally and buying directly from the Board would tend not to realise a higher or lower price. This is evidence that private traders, the main alternative to the GMB depot, are pricing on the basis of GMB price plus a cost of transfer factor. This is further evidenced by the coefficient on the transport factor. In all the estimates, when the purchaser used motorised transport to move purchased grains to the household, this discounted the purchasing price by over z$3 per tin. As noted earlier, the survey asked households how much they spent on the motorised transport (bus was the preferred mode of transport). Households actually paid on average z$4.13. Clearly, there may have been other benefits for the household in making the purchase trip - the trip may have combined other business - but for the present analysis those aspects cannot be assessed. The act of going to a distant area to purchase maize does not appear in itself to lead to significant price discounts.

When a household buys from a neighbour, however, significant price reduction is observed. Inter-household purchases give a 3% discount on the average price that households paid. This is entirely consistent with the model predictions discussed earlier. The household who sells to a neighbour can expect the low f.o.b. price for their grain if they were to sell to the external market. The opportunity to sell to a neighbour allows this price difference to be kept by the two households and some discount on the price can therefore be anticipated.

5. Discussion

This chapter has investigated the behaviour of a rural liberalised market across space at a time of food deficit. The grain marketing system of Zimbabwe had been heavily controlled for some years and one of the reasons for the freeing up of restrictions on the movement of grains had been the perverse impact of market control on rural deficit areas. A body of evidence had emerged in the 1980's and early 1990's indicating that the marketing system, while being highly effective in channelling grain out of producer areas and into the cities, had greatly added to rural food insecurity. This resulted from the marketing board's inability to move grains directly between rural areas. The routing of grains through cities added to the cost of grains. The rural areas where deficits are a regular feature were often poor and so least able to afford the consequent rise in the price of staples.

One hoped for consequence of market liberalisation was the emergence of private traders to more directly link areas of deficit to areas of surplus. Traders are viewed as more flexible than the marketing board and so more likely to be aware of the gaps in the marketing system. Entry into the food marketing system has been a feature of newly liberalised marketing systems in many developing countries. However, entry has been limited to the niches which employ little initial capital. Wholesaling, storage and long-distance transportation - the areas with the largest setting up costs - have remained in the hands of the large traders that existed in the pre-liberalisation era. These large traders were contracted by the marketing boards to undertake marketing activities in the more remote areas and so had made many of the investments needed for large-scale trading.

The present research concurs with these general findings regarding trader entry. The larger-scale traders in Buhera District had previously been Grain Marketing Board registered buyers. Entry into this part of the marketing system has not been significant while entry into the low-capital roles of grain retailing is observed. Further, the research adds to the understanding of the post-liberalisation marketing system from the perspective of the food deficit rural household. There has been a very real shift in the ways that grain deficit households source their staples. Liberalisation has allowed private traders to open channels which did not exist in the past. Long-distance movement of grains from areas of surplus is the preserve of the larger traders. To secure sources of grain requires contacts and the associated storage and distribution systems. The larger traders have built on their network of agents in surplus areas who can purchase grain to be shipped into a deficit region.

Some of the new channels used by deficit households involve new entrants into the marketing system without requiring them to make large initial investments. The GMB plays a pivotal role in allowing this type of trading. The GMB acts as a source of grain, i.e. the GMB wholesales grain. Procurement of grain is costly requiring the private trader has contacts in surplus food areas and transportation and storage. The GMB supplies the small-scale retailer with negligible additional costs of procurement on top of the depot purchase price.

As a result, small-scale traders can enter the market periodically to challenge the large-scale traders. Some small-scale traders were farming households which would indulge in trading activities more as a response to the behaviour of the large-scale traders. They thus act in preventing monopoly power being used by the large-scale traders. The GMB, in its role of wholesaler of grain, has facilitated the entry of small-scale traders.

The general spatial patterns in the grain market observed in section 3 are borne out in econometric analysis. A multilevel modelling framework has been use to better analyse the clustered structure of the data. This structure has resulted from the spatial stratification that was used in the sampling strategy. The price of grain purchased by a purchasing household is explained largely by the household's position relative to the GMB depot. As distance from the depot increases, the price level rises reflecting the cost of transfer. Purchasing directly from the depot made no significant difference to the price that the household paid. Also, incurring transfer costs and so enlarging the number of markets from which the household purchased significantly discounted the price the household paid, but by less than the additional transport costs. This 'pivoting' role of ward 5 - the ward which contains the GMB depot - is not replicated when the distance is measured from the other sample wards.

The results suggest that the price paid by the household was essentially determined by the c.i.f. cost of GMB grain in the particular location of the household. This is further supported by the way that households knew the price at which the GMB depot sold grain despite not actually purchasing from the depot. If the price deviated too much from the GMB c.i.f. price in a local market, households would know this. This would then precipitate spatial arbitrage. Thus, the analysis indicates the pivotal role of a public sector marketing board in a liberalised market may be performed by it being an external market - a backstop, in the terminology of the optimal control model of chapter 4.

6. Concluding Remarks

This chapter indicates that the new opportunities for trading channels offered by liberalisation have been realised. Direct channels between deficit rural areas and surplus areas are being established. In the drought conditions of 1994-95, the availability of grain would have been increased by these new developments. The research also identifies two roles that a public sector marketing board has in the structure of the marketing system of a rural deficit area.

Firstly, the marketing board supports the entry of the small-scale trader into the market. By offering a source of grain without considerable costs of procurement, the small-scale retailer can quickly establish competition to other operators in the market. Exit is equally easy. This hit-and-run option available to the entrepreneur with relatively little capital acts to moderate the monopoly power of the large scale traders. Anecdotal evidence from the present survey suggests that this is an option made some use of in the more remote parts of the study area.

A second effect of the public sector marketing board is in the anchoring of price. This is undoubtedly related to the first role: the credible threat that a small-scale trader will enter the market should a larger trader appear to be monopoly pricing acts as a deterrent against over-pricing. The empirical findings regarding price across the district suggests that the price paid by households for their maize was independent of the source of supply and largely determined by the distance from the depot of the grain purchase. Further research is required to establish what occurs in the pricing structure when the GMB depot is not participating in trade.

Appendix to Chapter 5

Table A1
Determinants of Price of Maize in Sample Wards
Round I

Ward		2	13	15	16	18	21	23	28	30
Co-efficient										
Int'cept	α	19.7	25.0	25.3	24.7	24.2	25.3	24.4	24.2	24.2
		(0.9)	(1.4)	(1.4)	(1.7)	(1.8)	(1.9)	(0.9)	(0.7)	(0.9)
d	β_1	6.0	-4.3	-5.2	-3.6	0.9	1.7	-1.3	2.3	2.4
		(1.4)	(3.4)	(4.0)	(4.2)	(5.2)	(2.1)	(5.1)	(1.5)	(1.4)
d^2	β_2	-1.7	2.6	3.1	2.3	-1.5	-0.9	-2.4	-2.1	-1.6
		(0.5)	(1.8)	(2.4)	(2.2)	(3.2)	(3.3)	(1.1)	(0.7)	(0.5)
q	β_3	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
t	β_4	-3.2	-3.1	-3.1	-3.1	-3.1	-3.2	-3.2	-3.1	-3.2
		(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
g	β_5	-0.6	-0.8	-0.8	-0.8	-0.7	-0.7	-0.7	-0.7	-0.7
		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
h	β_6	-1.4	-1.7	-1.7	-1.7	-1.7	-1.5	-1.7	-1.4	-1.7
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
σ_u^2		0.53	2.04	2.14	2.18	2.10	1.72	0.57	0.40	0.49
		(0.3)	(1.0)	(1.0)	(1.0)	(1.0)	(0.8)	(0.3)	(0.2)	(0.3)
σ_e^2		9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69
		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
ρ		0.05	0.17	0.18	0.18	0.18	0.15	0.06	0.04	0.05
N		850	850	850	850	850	850	850	850	850
Log Likelihood		-2176	-2183	-2183	-2183	-2183	-2182	-2177	-2176	-2177

Note: Standard errors in parenthesis.

Table A2
Determinants of Price of Maize in Sample Wards
Round 2

Ward		2	13	15	16	18	21	23	28	30
Co-efficient										
Int'cept	α	20.9	23.6	24.1	22.2	22.6	25.3	26.8	26.1	25.6
		(0.8)	(1.1)	(1.2)	(1.1)	(1.2)	(1.8)	(0.8)	(0.7)	(0.7)
d	β_1	4.6	0.74	-0.32	4.66	3.21	-1.40	-3.34	-1.15	0.52
		(1.1)	(2.9)	(3.6)	(2.9)	(3.2)	(5.0)	(1.8)	(1.5)	(1.2)
d^2	β_2	-1.1	0.28	0.73	-1.56	-0.83	0.08	0.37	-0.51	-0.87
		(0.4)	(1.5)	(2.1)	(1.5)	(1.7)	(3.2)	(0.9)	(0.7)	(0.5)
q	β_3	-0.4	-.45	-0.45	-0.46	-0.46	-0.43	-0.44	-0.41	-0.40
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
t	β_4	-3.6	-3.5	-3.5	-3.4	-3.5	-3.5	-3.6	-3.6	-3.6
		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
g	β_5	-1.4	-1.5	-1.4	-1.5	-1.5	-1.4	-1.4	-1.5	-1.5
		(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
h	β_6	0.1	0.03	0.04	0.04	0.05	0.02	-0.01	0.04	0.04
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
σ^2_u		0.17	1.38	1.60	0.87	1.12	1.63	0.37	0.32	0.34
		(0.1)	(0.7)	(0.8)	(0.5)	(0.6)	(0.8)	(0.2)	(0.2)	(0.2)
σ^2_e		5.86	5.86	5.86	5.87	5.86	5.86	5.86	5.86	5.86
		(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
ρ		0.03	0.19	0.22	0.13	0.16	0.22	0.06	0.05	0.05
N		460	460	460	460	460	460	460	460	460
Log Likelihood		-1063	-1071	-1072	-1069	-1070	-1072	-1066	-1065	-1066

Note: Standard errors in parenthesis.

Table A3
Determinants of Price of Maize in Sample Wards
Round 3

Ward		2	13	15	16	18	21	23	28	30
Co-efficient										
Int'cept	α	24.9	26.5	27.0	27.7	26.0	25.9	26.1	26.7	27.6
		(1.1)	(1.0)	(1.0)	(1.0)	(1.5)	(1.6)	(0.9)	(0.7)	(0.7)
d	β_1	0.96	-2.55	-4.06	-5.88	0.91	2.30	2.30	1.09	0.17
		(2.1)	(2.5)	(3.0)	(2.4)	(4.5)	(4.6)	(2.1)	(1.5)	(1.1)
d^2	β_2	-0.24	2.02	2.95	3.77	-0.72	-2.20	-2.16	-1.37	-0.58
		(0.9)	(1.3)	(1.8)	(1.3)	(2.8)	(2.9)	(1.1)	(0.7)	(0.4)
q	β_3	-0.48	-0.51	0.51	-0.52	-0.51	-0.51	-0.47	-0.44	-0.44
		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
t	β_4	-3.09	-3.10	-3.13	-3.07	-3.12	-3.14	-3.16	-3.15	-3.10
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
g	β_5	-0.16	-0.22	-0.23	-0.39	-0.30	-0.29	-0.18	-0.08	-0.02
		(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)
h	β_6	-1.5	-1.5	-1.6	-1.6	-1.6	-1.6	-1.5	-1.4	-1.4
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
σ_u^2		0.80	1.05	1.15	0.68	1.53	1.36	0.64	0.41	0.35
		(0.4)	(0.5)	(0.6)	(0.3)	(0.7)	(0.7)	(0.3)	(0.2)	(0.2)
σ_e^2		5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
ρ		0.12	0.16	0.17	0.11	0.21	0.19	0.10	0.07	0.06
N		664	664	664	664	664	664	664	664	664
Log Likelihood										
		-1525	-1526	-1527	-1524	-1528	-1527	-1524	-1522	-1521

Note: Standard errors in parenthesis.

CHAPTER 6:

An Econometric Appraisal of Grain Purchases

1. Introduction

In chapter 4, the dynamics of grain purchases between two regions were modelled. To make the analysis of the model tractable, simplifying assumptions were made. These focused primarily on the grain purchasing behaviour of rural regions. In particular, a rectangular demand function was employed which characterised the consumption decision of the region as unitary unless price exceeded a choke price after which the quantity demanded fell to zero. This regional behaviour will here be critically appraised using data from the household sample survey. The household level analysis will be used to suggest the plausibility of the aggregated regional demand function.

Direct assessment of the validity of a rectangular regional demand function would prove difficult given the paucity of data regarding grain purchases at this aggregate level. This chapter will look at grain procurement decisions at the household level and identify whether the behaviour observed is motivated by factors other than price of grain, i.e. it is assumed that the price elasticity of grain demand is close to zero. The model presented earlier suggests alternative determinants of the behaviour of the households. In particular, the desire of the region to postpone purchases until the region's harvest has been exhausted (motivated by the postponement of the costs of transfer caused by late purchasing), suggest that the decision to purchase grain would reflect an assessment of household grain stocks. Thus, at the household level a negative co-efficient on the level of grain stocks in the purchases of the household would appear appropriate. The rectangular demand function also dichotomises between the quantity demanded and the decision to procure grain. If demanded, the model suggests a fixed level of grain will be procured. The determinants of this fixed level are not explicitly noted. However, indicators of household size would appear plausible factors as grain purchases are primarily for subsistence of the family.

The chapter initially describes the sample survey data utilised in this chapter's analysis. The econometric estimation of quantity purchased undertaken in this chapter uses methods applied to censored data. It is the way that a household decides when and how much to purchase that underpins the conclusions of this chapter. The specification of the econometric model is therefore exhaustively tested so that the form of the decision to purchase can be provided with as much confidence as possible.

Censoring occurs when a sub-set of observations of the dependent variable are fixed at a certain value and there is complete information regarding the independent factors. This phenomenon occurs when the dependent variable is limited by some value either from above or below. In the present case, grain purchases are censored at zero. The data is censored because all explanatory data is present about those households who do not purchase grain. Thus, the effect of the censoring is that we are missing how much the non-purchasers did not want to purchase grain - a negative demand for grain is not exercised. Likelihood estimation techniques have been developed to empirically model censored data.

However, the literature on these parametric models of censored data has highlighted that the techniques rely on restrictive and testable assumptions about the distribution of the error term. In this chapter, I perform a series of specification tests on the standard maximum likelihood estimates and find the parametric form of the model is not well-specified. As it is the form of the disturbance term which is being questioned, estimation methods are then applied which make fewer assumptions about the distribution of the error term. These semiparametric models parameterise the functional form of the regression, allowing the disturbance term to be modelled as nonparametric.

2. Survey details

2.1 Survey area and data collection

The study area, Buhera District, lies 100 km south of Harare in Manicaland Province. The district supports a relatively high density of farmers on some of the least productive lands of Zimbabwe. The main staple crops farmed by Buhera households are maize, pearl millet and finger millet with groundnuts and sunflower being prominent cash crops. As most households in the district farm without irrigation, when rains are poor household production falls short of annual consumption requirement.

Over a year, beginning in November 1994, a sample of 354 households from across the district were interviewed. Nested stratified sampling was undertaken. At each stratification, units were randomly selected from each strata weighted across strata by population distribution across the strata. Three variables were used: agroecological zone (3 in the district), access to health facilities (2 types, near and far) and access to water (2 types, near or far). From the final stratification - twenty villages - households were randomly selected with each household in the village having an equal probability of being chosen. In appendix 1, further details are given.

In November 1994, these households were asked about their stock of stored staples. This was repeated three times at four-monthly intervals until October 1995. Also, the households were asked about in-flows and out-flows of the main staples over the period. This covered purchases, harvested production, government grain loans, sales and indirect household consumption (brewing and animal feeds). Harvest occurred in the middle of the survey period and the quantity of household production of staples was noted. Also, households were asked to estimate the quantity of grains consumed over a normal year. For simplicity, quantities of grains of different type - more than 90% was white maize, with pearl and finger millets making up the rest - were aggregated with unit weighting. Thus, by the end of the year, grain stock levels and main grain flows had been assessed for the sample households with 296 households completing every round of the survey.

2.2 Sources of grain in rural Zimbabwe in 1994/95

Zimbabwe's grain production system is predominantly rainfed and the 1994/95 rains were particularly poor. The rainy season usually begins in October, but by the end of 1994, there had been no significant downpours for most parts of the country. The result was a massive shortfall in aggregate supply with many households harvesting little or no production. Hence, own production made a smaller portion of annual consumption needs than in an average year. In the year from November 1994, own production by the average sample household contributed only forty per cent of household consumption.

Research has indicated that where production proves insufficient, purchases of grain replace the shortfall (see Heddon-Dunkhorst (1990); Corbett (1994)). There has been a pronounced change in the nature of grain sellers since the market liberalisation policy the government initiated in the early 1990s. Prior to this, laws constrained the private movement of grain across the country making the government owned marketing board the main wholesaler of grains. The workings of the marketing system ran counter to the needs of deficit households in the rural areas. Through the effective channelling of grain from rural areas to urban and export markets, grain purchases by rural deficit households were made relatively more expensive (Jayne and Rukuni (1995)).

The poor harvest of 1994/95 was the first opportunity for rural households to use private channels to meet shortages. In the year, forty-one per cent of annual consumption requirements were met by purchases of grain (see the previous chapter and Vaze et al. (1996) for details of the extent to which traders, households and other agents have adapted to the changed situation).

In the second half of 1995, the Government of Zimbabwe instigated the grain loan scheme to meet the shortage of grain that the drought caused. There was a high up-take level: the loan contributed over eighteen per cent of the households' annual grain needs. Households are expected to repay the loans when surplus rural stocks are restored.

2.3 Variables used and summary statistics

The variables used in this chapter form a small subset of the data collected over the survey. Godfrey[7] (footnote overleaf) notes that many of the limited dependent variable class of models have very different properties when the number of regressors is high. In particular, Monte Carlo simulations of specification tests that have validated their use, have usually only used a small number of explanotary variables. Godfrey finds the performance of the Breusch-Pagan tests is poor when the number of explanatory variables is high.

Also, the computation of the various models employed here is made more difficult if a large number of variables are employed. For example, simplex maximisation routines will be used later. These work in a K-dimension space, where K is the number of independent variables. The time take for the simple computation increases at an exponential rate as K increases.

Table 1 summarises the variables used in this chapter's analysis. The data appendix at the end of the thesis provides further details on collection and pre-processing of this data. In the model of chapter 4, the level of grain stocks at the start of the period is expected to influence the level of grain purchases. There, the regions are assumed to enter the market when their own stocks of grain are low. In the model, consumption is assumed to be one unit of grain per period of time.

This normalisation is relaxed in this empirical analysis by allowing the consumption needs of the household to enter the left-handside of the estimated regression. Annual harvest is the main driving force behind the model. This variable is PROD. Finally, WEALTH has been calculated to identify the household's economic status in terms of the domestic assets that the household has accumulated. A high level of domestic asset wealth is equated with a high income.

Table 1

Summary statistics of non-standardised data

	Mean	S.d.	Skew	Kurt	Min	Max	Cases
Dependent Variables							
Purchases Round 1[1]	1.53	1.73	1.5	5.9	0.0	10.8	333
Purchases Round 2[1]	1.08	1.43	1.8	7.1	0.0	9.1	305
Purchases Round 3[1]	1.62	1.77	2.7	16.2	0.0	13.9	315
Explanatory Vars							
Grain Stock Rnd 1[1]	2.44	3.14	2.5	12.0	0.0	22.8	343
Grain Stock Rnd 2[1]	1.27	1.83	2.4	9.8	0.0	12.0	323
Grain Stock Rnd 3[1]	1.75	2.74	3.1	14.8	0.0	18.9	279
Annual Cons[1]	10.61	6.68	2.2	9.9	1.7	45.5	325
Annual Production[1]	4.99	9.66	4.3	28.1	0.0	88.9	328
Wealth[2]	1.53	1.19	1.2	4.0	0.0	5.7	349

[1]All quantities measured in bags of grain (100kg).

[2]See data appendix.

In estimating all models, variables are standardised. For the continuous dependent variables, quantity purchased in each period, all observations are divided by the standard deviation of the variable in each round. This sets the standard deviation to one, but maintains the zero observations that results due to

[7] Les Godfrey, University of York. Post-seminar discussion, Edinburgh, March 1998.

censoring. For the independent variables, the standardisation involves the subtraction of the mean and then the division by the standard deviation of the variable. The resulting independent variable has a mean of zero and a standard deviation of one.

3. The Censored Regression Model

3.1 Censored data

Economic measures are often continuous and unbounded in the area of interest. Such properties of a variable make empirical analysis tractable and allows assessment of the factors impacting on the particular measure. For example, the price of a commodity relative to another may be measured and then used as a dependent variable in econometric analysis. However, in many situations, such measures of an economic action are bounded and their use as dependent variables is limited by the bounds. Judge et al. (1982) use the example of shooting at a target. If the target is hit, the distance from the centre can be measured. However, when the shooter misses the target, the bullet is lost and only a miss can be recorded. A general formulation is:

$$y^* = \beta' x + \varepsilon \qquad (1)$$

where y^* is a dependent variable, x a matrix of K independent variables, β is a vector of unknown parameters and ε is a disturbance term. This is censored at zero so that negative values of y^* are observed as zeros. The resulting variable, y, is the actual observed data and is given by:

$$y = \max(0, y^*) . \qquad (2)$$

In the present case, the desire not to purchase grain is bounded at zero (if sales of the good are ignored) so that the consumer with the strongest preference not to purchase cannot readily be differentiated from all those consumers who chose not to purchase but had a considerably lower aversion to grain purchasing. If the characteristics of the consumer are available so that the factors impacting on the decision not to purchase can be assessed, the data is said to censored. While the independent variables affecting the consumers choice have been collected, the dependent variable has been bounded to a particular value (in this case zero) for some sub-set of the sample.

3.2 Parametric estimation of censored data

3.2.1 Tobit estimation

The Tobit model (Tobin (1958)) provides a log-likelihood framework to estimate regressions where the dependent variable is censored. It is assumed that the error term in equation 1, ε, is normally distributed. Estimation proceeds through splitting the sample into non-limit ($y>0$) and limit ($y=0$) observations. Firstly, a line is fitted to the non-zero observations. Ordinary least squares would neglect the upward bias caused by the truncation so maximum likelihood method is employed which takes into account that a portion of the observations will fall on the 'wrong' side of the bounds. In the truncation estimate, the density of a random observation, $i=1,.., n$, is the probability of a non-zero estimate given that the below zero tail cannot be observed, i.e.:

$$f(y_i \,|\, y_i > 0) = \frac{f(y_i)}{P(y_i > 0)} \qquad (3)$$

where P is the probability function and $f(.)$ is the probability density function (p.d.f.). When the variable is normally distributed, this ratio of p.d.f. to c.d.f. (cumulative distribution function) becomes:

$$f(y_i | y_i > 0) = \frac{1/\sigma\, \phi[(y_i - \beta' x_i)/\sigma]}{1 - \Phi[-\beta' x_i/\sigma]} \qquad (4)$$

where σ is the standard deviation of the disturbance term. Φ (.) and ϕ(.) are the c.d.f. and p.d.f. respectively of a normal distribution.

Now, consider the limit sample of the observed purchases, where y_i is zero. The density function of this is given by:

$$f(y_i^* \le 0) = 1 - \Phi\left(\frac{\beta' x}{\sigma}\right) \tag{5}$$

Here, the value zero is taken by all y^* below or equal to zero.

The likelihood function is the joint density of n observed purchase quantities and the N-n zero purchases. This is logged to give the log-likelihood function, L_C:

$$\begin{aligned} \ln L_c &= \sum_{y_i>0} -\frac{1}{2}\left[\ln 2\pi + \ln\sigma^2 + \frac{(y_i - \beta' x_i)^2}{\sigma^2}\right] + \sum_{y_i=0} \ln\left[1 - \Phi\left(\frac{\beta' x_i}{\sigma}\right)\right] \\ &= \frac{-n}{2}\left(\ln 2\pi + \ln\sigma^2\right) + -\frac{1}{2\sigma^2}\sum_{y_i>0}(y_i - \beta' x_i)^2 + \sum_{y_i=0}\ln\left[1 - \Phi\left(\frac{\beta' x_i}{\sigma}\right)\right] \end{aligned} \tag{6}$$

The first line indicates the derivation of the Tobit log-likelihood function. The first summation is the likelihood of observing a positive observation given a normally distributed disturbance term, i.e. equation 4. The second summation considers the probability of a limit observation and is equation 5. Ameniya (1973) shows that, while difficult in practise, maximisation of (6) produces estimates which are consistent. Olsen's reparamatisation, substituting $\theta=1/\sigma$ and $\gamma=(1/\sigma)\beta$, considerably simplifies the problem so that the Tobit model can be estimated using standard numerical gradient methods of maximisation, such as Newton-Raphson, on the likelihood function given in Olsen (1978):

$$\max_{\beta_T} \ln L_c = \sum_{y_i>0} -\frac{1}{2}\left(\ln(2\pi) + \ln\theta^2 + (\theta y_i - \gamma'' x_i)^2\right) + \sum_{y_i=0}\ln\left[1 - \Phi\left(\frac{\gamma' x_i}{\sigma}\right)\right]. \tag{7}$$

Having calculated the parameter estimates, an estimate of the covariance matrix is more complex than the hessian of the likelihood function calculated at the parameter estimates, H, because of Olsen's transformations. The Tobit covariance matrix, V_T, is given as JHJ' where (Greene (1997), p.966) J is a $(K+1)\times(K+1)$ matrix:

$$J = \begin{bmatrix} \frac{\partial\beta}{\partial\gamma'} & \frac{\partial\beta}{\partial\theta} \\ \frac{\partial\sigma}{\partial\gamma'} & \frac{\partial\sigma}{\partial\theta} \end{bmatrix} = \begin{bmatrix} \frac{1}{\theta}I & \frac{-1}{\theta^2}\gamma \\ 0' & \frac{-1}{\theta^2} \end{bmatrix} \tag{8}$$

3.2.2 Score tests for the error term

A problem with Tobit estimates is that they are generally inconsistent if the error terms are heteroskedastic or non-normal (Hurd (1979); Goldberger (1983)). The assumption that the errors are independently normally distributed is most commonly tested using Lagrange multiplier tests. Two will be focused on in the present work:

1. The disturbances in the model are homoskedastic;
2. The underlying disturbances in the model are normally distributed.

Petersen and Waldman (1981) give a test for the homoskedasticity of the Tobit model. In their test, the variance of the disturbance term is assumed to be exponentially related to some subset size *L*, *w*, of the independent variables, *x*:

$$\sigma_i^2 = \sigma^2 \cdot e^{\alpha w_i} \tag{9}$$

This specification of the disturbance term can be substituted into the log-likelihood function for the tobit estimation (equation 6) and the hypothesis of homoskedasticity, α=0, can be tested. The LM statistic is calculated using the gradient of the unrestricted model evaluated at the restricted parameter vector. The derivatives of the likelihood function with respect to the parameters can readily be ascertained by differentiating equation (6) to give (Greene, 1997, p.969):

$$\ln L_\beta = \sum_{i=1}^{n} a_i x_i \, , \quad \ln L_{\sigma^2} = \sum_{i=1}^{n} b_i \, , \quad \ln L_\alpha = \sum_{i=1}^{n} \sigma^2 b_i w_i \tag{10}$$

where z_i is 1 for positive *y*, zero otherwise and:

$$a_i = z_i \left(\frac{\varepsilon_i}{\sigma^2} \right) + (1 - z_i) \left(\frac{(-1)\lambda_i}{\sigma} \right),$$

$$b_i = z_i \left(\frac{\varepsilon_i^2 / \sigma^2 - 1}{2\sigma^2} \right) + (1 - z_i) \left(\frac{(\beta' x_i)\lambda_i}{2\sigma^3} \right),$$

$$\lambda = \frac{\phi(\beta' \mathbf{x}/\sigma)}{1 - \Phi(\beta' \mathbf{x}/\sigma)}.$$

The term λ_i is the inverse Mill's ratio or hazard function and equals the ratio of the marginal (ϕ) to the cumulative (Φ) normal distribution when the bounding of the quantity purchased (at zero in this case) bites. It measures the extent of the tail of the normal distribution which has been truncated through the setting of a zero bound.

All the gradients are calculated for parameter values where the null hypothesis that $\boldsymbol{\alpha}=\mathbf{0}$ holds is assumed. The calculated test statistic essentially calculates the increase in the likelihood for small changes in α away from zero. It may be thought that this would be entirely based on the value of L_α and testing whether this is significantly different from zero. However, this would ignore that when heteroskedasticity is allowed, the other parameter estimates in the model - β and σ - would also be converging to their probabality limit. A statistic taking this into account is:

$$\text{LM} = \mathbf{i}'\mathbf{G}[\mathbf{G}'\mathbf{G}]^{-1}\mathbf{G}'\mathbf{i} \tag{11}$$

where $\mathbf{G}$ is a matrix of derivatives with ith row (L_β, L_{σ^2}, L_α) and $\mathbf{i}$ is a vector of 1's which has the same number of rows as there are observations, n. The matrix $\mathbf{G}$ hence consists of K columns which evaluates the gradient with respect to the parameters of equation 10, a single column for the gradient with respect to the variance and L final columns which evaluate the effect of the null hypothesis. The statistic is χ^2 distributed with the same numbers of degrees of freedom as elements in α.

Testing whether the disturbance term is normally distributed uses a property of the normal distribution - that its skewness and kurtosis take the values 0 and $3\sigma^4$ respectively. The tests then becomes a conditional moments test (Greene, 1997, p.534-6) with null being that the errors, e_i, are normally distributed:

$$\begin{aligned} &E(e_i^3) = 0; \\ &E(e_i^4 - 3\sigma^4) = 0 \end{aligned} \tag{12}$$

The difficulty of the test is that a complete set of error terms is not available for the Tobit regression considered here. In the Tobit model, the difference between observed purchases and estimated purchases can only be estimated for the households who made a purchase. When testing for normality, a complete series for the error term is needed. Chesher and Irish (1987) provide error estimates for the Tobit regression. Their estimates for the Tobit model is:

$$e_i = z_i\left(\frac{y - \beta'\mathbf{x}_i}{\sigma}\right) + (1 - z_i)(-1)\ \lambda_i . \tag{13}$$

It can be readily seen that in the case of non-limit observations, the Chesher-Irish estimates of the error take a familiar form. With the limit observations, left of the addition in (13), the estimated error is the inverse Mill's ratio. With an estimate of the errors, the test for normality follows a similar course to that for the test for homoskedasticity. Again, it is incorrect to merely check that the two hypotheses are jointly true as this ignores that under the null, the other parameters will be converging to their probability limits. A matrix G appropriate for the current specification test would have rows of the form: (L_β, L_{σ^2}, e_i^3, $e_i^4 - 3e_i^2$). Calculating the test statistic in equation (11) would give a result which would be distributed $\chi^2(2)$.

3.3 Semiparametric estimation of censored regressions

3.3.1 Censored Least Absolute Deviations (Powell, 1984)

It is commonly acknowledged that the Tobit maximum likelihood estimator of a censored variable is sensitive to miss-specification of the distribution of the disturbance term. Hurd (1979) highlights problems of Tobit estimation associated with heteroskedasticity, while Goldberger (1983) considers the use of the method when the normality assumption does not hold. Powell (1984) considers semiparametric estimates of the censored variable and provides an alternative means to estimate a regression with censoring which does not impose normality or homoskedasticity on the distribution of the disturbance term.

The estimator uses the observation that medians are preserved by monotone functions. Hence, in the censored data, the median of the observations is identical before and after the censoring (the function max(0, z) is a monotone function) (Deaton (1997)). This is not the case for the mean function which is necessary for other estimates. Censoring left of zero biases the mean positively. By using a method which minimises the absolute deviations, rather than maximising a likelihood function, one can use this property of the median to derive consistent parameter estimates by treating the disturbance term nonparametrically. This means that parameter estimates are robust to non-normally distributed errors. The method also has the advantage of being relatively easy to calculate. Powell's censored least absolute deviation (CLAD) methodology also provides an estimate of the covariance matrix allowing Hausman (1978) specification tests to be performed.

More formally, Powell's suggests that the median function of max $\{0, y_i\}$ be estimated. In the censored model, the median can be written as max $\{0, \beta' \mathbf{x}_i\}$ so that Powell's minimisation problem becomes:

$$\min_{\beta_C} \sum_{i=1}^{n} \left| y_i - \max\{0, \boldsymbol{\beta}'\mathbf{x}_i\} \right| \tag{14}$$

This is a non-differentiable function so that conventional gradient optimisation methods cannot be used. Paarsch (1984) uses a grid-search to find the minimising vector of parameters. Here, the method used by Melenberg and van Soest (1996) is followed. They use a simplex algorithm devised by Nelder and Mead (1965). I rewrote the Fortran code for this algorithm in the mathematical package Gauss (algorithm source was O'Neill (1971)). The algorithm converges to a minimum quickly (less than thirty iterations). One problem with the minimisation is the difficulty of finding a global minimum. The function is not convex so that several local minima can be anticipated. Different starting conditions for the algorithm were employed to check for the presence of other minima. A more robust check has not been coded into the algorithm (though one has been suggested by O'Neill). Full code is appendix 2 and section 4 describes how the algorithm performs.

Unlike other nonparametric estimates, the solution of equation 8 requires few assumptions regarding the density function of the error term. Thus, no smoothing terms or banwidths need to be provided. However, this advantage of the methodology does not extend to the estimation of the CLAD covariance matrix. Powell (1984) suggests an estimation for the covariance matrix which requires an approximation to the density function of the disturbance term. Given the estimated coefficients of the covariates through solving equation 8, the error terms associated with each observation can be derived. A histogram of these errors would provide the basis for a density function. To approximate a continuous function for this, Powell suggests a smoothing function dependent on two parameters, λ and c. He suggests that the former takes the value -0.2. For c, experimentation is suggested. As these parameters affect the covariance matrix and not the parameter estimates, only the standard errors of the estimated parameters are changed by the choice made. The CLAD covariance matrix, $\mathbf{V}_C$, is given by $\hat{\mathbf{C}}_C^{-1}\hat{\mathbf{M}}_C\hat{\mathbf{C}}_C^{-1}$ where:

$$\hat{\mathbf{C}}_C \equiv 2(cn)^{-1}\sum_{i=1}^{n} 1(\boldsymbol{\beta}'\mathbf{x} > 0)1(0 \le u_i \le c)\mathbf{x}_i\mathbf{x}_i' \tag{15}$$

$$\hat{\mathbf{M}}_C \equiv (1/n)\sum_{i=1}^{n} 1(\boldsymbol{\beta}'\mathbf{x} > 0)\mathbf{x}_i\mathbf{x}_i' \tag{16}$$

where the function 1(.) is an indicator function, taking the value 1 when the condition in the brackets is true, zero otherwise, and $u_i = y_i - \boldsymbol{\beta}'\mathbf{x}$.

Paarsch (1984) investigates the performance of the CLAD estimate using Monte Carlo simulations. He uses a variety of distributions for the error term. The Tobit estimator performs as well as or better than the semiparametric estimator in the small samples that he considers (200 observations or smaller). The Tobit estimator, unsurprisingly performs very well when the error is distributed normally. There is evidence, however, that as the sample size increases, CLAD outperforms the MLE estimates when the error term has a fat-tailed distribution. This suggests that the CLAD is consistent but that this property is of the estimate is compromised by its low efficiency.

3.3.2 Hausman specification tests

Powell's estimates of the covariance matrix allow the Tobit and CLAD estimates to be compared. Hausman (1978) noted that if one estimate is consistent, but less efficient (the CLAD estimates), then it can be compared to the more efficient estimate for consistency. In particular, for the case where the Tobit estimate is compared with the CLAD estimate, the difference in the two estimates is tested using the following statistic:

$$(\mathbf{b}_C - \mathbf{b}_T)'(\mathbf{V}_C - \mathbf{V}_T)^{-1}(\mathbf{b}_C - \mathbf{b}_T). \qquad (17)$$

This statistic is χ^2 distributed with degrees of freedom equal to the number of estimated parameters. Newey (1987) gives further specification tests. A problem with (23) is that it is difficult to guarantee that the difference in estimated covariance matrices is positive semi-definite. If it is not, then the test statistic can become negative. Newey suggests an estimation for the difference in covariance matrices which is positive semi-definite for another semiparametric estimation method, STLS model (Powell (1986)). This gives a test statistic which avoids the negativity problem. Newey notes that a similiar statistic would prove difficult for the CLAD model versus the Tobit model.

4. The Two-Equation Model

4.1 Hurdle models and the two-equation specification

The Tobit specification is very restrictive. In particular, the separation of the decision to purchase from the quantity to purchase may be significant. As Fin and Schmidt (1984) have noted, an independent variable may affect the two decisions in opposite directions and this would be ignored in the Tobit specification. They cite the example of building insurance claims due to fire. Most buildings would be unaffected and so register a zero observation. A Tobit specification would appear appropriate. However, in the Tobit estimation, the estimate of the co-efficient on building age would be unable to differentiate between the impact of, for example, building age on the chance of a fire and the value of the payment after a fire. It could be hypothesised that older buildings would be more at risk of a fire. However, the damage to newer buildings could be more costly. Under such circumstances, an alternative two-equation specification has been suggested by Cragg (1971).

In the Cragg model, the level of insurance claim would be modelled in two stages. First, the event of a fire occuring is estimated as a binary variable. The variable z_i has been defined already (it takes the value 1 when y_i is positive, i.e. a claim is made, and zero otherwise) and this is the dependent variable in the first equation. The second equation then models the value of the claim once a fire has meant a claim has been made. Thus, only a sub-sample of the households - those where $y_i>0$; $z_i=1$ - are considered in the second model.

4.2 Parametric estimation of the two-equation model

4.2.1 Binary choice model

As noted earlier, parametric estimation techniques parameterise both the functional form of the regression equation and the disturbance term. Thus, assuming that the functional form of the regression is a linear combination of the independent variable, the probability of a particular observation can be written:

$$\Pr(z_i = 1) = \Pr(\psi'\mathbf{x}_i + \varepsilon_i > 0) = \Pr(\ \varepsilon_i > -\psi'\mathbf{x}_i\ )\ ; \qquad (18)$$

$$\Pr(z_i = 0) = 1 - \Pr(z_i = 1) = 1 - \Pr(\ \varepsilon_i > -\psi'\mathbf{x}_i\ )\ . \qquad (19)$$

where ψ is the parameter vector to be estimated and Pr(.) the probability function. By assuming a normal distribution for the disturbance term, the probability function can be parameterised in terms of the cumulative density function of the normal distribution $\Phi(.)$:

$$\Pr(z_i = 1) = \Phi(\psi'\mathbf{x}_i); \tag{20}$$

$$\Pr(z_i = 0) = 1 - \Phi(\psi'\mathbf{x}_i). \tag{21}$$

This the Probit model and its log-likelihood function can be written down as the sum of the logs of the probability of outcome, conditional on the actual observed outcome:

$$\max_{\psi_P} \ln L_P = \sum_{z_i=0} \ln\left(1 - \Phi(\psi\mathbf{x}_i)\right) + \sum_{z_i=1} \left(\Phi(\psi\mathbf{x}_i)\right). \tag{22}$$

The first summation is the likelihood of observing a zero, given a zero is actually observed; the second summation indicates the likelihood of a purchase of grain, conditional on a purchase being made.

Estimation of this model is a straightforward application of any gradient method and the inverse of the hessian matrix evaluated at the maximum likelihood estimates provides an estimate of the covariance matrix $\mathbf{V}_P$. The Gauss code used to maxmise equation (22) also provided an estimate of the hessian so that the covariance matrix was derived through use of the hessian matrix. Other estimates of the covariance matrix are detailed in Greene (1997, p.883-4) based on the gradient of the likelihood function at the estimated parameters.

Lagrange multiplier test statistics for homoskedasticity and normality in the error terms is similar to the Tobit test outlined in section 3.2.2 of this chapter, but is much simplified (see Greene, 1997, p.887).

4.2.2 Estimation of the truncated regression

Truncation occurs when the sample only includes those registering a positive value. This means that the characteristics of the non-participants are not within the sample. Returning to the example of insurance claims, one can imagine a situation where the researcher is constrained to collect data only at times when a claim is made. Thus, necessarily, a complete dataset will only exist for claimants so that, for the claimants, the various independent variables are known. However, where building owners have not made a claim, the values of the variables would be unknown.

When truncion is modelled econometrically, the value of the dependent variable is parameterised as in the Tobit model (equations 1 and 2):

$$y_i = \beta'\mathbf{x} + \varepsilon_i. \tag{23}$$

In the parametric model, the standard assumption is that the disturbance term is normally distributed, $\varepsilon_i \sim N\ (0,\ \sigma^2)$. Noting that the inequality $y_i>0$ can be rewritten as $\varepsilon_i > -\beta' x_i$, the density of a the dependent varaible, $f(y_i| \ y_i > 0)$ can be derived (see equation 4). The log-likelhood becomes the sum of the log density functions across i:

$$\ln L_{Tr} = \frac{-m}{2}(\ln(2\pi) + \ln\sigma^2) - \frac{1}{2\sigma^2}\sum_{y_i>0}(y_i - \beta'\mathbf{x}_i)^2 - \sum_{q_i>0}\ln\Phi\left(\frac{\beta'\mathbf{x}_i}{\sigma}\right), \tag{24}$$

where m is the number of non-zero observations. Like the Tobit model earlier, estimation in this form is complicated and Olsen's reparametisation again provides a means to simplify the process. Setting $\theta=\sigma$ and $\gamma=\theta\beta$, the estimated likelihood function becomes:

$$\ln L^e_{Tr} = \frac{m}{2}\left[\ln(2\pi) + m\ln\theta\right] - \frac{1}{2}\sum_{i=1}^{m}(\theta y_i - \gamma'\mathbf{x}_i)^2 - \sum_{i=1}^{m}\Phi(\gamma'\mathbf{x}_i)\,. \tag{25}$$

The covariance matrix for this estimate, $\mathbf{V}_{Tr}$, is given as **JHJ**' where (Greene, 1997, p.966) **J** is a $(K+1)\times(K+1)$ matrix in equation 8 and **H** is the hessian matrix of the estimate log likelihood (equation 25).

4.2.3 Testing the Tobit specification against Cragg's

Lin and Schmidt (1984) compare the likelihood functions of the two stage model with that of the censored regression. Their analysis finds that the log-likelihood of the censored regression (6) is merely the sum of the likelihoods of the two-equation model, i.e. (22) and (24). Thus, the censored data estimation technique may be split into a dichotomous choice whether to engage in a particular activity and then a truncated decision regarding the extent of engagement. For the combining of the two decisions to be valid, two assumptions must hold across the two processes. Firstly, the vector of variables, x, that are used should be the same. Secondly, the co-efficients of the variables considered should not alter across the two decisions. i.e. $\psi=\beta$. If these two conditions hold then the censored data estimation technique side-steps the need for a two-stage analysis. However, if the decision to purchase is motivated in a different manner to the decision over the quantity to purchase, then the censored data estimation is inadequate. The latter restriction, that $\psi=\beta$, is testable with a log likelihood ratio test on the results of the three implied models (Probit, truncated and censored estimation using identical variables):

$$\Lambda = -2\left(\ln L_T - (\ln L_{Tr} + \ln L_P)\right). \tag{26}$$

This statistic is distributed with a χ^2-distribution with the degrees of freedom equalling the number of independent variables, K. Thus, the applicability of the tobit model can be readily addressed.

4.3 Semiparametric estimation of the two-stage model

4.3.1 Maximum score estimation (Manski, 1975)

A semiparamatric estimator of the binary choice model which is commonly used is the maximum score method (MSCORE) orginally proposed in Manski (1975). Greene (1997, p. 902-4) gives extensive details of this method which attempts to maximise the predictive power of the estimator. Again the independent variables are combined in a specified function, i.e. the regression equation is parameterised. Usually the functional form of the equation is a linear combination of the independent variables. If, for a given vector of the independent variables $\mathbf{x}_i$, the predicted value is positive, then the prediction for the binary dependent variable is 1; otherwise the prediction is 0. The estimation technique proceeds by scoring the prediction of the dummy dependent variable against the actual observed behaviour.

Formally, the MSCORE estimator is based on the fitting rule:

$$\underset{\psi_M}{\mathrm{Max}}\, S(\psi) = \frac{1}{n}\sum_{j=1}^{n}((2\mathbf{z}_j - 1) - (1-2a)\,\mathrm{sgn}((2\mathbf{z}_j - 1)\psi)) \tag{27}$$

where a is a preset quantile and the sgn(.) function returns a 1 for postive values and a zero otherise. Note how the binary dependent variable is transformed to take the value -1 when $\mathbf{z}_j$=0; +1 otherwise. If the value taken by a is a half, then the MSCORE estimator maximises the number of times that the prediction has the same sign as $\mathbf{z}$. Note that the sgn(.) function is the same if all the terms of a parameter estimate are multiplied by a constant. Thus, the computed value for ψ_M is such that $\psi_M{}'\,\psi_M = 1$.

MSCORE estimations are coded into Limdep. Since there is no underlying likelihood functions behind this estimator, there is no information matrix to provide standard errors of estimates. The Limdep procedure uses bootstrapping techniques to compute some idea of sampling variability. Greene cautions that these estimates of the standard error are useful for little more than descriptive purposes.

5. Econometric estimation

5.1 Nelder-Mead simplex algorithm (Nelder and Mead, 1965)

Most of the econometric models indicated in the last sections can be estimated using the algorithms provided in proprietory software programs such as Limdep. In the case of the CLAD model, however, the estimated required the coding of a maximisation routine which did not make use of the gradient of the maximand. Nelder and Mead (1965) propose a simplex algorithm for the maximisation of a function which is discontinuous. This allows estimation of maxima where gradient based algorithms cannot be used. Consider a function $V(b)$ which is to be maximised at b, a K-length vector. Let { b_0, b_1, b_2, b_3 ....} be a series of estimates of the maximising parameter $b_{\max}$. Nelder and Mead propose a strategy to find b_i given an initial estimate of the parameter: b_0. The method first creates a simplex around this initial estimate. For this, the user provides a vector the same length as the parameter estimate, q. Each element of this is added to b_0 so that K vectors are formed. For example, if K is 3 and q=(0.1, 0.2, 0.3), then b_1= b_0+(0.1, 0, 0), b_2= b_0+(0, 0.2, 0) and b_3= b_0+(0, 0, 0.3). The size of the elements of q are determined by the metric used in each of the independent variables. This gives an initial simplex with K+1 points, the K vectors derived using q as well as the initial estimate.

The algorithm seeks to substitute the least successful parameter estimate, b_{i-K}, with a new estimate. In Figure 1, the possible candidates for this substitution are indicated when $K = 2$. In this case, the new estimate lies on the line which has the estimate b_{i-2} and the midpoint of the other two estimates, d. The estimate g lies between the b_{i-2} and d. The other three estimates - h, e and j - lie on the same line but at points 1.5, 2 and 3 times the distance between b_{i-2} and a. The point e is the reflection of b_{i-2} in the line that joins the other two (better) estimates. The choice of whether to take d, e, h or j depends on the following rules:

a) If e is not as good an estimate as any of the b's, i.e. $V(e)<V(b_{i-2})$, then g is chosen over h;

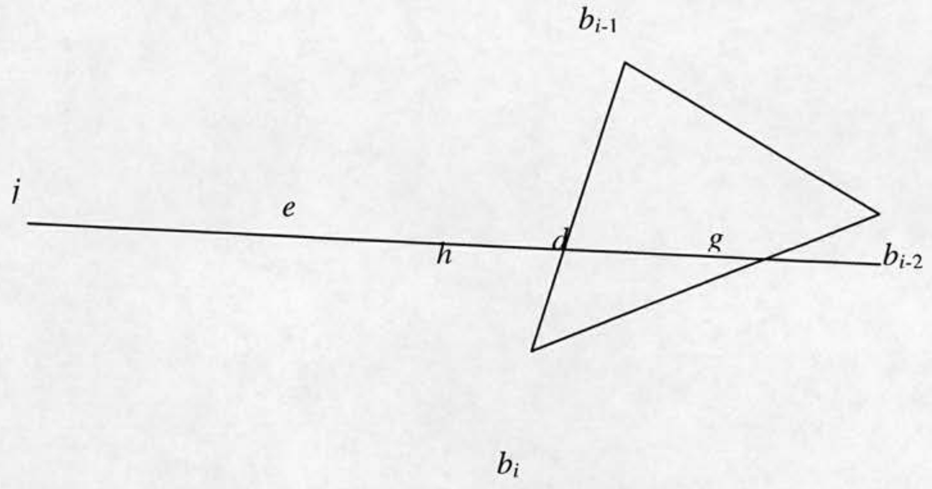
b) If e is a better estimate than any of the other three b's, i.e. $V(e)<V(b_i)$, and j is better then e, then the search is expanded to j (which is the furthest point);

c) If e is not as good an estimate as b_{i-1}, then h or g is chosen depending on (a);

d) Otherwise, chose e.

Figure 1

The Nelder-Mead Algorithm



5.2 Performance of algorithms

The estimation procedures used were either proprietary software modules from Limdep or coded by the author in Gauss. The full Gauss code is found in appendix 2. All the parametric models and the MSCORE model are found in the Limdep package. However, some of the specification tests used in the analysis of the parametric regressions are not performed by Limdep so I have written Gauss code. The major part of the code in the appendix is a routine to minimise functions which are not continuous, the Nelder-Mead algorithm described in section (5.1). To validate the use of this algorithm (and to verify that it does minimise well), the routine was benchmarked. The results from proprietory software packages estimating a regression which used a continuous maximand is compared to the results of the Nelder-Mead algorithm. Nelder-Mead is general enough to be able to estimate differentiable maximands. The choice of possible models to be used in this test is limited to the parametric models and I have selected the Tobit model for data from round 1. The two tables below presents the results of that preliminary analysis.

Table 2

Relative performance of algorithms on Tobit model

	Model estimated: Tobit		
	Newton (Limdep)	Newton (Gauss)	Nelder-Mead (Author code in Gauss)
S1	-0.47757	-0.47756	-0.47858
C	0.40872	0.40874	0.40666
W	-0.12715	-0.12720	-0.12795
P	-0.15350	-0.15349	-0.15541
Constant	0.55990	0.55995	0.55965
Sigma	1.24503	1.24498	1.23974
Log Likelihood	-419.251	-419.246	-419.251

Note: Round 1 data, Tobit likelihood function maximised.

Table 2 gives the estimates of the parameters for round 1 assuming a standard Tobit model. Both the Limdep and Gauss programs have been set to use the gradient method Newton-Raphson. The Limdep procedure 'TOBIT' initially estimates the ordinary least squares (OLS) estimates of the parameter vector. This estimate is then used as the start values in the gradient minimisation routine. Gauss does not come with a Tobit estimation routine. However, the replication of the Limdep analysis is possible. OLS estimates can be derived using matrix algebra and this can then be (manually) fed into the Gauss minimisation routine. I wrote Gauss code for this routine, which also calculates standard errors and some specification test statistics (this appears in the software appendix).

I wrote code for a Nelder-Mead simplex minimisation. The OLS estimates were used for the initial parameter estimate around which the simplex was constructed. Then the algorithm was run to find a minimising parameter with 200 iterations. This high number of iterations guaranteed a (local) minimum was found. The

Gauss code begins by defining the function to be maximised. This may be a standard loglikelihood function such as equation (7), the Tobit model, which is differentiable. However, the routine proceeds only using the value function defined, thus not requiring differentiation of the function to be minimised.

The shape of the initial simplex is an important initial parameterisation. A vector q is used to create the initial simplex. This has an element for each element of the parameter vector. The vector q is chosen by the analyst setting the expansion of the initial simplex about an initial estimate of the parameter. If an element in q is large, the initial expansion in the direction of the particular parameter estimate is large. As Nelder and Mead (1965) note, the amount which is added to the initial estimate in the direction of a particular parameter depends on the relative size of the units of the independent variables. As the independent variables were standardised so that the mean was zero and the standard error one, I assume that the metric for the different continuous independent variables is the same so that I use the same value in vector q for these variables (STOCK, CONS, WEALTH and ASSET). I experimented with values between 0.1 and 1. This would mean that the size of the initial simplex around the OLS estimates of the continuous variables is the same for these variables.

However, with the remaining two parameter estimates, the same metric cannot be assumed. For the estimate of the intercept, a different expansion in the simplex is used. The Tobit model also estimates the standard deviation of the disturbance term, sigma. I experimented with different values for the elements in q corresponding to the constant term and the sigma co-efficient. Thus q was of the form $(q_0, q_0, q_0, q_0, q_c, q_s)$. Table 3 gives the estimated loglikelihood for a variety of values of q.

Table 3

Nelder and Mead maximum loglikelihoods and q

Log Likelihood	q_0	q_c	q_s
-419.666	0.25	0.4	0.09
-419.273	0.25	0.4	0.08
-419.358	0.3	0.35	0.09
-419.412	0.3	0.4	0.07
-419.251	**0.3***	**0.4***	**0.08***
-419.299	0.3	0.4	0.09
-419.799	0.3	0.45	0.09
-419.320	0.35	0.4	0.08
-419.479	0.35	0.4	0.09

*Selected values for q for results in Table 2.

As can be seen from table 2, the Nelder and Mead algorithm does converge to the parameter values estimated using a Newton gradient method with reasonable accuracy. Parameter estimates are almost identical to the ones estimated by the gradient methods. However, the method is computationally demanding. Firstly, the number of iterations is very high. The log-likelihood function of the tobit model is easy to calculate so the time taken for an individual iteration is small. However, when more complex functions are maximised this clearly becomes a significant issue. A second computational aspect is the size of the simplex. Table 3 indicates some of the experiments that were done to find the right size of the simplex. The possible values for q are very high and testing each one multiplies the estimation time considerably.

6. Model Findings

6.1 Parametric estimation of censored regression

Table 4 presents results of parametric estimation of the censored regression using the data collected in the three rounds of surveying. The model estimates the quantity of grain purchased assuming that censoring occurs at zero. The top half of the table gives the parameter estimates and the standard errors of these estimates.

The intercept term is significant and positive in each of the three rounds. Remembering the independent variables are all normalised to have mean zero, this is consistent with the observation that more than half the households made grain purchases in each round. The positive intercept suggests that the average household would have purchased grain. However, a large drop in the value of the intercept estimate in the second round is clear. Remembering that this period could be considered as the harvest period of the year, this finding is unsurprising. Households have switched away from the market for supplies of grain at the time of the year when their own production is arriving.

Table 4

Tobit Estimates of the Quantity of Grain Purchased

		Round 1 (N=312)	Round 2 (N=287)	Round 3 (N=260)
		Co-efficient (s.e.)	Co-efficient (s.e.)	Co-efficient (s.e)
Intercept		0.560	0.239	0.682
		(0.0778)	(0.0954)	(0.0780)
STOCK		-0.478	-0.313	-0.345
		(0.113)	(0.105)	(0.109)
CONS		0.409	0.369	0.212
		(0.0755)	(0.0562)	(0.0754)
WEALTH		-0.127	0.0360	0.131
		(0.091)	(0.0611)	(0.0852)
PROD		-0.153	-0.618	-0.373
		(0.108)	(0.156)	(0.119)
Sigma		1.245	1.358	1.159
		(0.065)	(0.081)	(0.061)
Log Likelihood		-419.2	-369.8	-360.2
Specification Tests		Test Statistic (Significance)	Test Statistic (Significance)	Test Statistic (Significance)
Normality	$\chi^2(2)$	1.81	0.36	22.99
		(.41)	(.83)	(.00)
Heteroskedasticity:				
STOCK	$\chi^2(1)$	3.56 (.06)	1.99 (.16)	3.35 (.07)
CONS	$\chi^2(1)$	12.33 (.00)	12.57 (.00)	3.93 (.02)
WEALTH	$\chi^2(1)$	6.18 (.01)	10.25 (.00)	35.39 (.00)
PROD	$\chi^2(1)$	0.41 (.52)	0.07 (.80)	1.76 (.00)
All Variables	$\chi^2(4)$	19.38	30.34	75.54
		(.00)	(.00)	(.00)

The results in table 4 indicate that the level of grain stocks significantly affects the level of grain purchases and that the sign on this parameter is consistently negative. The size of the parameter estimates are similar across rounds. Households are clearly considering the level of grains in their stores before purchasing from the market. The larger the supply of grain in the stores, the smaller the size of grain purchases. Such consistency of parameter estimates across rounds is also observed with household consumption level. This factor affects grain purchases positively. Households with large consumption needs, due to the size and age distribution of the household, were large purchasers of grain than household where consumption needs were smaller. The two findings taken together lend support to a view that a household is purchasing grain primarily to meet the household's consumptive needs. However, such purchases are determined also by the lack of adequate own stocks of grain.

The wealth of the household does not appear significant across any of the three rounds. The wealth of households, in terms of their domestic assets, appears not increase or decrease the propensity of the household to turn to the market for food purchasing. In one sense, this may be a positive aspect, indicating that the market is accessible to both rich and poor households. However, the hypothesis of homoskedasticity is emphatically rejected with regard to the WEALTH variable. Whether there is a basis for this initial optimism with regard to the impact of household wealth will be commented on more later. The parameter estimate for production supports earlier findings regarding the harvest period. A high level of harvested production negatively affects the level of purchases in the period where farms are being harvested. This effect is not observed in the period before harvest. In the final period, the negative effect on grain purchases of a large harvest remains significant but is smaller in magnitude.

Specification tests on the estimated model are indicated in the bottom half of the table. A hypothesis of normality of the disturbance term is rejected using the Chesher-Irish tests for the third round only. The $\chi^2(2)$ statistic for this test are 0.4, 1.8 and 22.9. The results of tests for the hypothesis of homoskedasticity are noted in the bottom half of the table also. The test statistics, which is distributed $\chi^2(4)$, are very highly significant - 19.4, 23.9 and 55.6 - suggesting the hypothesis of homoskedasticity is rejected. The disturbance term is not distributed in the manner assumed by the Tobit estimation.

One can see more detail about the determinants of the heteroskedasticity in the lower part of the table. The variance of the error term is modelled as an exponential function of the non-constant regressors in the model. The estimated parameter is the γ in equation (9). The results of the tests suggest that the variance in the disturbance term is largely explained by the level of household consumption and the wealth of the household. Across all three periods, homoskedasticity is rejected for these two variables individually, as well as for all the variables jointly.

6.2 Semiparametric estimation of the censored regression

The previous section has indicated that assumptions about the distribution of the disturbance term made in the Tobit model are not supported by the empirical evidence. The errors generated by using Tobit parameter estimates are not normally distributed in the final period suggesting that such a parameterisation of the disturbance term is incorrect. Further, there is evidence of heteroskedasticity in the errors. Heteroskedasticty will here be corrected using parametric techniques. Non-normality of the disturbance term will be addressed by modelling the distribution of the disturbance term nonparametrically.

The methods employed in this section place less restrictive specification assumptions on the error term. Table 5 below indicates estimates using parametric and semiparametric estimation of the censored regression. The first column gives the results of the Tobit estimation and is identical to the top half of table 4. Also, a parametric estimate which corrects for the presence of heteroskedasticity is presented in the second column. This specification models the heteroskedasticity in the disturbance term as exponential in form. Loglikelihoods are given in the optimal value row of the table. The specification modelling heteroskedasticity improves the loglikelihood by at least 15 in all the rounds. This is a significant improvement at one per cent confidence.

The final columns give results of the censored least absolute deviation (CLAD) method of Powell (1984) described in the earlier sections of this chapter. In both of these model, the estimation proceeds by minimising the (positive) sum of deviations, rather than maximising the (negative) sum of log likelihoods. Optimal values of the minimand are given below the parameter estimates.

With the CLAD estimate, the estimate of the covariance matrix (which is required to perform the Hausman test) depends on the smoothing parameter. This is discussed earlier. The smoothing parameter of 0.73 generally gives minimum estimates of the standard errors in comparison to the other two values used for the smoothing parameter (0.35 and 1.5). Choosing this value for the smoothing parameter is consistent with other researchers' work (Melenberg and Van Soest, 1996), where estimation results for the smoothing parameter associated with the minimum values of the standard errors are given.

With the round 1 estimates and smoothing parameter taking the value 0.73, the calculated Hausman statistic is -5.1. Other smoothing parameter values give negative test statistics also. This is a problem of the of the Hausman test methodology with regard to the CLAD. The covariance matrix for the Hausman test is calculated as the difference between the difference between the Tobit and CLAD covariance matrix. This calculation cannot guarantee a positive semi-definite matrix so that the test statistic may be negative. It is difficult to assess the test statistic as a result.

Table 5

Semiparametric and parametric estimates of the censored regression

	Tobit	Tobit Hetero	CLAD
		Round 1 (N=312)	
Intercept	0.560	0.552	0.662
	(0.0778)	(0.0919)	(0.080)
STOCK	-0.478	-0.597	-0.319
	(0.113)	(0.154)	(0.097)
CONS	0.409	0.525	0.456
	(0.0755)	(0.111)	(0.081)
WEALTH	-0.127	-0.200	-0.103
	(0.091)	(0.143)	(0.093)
PROD	-0.153	-0.116	-0.001
	(0.108)	(0.099)	(0.093)
Sigma	1.245	1.203	n/a
	(0.065)	(1.20)	
Opt Value	-419.2	-404.5	207.5
		Round 2 (N=287)	
Intercept	0.239	0.342	0.485
	(0.0954)	(0.098)	(0.092)
STOCK	-0.313	-0.404	-0.233
	(0.105)	(0.132)	(0.098)
CONS	0.369	0.129	0.497
	(0.0562)	(0.101)	(0.095)
WEALTH	0.0360	-0.511	0.111
	(0.0611)	(0.139)	(0.103)
PROD	-0.618	0.521	-0.234
	(0.156)	(0.114)	(0.092)
Sigma	1.358	1.174	n/a
	(0.081)	(0.081)	
Opt Value	-369.8	-352.4	181.4
		Round 3 (N=260)	
Intercept	0.682	0.698	0.720
	(0.0780)	(0.083)	(0.081)
STOCK	-0.345	-0.420	-0.245
	(0.109)	(0.134)	(0.098)
CONS	0.212	0.194	0.334
	(0.0754)	(0.072)	(0.082)
WEALTH	0.131	0.104	0.010
	(0.0852)	(0.101)	(0.089)
PROD	-0.373	-0.146	-0.159
	(0.119)	(0.085)	(0.103)
Sigma	1.159	0.980	n/a
	(0.061)	(0.063)	
Opt Value	-360.2	-308.5	157.5

Standard errors in parenthesis; smoothing parameter is 0.73 in CLAD estimates.

Table 6

Impact of different estimates on estimated grain purchases

	Round 1		Round 2		Round 3	
	Tobit	CLAD	Tobit	CLAD	Tobit	CLAD
STOCK	-53%	-36%	-42%	-31%	-38%	-27%
CONS	+46%	+51%	+36%	+67%	+24%	+30%
WEALTH	(-15%)	(-12%)	(+12%)	(+15%)	(-15%)	(+1%)
PROD	(+17%)	(0%)	-83.2%	-31%	-41%	(-18%)

Note: Impacts in parenthesis are derived using parameters which are insignificantly different from zero.

In the second round, the semiparametric estimates differ significantly from the parametric estimates. The Hausman statistic when the smoothing parameter is 0.73 is 82.3. This statistic is distributed $\chi^2(5)$ and is significant at 1%. The statistic for the final round is 1.34 indicating that a hypothesis that the third round's parameter CLAD estimates are the same as the Tobit estimates cannot be rejected. Looking at the parameter estimates of the second round, it is clear that the difference in two parameter estimates - the intercept and the coefficient on PROD - are very different. Such large parameter estimate differences are not found in the first and the third round estimates when CLAD is compared with the Tobit model.

Table 6 quantifies the difference in the amount purchased when the independent variables are increased by a single standard deviation. The Tobit and CLAD estimates were used in the analysis. The figures in parenthesis are changes in the amount purchased which have been calculated where the parameter estimate is not significantly different to zero (at 5%). The table indicates that the sign of all estimates is preserved across the different estimation techniques. A general observation is that the CLAD estimates decrease the effects of a change of one standard deviation in STOCK levels while increasing the effect of a change in CONS in comparison to the Tobit model.

From a policy point of view, the significant negative relationship between grain purchases and stock levels and the positive relationship with household consumption needs is kept thrroughout the survey. The different nature of the second round - with harvested grains entering the household stocks - is also borned out. A significant fall in purchases amongst households with high production is predicted. However, the semiparametric estimate, as well as the Tobit estimate which corrects for heteroskedasticity (see Table 5), suggests this behaviour does not continue into the third round of surveying.

6.3 Parametric estimation of the binary decision to purchase

In estimating the decision to purchase grain, binary decision models are estimated. When a purchase is made in the four month periods, the dependent variable takes the value 1; when no purchases are made, this variable is zero. The same independent variables are used as with the censored analysis, namely the stock level (STOCK), the annual consumption of the household (CONS), an index of household assets (WEALTH) and harvested production (PROD).

Table 7 presents the results for the parametric Probit model. The signs of the parameters bear a strong resemblance to those of the censored estimation. Only the signs on WEALTH and CONS in the third round differs from the results of the Tobit estimation in table 4. As with the Tobit estimation, high grain stocks at the start of the periods are associated with a low probability of purchase. The coefficient on the stock levels at the start of each of the three periods are strongly significant in all the rounds.

In the first two rounds, the coefficient on CONS is significant and positive as in the Tobit estimation. This implies that households with higher consumptive needs were more likely to buy grain. However, in the third round CONS does not significantly affect the chance of a grain purchase. It can also be noted that the parameter estimates for the CONS variable are not as significantly different from zero as in the Tobit model. The co-efficient estimates in the Tobit model are five or more standard errors away from zero while the Probit results differe from zero by less than this level.

While the Tobit estimation suggested that the WEALTH of households did not affect the amount purchased, the Probit estimates of the chance of purchasing is negatively related to this variable. The parameter estimate is negative and significant in two of the three rounds. Households which are wealthier appear to be less likely to purchase grain in the first and third rounds. so that poorer households are more likely to source their grain from the market than rich households. As with the Tobit estimation, the effect of production levels again appears to be limited to the second and third rounds. High levels of harvest rather unsurprisingly make purchases of grain less likely.

Table 7

Probit Estimates of the Decision to Purchase

		Round 1 (N=312)	Round 2 (N=287)	Round 3 (N=260)
		Co-efficient (s.e.)	Co-efficient (s.e.)	Co-efficient (s.e)
Intercept		0.482	0.178	0.795
		(0.080)	(0.078)	(0.097)
STOCK		-0.521	-0.289	-0.434
		(0.111)	(0.087)	(0.114)
CONS		0.265	0.205	-0.020
		(0.094)	(0.079)	(0.087)
WEALTH		-0.243	0.015	-0.320
		(0.090)	(0.087)	(0.099)
PROD		-0.073	-0.416	-0.275
		(0.099)	(0.123)	(0.132)
Log Likelihood		-165.23	-195.39	-111.32
Specification Tests		Test Statistic (Significance)	Test Statistic (Significance)	Test Statistic (Significance)
Overall	$\chi^2(4)$	65.32 (.00)	35.85 (.00)	62.99 (.00)
Normality	$\chi^2(2)$	0.36 (.83)	0.36 (.83)	1.69 (.89)
Heteroskedasticity:				
STOCK	$\chi^2(1)$	0.14 (.29)	0.46 (.49)	1.67 (.20)
CONS	$\chi^2(1)$	2.19 (.14)	2.21 (.14)	3.93 (.05)
WEALTH	$\chi^2(1)$	0.15 (.70)	1.06 (.30)	0.08 (.78)
PROD	$\chi^2(1)$	0.61 (.44)	0.60 (.44)	0.03 (.87)
All Variables	$\chi^2(4)$	2.57	4.94	6.92
		(.11)	(.29)	(.14)

At the bottom of Table 7 are the specification tests performed on the parametric Probit model. The model appears to be well-specified. Overall the model is highly significant. A hypothesis of normality of the disturbance term cannot be rejected at standard significance levels in all the rounds. Also, there is no evidence for heteroskedasticity in the model.

6.4 Semiparamatric estimation of the binary decision to purchase

Table 8 presents parametric and semiparametric estimates of the binary decision to purchase grains. The first colums reproduces the reults of the previous table by giving each rounds' parametric Tobit estimates. In the second column, the semiparametric MSCORE estimate is given. All estimates have been standardised so that the coefficient of STOCK is minus one. Comparison of the parameter estimates can be done through looking at co-efficients which are significantly different from zero. Across the rounds, there are some parameter estimates which differ between the rounds (most notably, the co-efficient on CONS differs considerably in the first round). However, the significant parameter estimates across the rounds match closely. This is not surprising given the results of the specification tests of the Probit model.

Table 8

Semiparametric and parametric estimates of purchase decision

	Round 1 (N=312)		Round 2 (N=287)		Round 3 (N=260)	
	Probit	MSCORE	Probit	MSCORE	Probit	MSCORE
Intercept	0.925	0.963	0.617	0.613	1.830	1.810
	(0.154)	(0.460)	(0.271)	(0.376)	(0.223)	(0.475)
STOCK	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
	(0.214)	(0.358)	(0.299)	(0.408)	(0.263)	(0.475)
CONS	0.509	1.157	0.710	0.722	-0.046	0.168
	(0.181)	(0.598)	(0.274)	(0.632)	(0.201)	(0.690)
WEALTH	-0.466	-0.593	0.052	-0.190	-0.736	-0.798
	(0.173)	(0.507)	(0.301)	(0.404)	(0.228)	(0.586)
PROD	-0.141	-0.577	-1.441	-0.765	-0.634	-1.576
	(0.190)	(0.507)	(0.425)	(0.411)	(0.304)	(1.021)
Predictions	0.75	0.77	0.67	0.70	0.80	0.83
Max Value	-165.23	0.77	-195.4	0.70	-111.3	0.83

Note: Standard errors in parenthesis.

6.5 Paramatric estimation of the truncated quantity purchased

Tables 9 and 10 provide the parameter estimates for the truncated regression. Table 9 gives results without correcting for heteroskedaticity in the model. As can be seen in the diagnostic statistics at the foot of the table, such a specification is rejected for a large proportion of the variables. The results given in Table 10 refer to a model which assumes that the heteroskedasticity in the disturbance term is exponential in the independent variables. The form of the disturbance term is given as equation (9) and the estimate of the parameter vector, α, is given in the final rows of the table. The change in the log-likelihood of the truncated model when the heteroskedasticity in the disturbance term is modelled forms the basis of a test of the model's validity. The change in the log-likelihood is doubled to give a test statistic. This statistic takes the value 16.2, 14.2 and 42.3 across the three rounds. Noting that $\chi^2(5)$ takes the value 11.1 at 5% confidence level and 15.1 at 1%, these test statistics indicate a significant improvement in the explanatory power of the model once heteroskedasticity is allowed for.

The actual parameter estimates give some indication of the determinants of the quantity purchased. The coefficients on the variables STOCK and PROD are insignificant in each of the three rounds. The first variable has had negative and significant parameter estimates for previous estimation techniques. In particular, the Tobit model, which also models the quantity of grain purchased, predicts that the level of grain stocks is negatively related to the quantity purchased. However, when the decision to buy is separated from the decision over the quantity purchased, it is clear that the quantity variable is less affected by stored grains. This can be taken in the light of the findings of table 7, where the decision whether to buy or not is determined by the level of household grain stocks.

Table 9

Estimation of the quantity purchased for non-zero observations

		Round 1 (N=312)	Round 2 (N=287)	Round 3 (N=260)
		Co-efficient (s.e.)	Co-efficient (s.e.)	Co-efficient (s.e)
Intercept		0.706	0.137	0.120
		(0.232)	(0.389)	(0.411)
STOCK		0.066	-0.204	-0.042
		(0.210)	(0.186)	(0.245)
CONS		0.472	0.875	0.529
		(0.107)	(0.186)	(0.156)
WEALTH		0.227	0.368	1.000
		(0.153)	(0.192)	(0.217)
PROD		-0.306	-0.978	-0.460
		(0.218)	(0.417)	(0.311)
Sigma		1.238	1.299	0.120
		(0.124)	(0.155)	(0.411)
Log Likelihood		-241.4	-181.7	-205.2
Specification Tests		Test Statistic (Significance)	Test Statistic (Significance)	Test Statistic (Significance)
Heteroskedasticity:				
STOCK	$\chi^2(1)$	3.77 (.05)	1.75 (.19)	18.72 (.00)
CONS	$\chi^2(1)$	15.67 (.00)	2.03 (.15)	22.1 (.00)
WEALTH	$\chi^2(1)$	1.08 (.30)	7.61 (.01)	19.5 (.00)
PROD	$\chi^2(1)$	1.16 (.28)	9.08 (.00)	16.8 (.00)
All Variables	$\chi^2(4)$	22.38	13.84	25.8
		(.00)	(.01)	(.00)

This result - that quantity is not related to the stores of grain while the binary decision to buy is - is borne out by the co-efficient on household production. The negative impact of the level of harvest that previously has been shown to occur in the second round is not evident in the truncated quantity purchased. Thus, the Tobit and Probit models had significant negative co-efficients on the PROD variable, while the truncated quantity purchased is not significantly affected by this variable.

Table 10

Estimation of the truncated quantity purchased with exponential heteroskedasticity

	Round 1 (N=312)	Round 2 (N=287)	Round 3 (N=260)
	Co-efficient (s.e.)	Co-efficient (s.e.)	Co-efficient (s.e)
Intercept	1.090	0.687	0.919
	(0.157)	(0.234)	(0.158)
STOCK	0.217	-0.470	-0.155
	(1.157)	(0.376)	(0.187)
CONS	0.451	0.510	0.357
	(0.159)	(0.181)	(0.091)
WEALTH	0.103	0.398	0.258
	(0.132)	(0.125)	(0.157)
PROD	-0.345	-0.257	0.043
	(0.342)	(0.162)	(0.096)
Sigma	0.941	0.915	0.880
	(0.089)	(0.085)	(0.086)
Log-Likelihood	-233.3	-174.5	-184.0
Improvement in Log-Likelihood $\chi^2_{(5)}$	16.2	14.2	42.3
Exponential heteroskedasticity model:			
STOCK	-0.160 (.157)	0.154 (.146)	0.109 (.151)
CONS	0.315 (.092)	0.280 (.109)	-0.075 (.085)
WEALTH	-0.032 (.130)	0.142 (.113)	0.458 (.067)
PROD	0.112 (.114)	-0.647 (.174)	-0.348 (.143)

The question then turns to what determines the quantity purchased, given a household has purchased grains. Table 10 indicates that it is household consumption levels which determine truncated purchase quantity. Households with a high annual consumption level are, when they go to the market, purchasing higher level of grains. The coefficients are positive and significantly different from zero by three standard deviations. The WEALTH of the households also becomes prominent in the second round where the parameter estimate indicates that the wealthier households buy more grain.

7. Concluding Remarks

The estimations in this chapter empirically assessed the determinants of the level of grain purchases. This has been done with specific reference to the grain marketing model presented in an earlier chapter. In that model, the level of grain purchases are assumed to be determined by the level of grain stocks as storage of grains is viewed as a substitute for the market. A high level of grains in store means that regions can postpone purchases and thus postpone the cost of transfer. This chapter uses household level data to see if the main storers of grain in rural areas - the household units - behave in a manner consistent with this regional level model.

Much of the chapter discusses the empirical models employed. Apart from standard parametric models used on censored data - most notably the Tobit model - a number of other specifications are discussed. Semiparametric estimation techniques which make less restrictive assumptions about the functional form of the disturbance term are described and such techniques are used to contrast with the results of parametric estimation.

The findings of this chapter support the important role of grain stores in determining the level of grain purchases. In the censored regression estimation, the coefficient on the level of grain stocks at the start of the period is shown to be significant and negative. Households with large stores of grain appear not to enter the market. The level of grain purchases are positively related to the consumption needs of the household. This is again consistent with chapter 4's grain marketing model where regional consumption is modelled as a constant. In the model the constant takes the value 1; however, this value would more reasonably equal the regional level of consumption. The empirical findings also indicate a role for the level of harvest in the second round. Harvesting of grains took place in this period of surveying and the level of grain stocks at the beginning of the period therefore would not take this harvest into account. The negative effect on grain purchases of harvest in round two therefore can be seen as households taking into account the large change in the level of grain stocks that household production can cause.

However, the censored regression suffers from a number of specification problems. The disturbance term is not normally distributed or homoskedatic. The literature on the Tobit model highlights that relaxing these two assumptions of the model can make significant changes on the parameter estimates. There is some evidence of this when the semiparametric estimates of the censored regression are considered in the second round where a Hausman statistic indicates a significant difference in parameter estimates when the censored regression is estimated using a Tobit and CLAD estimation technique.

The empirical findings of the two-equation model are then presented. The Probit model is well-specified. Statistics testing for normality and homoskedasticity are insignificant. The Probit model estimates are similar to those estimated by semiparametric methods. The Truncated regression model is estimated and the disturbance term is heteroskedastic. When the regression is re-estimated allowing for this, consistent parameter estimates can be derived.

The findings of this specification are interesting. The main variable that determine whether a household purchases grain or not is the level of grain stocks. The quantity purchased is determined by the level of household consumption needs. This empirical finding is intitively appealing and the separation of the decision to purchase from the quanitity purchased is borned out by the Table 11 below which presents the results of a Cragg specification test. Under the null, the hypothesis is that the Probit, the Truncated and Tobit estimates are equal. If true, then the sum of the two-equation regresion loglikelihoods would equal the Tobit loglikelhood. The null is rejected in each of the three rounds at the 5% significance level.

Table 11

Cragg's specification test

	Model Loglikelihoods			Cragg Test
	Tobit L_T	Probit L_P	Truncated L_{Tr}	Λ
Round 1	-419.2	-165.2	-241.4	25.2
Round 2	-369.8	-195.4	-181.7	14.6
Round 3	-360.2	-111.3	-205.2	87.4
	Models with exponential heteroskedasticity			
Round 1	-404.5	-163.4	-233.3	15.6
Round 2	-352.4	-181.7	-174.6	7.8
Round 3	-308.5	-104.6	-184.0	19.9

At 95%, $\chi(5)=11.1$; at 99% $\chi(5)=15.1$;

CHAPTER 7:

Seasonality and Arbitrage in Food Markets

1. Introduction

In chapter 3, the Takayama-Judge model of spatial price equilibrium was described (Takayama and Judge (1971)). This underpins many of the tests of food market integration that have been used in developing countries by economists. In the model, spatial arbitrage across regional food markets restricts regional price differentials to at most the cost of transfer between the regions. At times where transfer takes place, the price differential equals the cost of transfer. Analysts have then proceeded by testing this spatial arbitrage rule. When market prices are integrated (in the econometric co-integration sense), this is taken as a sign that the markets are trading and therefore, rather confusingly, integrated in the food marketing sense. This has generally been judged as 'good'. When market prices diverge, there may be short or long-term impediments to trade. This would be detrimental to welfare and the removal of the obstacles to trade would be suggested.

In chapter 4, a more complex structure to regional food markets is hypothesised. While the Takayama-Judge model allows the spatial aspects of food markets to be explored, the temporal features of food markets are not discussed. The chapter analyses this aspect through more explicit reference to the dynamics of market trade. In particular, the departure from conventional modelling is the inclusion of commodity storage into a model of inter-regional trade. The addition of storage of grain yields interesting results. Most notably, trade is intermittent with periods where a region will consume its stored grains or purchase from another market. In such periods, tests for correlation in market prices would be inappropriate as inter-regional trading would not take place.

Recent empirical research has highlighted that trade may switch between periods of trade and periods with no trade. Baulch (1997) proposes the parity bounds model where breaks of trade are explicitly modelled when analysing price time series data. In the model, the price difference between markets is compared with the level of transfer costs. The model allows for three mutually exclusive trading conditions. In one case - when the price spread equals the cost of transfer - the two markets are trading. However, the advance is to allow for non-trading which is consistent with market integration. Baulch explicitly models the case where trading is not taking place because the price spread is lower than the cost of transfer. He differentiates this from the third case where there is some impediment to trade and price spreads are persistently above the cost of transfer. It is only in this last case that the market analyst should worry about market performance and explore the role for intervention. In the second case, markets are not trading and price series would not be related. However, this is not a consequence of any inefficiency in the market; merely a result of clearing in regional markets at price levels which would not cause inter-market trade.

Baulch (1994) introduces an empirical test for the model. This is based on the stochastic frontier model pioneered by Aigner et al. (1977). In this type of modelling, regimes are defined and the switching between regimes is modelled as stochastic. The different regimes, in this case, model the three different trading cases above. In the trading regime, the difference between the cost of transfer and the inter-market spread is modelled as a normally distributed, zero mean variable. Such a specification allows for a symmetric distribution of the price spread around the transfer costs. Baulch (1995) suggests that this normally distributed term can be viewed as a stochastic component in the cost of transfer. In the other two regimes, asymmetry in the distribution is assumed. In the second regime, where there is some impediment to trade so that price spread exceeds the cost of transfer, the difference is the positive half of a normal distribution. In the third regime, where price spreads are below the cost of transfer so that there is no trade, the inter-market spread less the cost of transfer is assumed to be only the negative half of a zero mean normal distribution. The probability that the three different market conditions occur can then be empirically estimated.

Such a model is applied to maize price data from six markets in Tanzania. The retail price of maize was collected at monthly intervals in each of the markets. The data are used in the third section to empirically investigate the Baulch model. Generally, the analysis indicates that the markets are integrated. The regime where price spreads exceed the cost of transfer does not prove significant. Given the markets are integrated in many of the market pairs, the analysis then turns to the switching between the other two regimes. A stochastic frontier model is estimated using the price difference between pairs of markets. The frontier in this analysis is the cost of transfer between the markets. When there is trade, arbitrage would equate the cost of transfer and the price difference. In this regime, the markets are at the frontier. When trade is not taking place, price differences would, on average, be below the cost of transfer so that the market spread would be inside the frontier.

The main purpose of this chapter is its exploration of the seasonality of inter-regional trade which the model in chapter 4 predicts. The model indicates when inter-regional trade would be most likely to occur. In the scenario where both regions have own stocks of grain, there would be little trade post-harvest. However, trade would occur as the next harvest approaches. Towards the end of the agricultural year, an external market may become significant and inter-regional trade would stop. If a region is not a producer of grain, such as an urban area, initial grain stocks would be zero and trade would begin at the start of the year. Again, however, the high price of grain at the end of the agricultural year may mean that external sources of grain would be cheaper then. This dynamic structure to market trade will be analysed at the end of the chapter.

2. Seasonality in Spatial Arbitrage

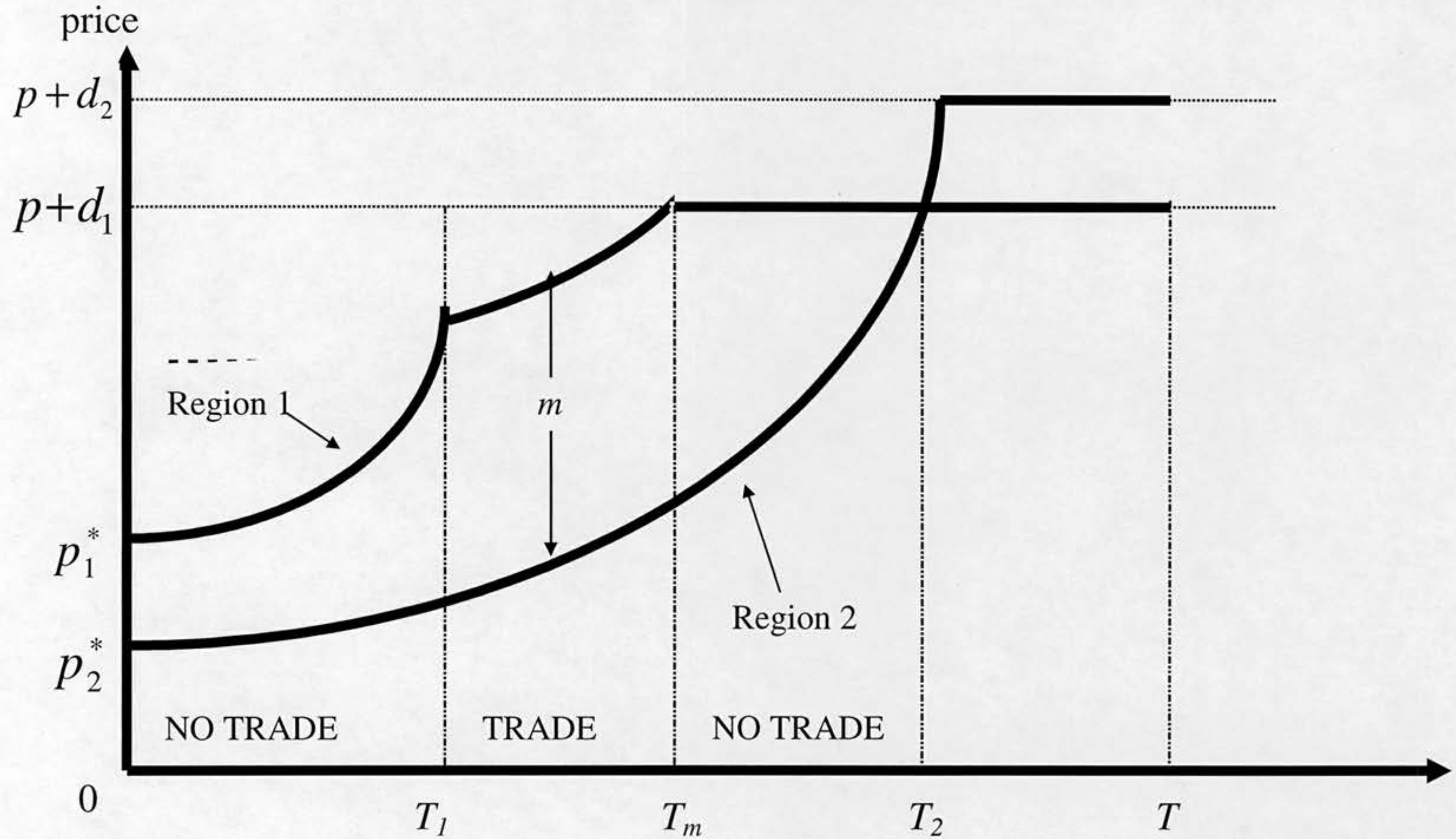
Chapter 4 analysed a model of food marketing over time between two separated but not segmented markets. It was assumed that there were two regional markets trading, storing and consuming a single homogenous good. The start of the period saw the years single harvest of the good and the two regions were then modelled as consuming a fixed amount over the year up to the next harvest. Further, it was assumed that there was an external market. This external market guaranteed to purchase the good at a low price and sell the good at a fixed higher price with these prices fixed throughout the year. The external market therefore constrained the extent to which prices could rise post-harvest. The price of the good rises in both markets because there is cost to storage. This would be made up of the physical cost of maintaining storage systems and the cost of capital tied up in the stored quantity of the commodity.

The dynamics of the two regions' food stocks and the trade between the regions was analysed. Underpinning the behaviour of the markets is that the price level in a region with grain stocks rises at the rate of discount. This means that other sources of grain become cheaper relative to the consumption of stored grain and causes markets to switch between different sources. One of the general results is that trade is intermittent. The three possible sources for grain - own harvest, trade with the neighbour and purchases from the external market - may all be utilised over the year after harvest and the order in which this occurs can be shown.

The ordering of the different sources was proven. Figure 1 indicates the dynamics of two regions' prices assuming that region 1 has a smaller harvest than region 2. It indicates that the regions would consume own stocks of grain first. In this period, prices rise exponentially at the rate of discount. The price spread between the markets is less than the cost of transfer during this period. If there is trade, then it will occur after the region with the smaller harvest exhausts this initial stock of grain, T_1. During inter-regional trade, the region with the greater harvest is selling some of that harvest to its neighbour and this incurs the costs of transfer. The inter-market spread equals the cost of transfer. The trading continues until the price in the market with the smaller harvest equals the price of the external market. At this point, time is T_m. The external market supplies the region; inter-market trade ends and the inter-market spread falls below the cost of transfer. The second region continues trading until T_2.

This chapter explores empirically whether the model predictions are borne out using data from Tanzania. The analysis focuses on the behaviour of the inter-market spread. The model predicts that after harvest the inter-market spread would be less than the cost of transfer until one of the regions runs out of grain stocks. If one of the regions has no or little grain this period may be very short. One can imagine this to be the case if one of the regions has a poor harvest or does not contain producers, such as an urban area. The period of trade last from T_1 to T_m and the length of this period is determined by a variety of parameters and given in chapter 5. After the trade ends, it is worth noting that no trade would occur until the following year's harvest.

Figure 1: Regional Prices of Grain over Time



3. Maize Markets in Tanzania

3.1 Tanzania's Food Marketing System

In Tanzania, the late 1980s were a time of transition from a highly controlled marketing system to a food system with an increased role for the market. The pre-liberalisation era had been marked by the outlawing of private grain movements. This led to the channelling of grain from farmer to consumer going through state organisations. The state regulated system proved inefficient and could not cover its costs. The mounting losses of the marketing institutions proved a burden on government finances. In 1984, the controls on grain movement were relaxed signalling a toleration of private trade. By 1987, movement restrictions had been entirely abolished. The liberalisation process has been described as a 'reluctant metamorphosis' by Coulter (1994) who found in 1991 'a strange mixture of the new liberal order and the old state-controlled system, with the former in ascendancy but not the outright winner' (p.5).

The agricultural year in Tanzania centres around the single growing season. As much of the country's agricultural land is unirrigated, the single harvest in March-April provides the bulk of the food supplies for the country. Storage of grain for consumption until the next harvest becomes vital. Also, as with much of the sub-Saharan region, outside the cities, population density is very low and the movement of grains from growing areas to consumers involve transport over large distances. These two characteristics of the food sector have defined the marketing system.

Figure 1 indicates the transport infrastructure between the six selected markets. Railway lines link three of the markets to Dar es Salaam. Only Iringa in central Tanzania and Songea to the south do not have a railway station. The importance of the railway lines on figure 2 is that high-quality roads run parallel to the tracks. For example, the TAZARA rail line joining Dar es Salaam to

Mbeya runs beside the TANZAM highway. Long-distance private transfers of maize are by road through use of trucks. The cost of transport then depend on the quality of the road and trader access to hired transport.

3.2. Price Data and Regional Markets

The retail price of maize was collected by Government of Tanzania's Marketing Development Bureau from six large markets in Tanzania at monthly intervals from January 1986 to December 1990. Figure 2 gives the position of the selected markets: Arusha, Iringa, Mbeya, Shinyanga, Songea and Dar es Salaam are used. In addition to price time series data, a single estimate of the cost of transfer between market pairs was taken from a survey of the literature. A consumer price index series, using only non-food goods, was used to express the maize prices and transfer costs in January 1991 prices.

Bryceson (1993) investigates the workings of the Tanzanian grain markets. She gives a taxonomy of the six markets considered here. Dar es Salaam is the largest city in the country by a large margin; its 1.1 million inhabitants make it ten times larger than Tanzania's second city (Bryceson, 1993, p.243). As a result of the high density of population in Dar es Salaam and the surrounding areas, the city is maize deficit purchasing from other regions or, as it is also a major port, from international markets. Shinyanga is a small town located on the rail line to Lake Victoria. The area which supplies this market is not as densely populated as Dar es Salaam. However, as it is a rice growing area, maize production is low making it a maize purchasing market. The northern region surrounding Arusha and the more central Iringa market are both net sellers of maize. These areas specialise in maize production. It is only in the south that both crops are grown. Bryceson (1993) characterises Songea and Mbeya markets as surplus in rice and maize.

4. Price Spreads in Tanzania's Maize Markets

4.1. Transfer between Markets

Bryceson (1993) presents estimates of the cost of transfer to Dar es Salaam from the five rural markets. The study highlights various fees and other charges that traders incur when moving grain across Tanzania with the largest component of transfer cost being transport. Table 1 presents some summary statistics. The first column gives the cost of transferring a 17 kg tin of maize as estimated in Bryceson's survey of traders. These figures are similar to other comparable studies (Santorum and Tibaijuka (1992) gives TSh 162, 162, 106 and 219 for Arusha, Mbeya, Iringa and Songea respectively)[8].

The second column indicates the average of the absolute difference between the price of a tin of maize in Dar es Salaam and the other markets. A result of the spatial price equilibrium model (Takayama and Judge (1971)) is that the mean absolute price spread would be lower than or, at most, equal to the cost of transfer. This is because there is downward pressure on price differentials if they exceed transfer costs: arbitrage would be profitable whenever the price spread is higher than the cost of transfer. However, there is be no upward pressure on the price spread when it falls below the transfer cost. Thus, price differences below the cost of transfer could persist indefinitely. Mbeya, Shinyanga and Arusha all have average absolute price spreads below or close to the cost of transfer. Iringa and Songea appear to behave against this intuition. There, price spreads are higher that the cost of transfer on average.

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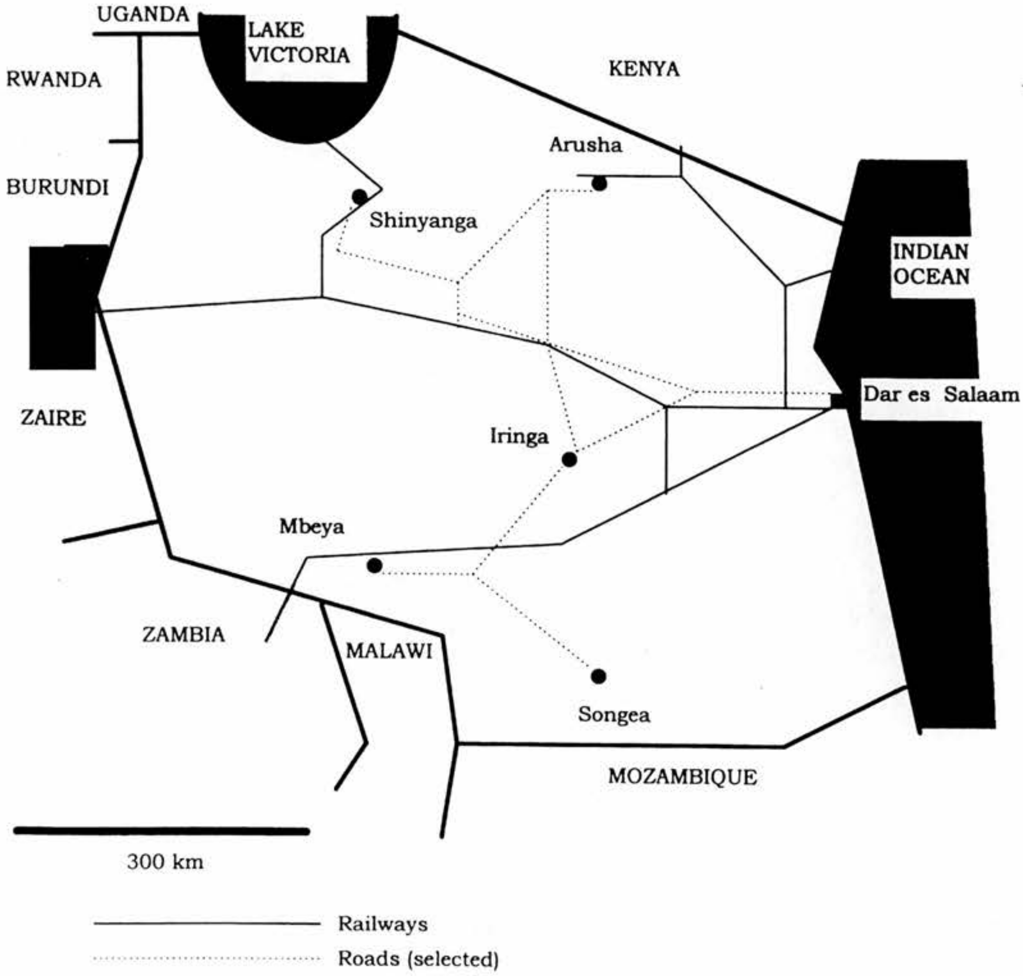
[8] Bryceson surveyed 196 traders in 1988 about various aspects of grain trading. As the survey was conducted in the middle of the price dataset and with a relatively large number of respondents, its results are used here (Santorum and Tibaijuka interviewed 30 traders in 1991).

A possible explanation for this is that the estimate of transfer costs is based on a single survey. It can be expected that there is variation in transfer costs across time. Poor road conditions could be exacerbated by the weather so that periods of much higher transfer costs can be envisaged. While such factors may be seasonal, non-seasonal factors such as localised fuel shortages may also contribute. The location of Songea is worth noting: Songea is a particularly remote part of Tanzania, the road from Mbeya crosses some high mountains and has had a history of maintenance problems. The consequent remoteness is explored greater in the empirical analysis.

Figure 2: *Tanzanian Food Markets*



This stylised map indicates all the railways of Tanzania and the roads used to link the selected six markets. It is based on Bryceson (1987)

Figure 3

Plot of the Log Absolute Price Spread Adjusted by Transfer Costs

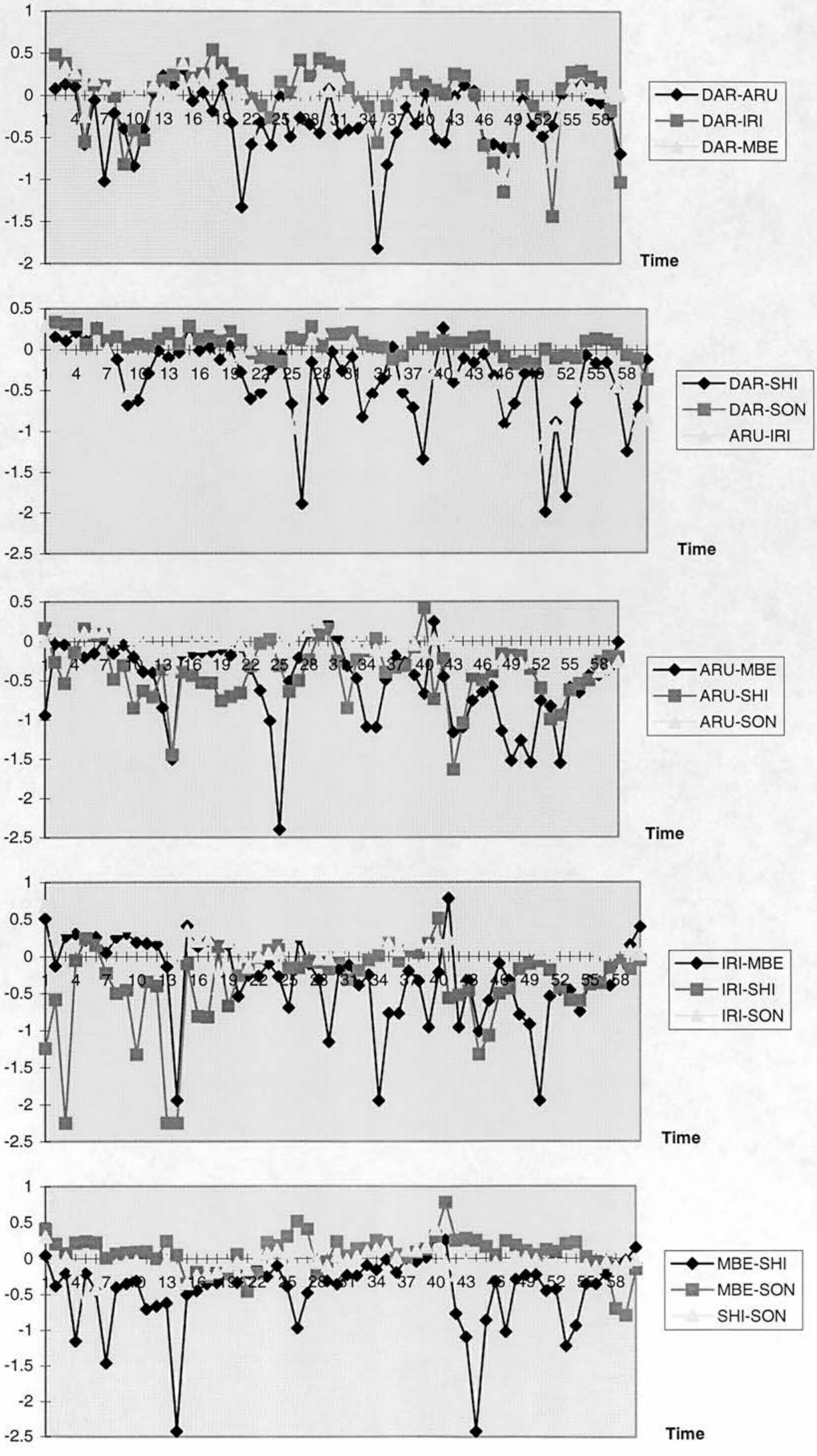
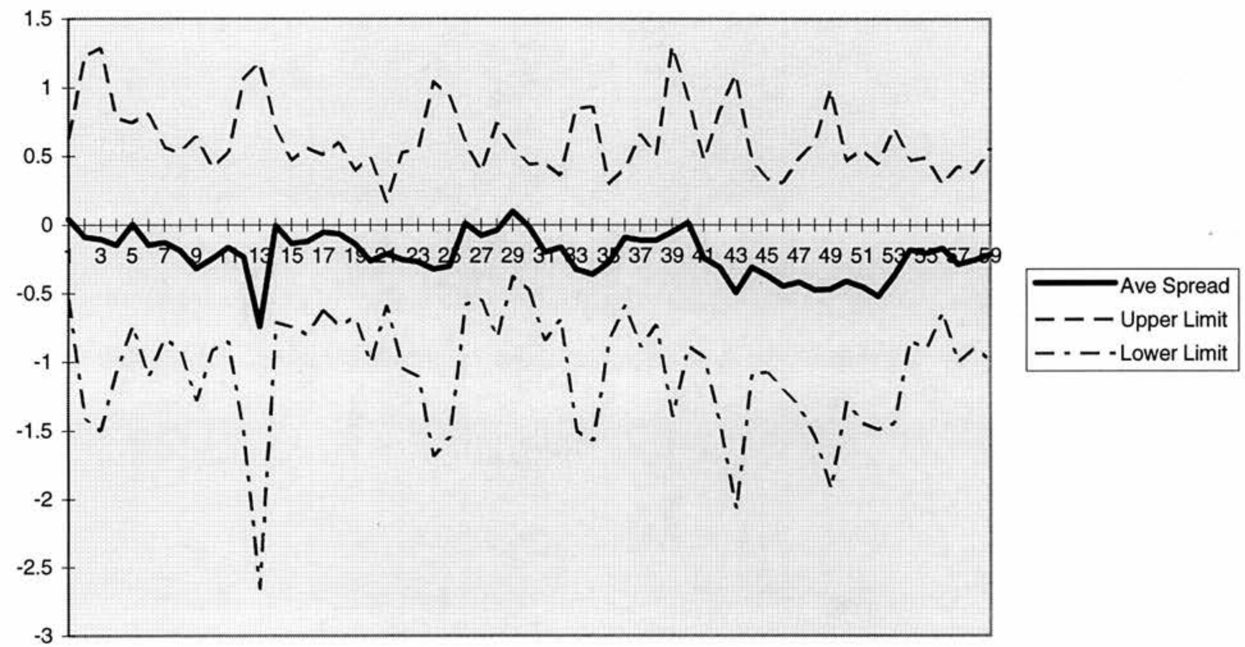


Figure 4

Plot of the Log Absolute Price Spread Adjusted by Transfer Costs
Averaged over all Market Pairs



A general feature about price spreads is that Dar es Salaam's maize price is greater than that of the other markets. This is unsurprising as Dar es Salaam is by far the largest city in the country and its urban populace requires food supplies. The greater value given to grain in Dar es Salaam therefore is a reflection of the city's drawing in of maize supplies from the other markets.

Table 1

Summary Statistics on Transfers to Dar es Salaam (Jan 1991 prices)

Inter-Market Trade	Cost of Transfer [b] (TSh/tin[a])	Mean Abs. Price Spread (TSh/tin)	Minimum Price Spread (TSh/tin)	Maximum Price Spread (TSh/tin)
Dar[c]→Arusha	161	107	-191	331
Dar→Shin'ga	190	143	-409	420
Dar→Mbeya	196	202	-395	501
Dar→Iringa	129	153	-32	409
Dar→Songea	196	351	122	619

Notes: [a] Tanzanian Shillings per 17 kg tin; [b] Bryceson (1993, p.252); [c] Dar es Salaam.

The results presented in table 1 can be combined with the geographical distances between Dar es Salaam and other markets to estimate the transfer costs between all market pairs. There is a fixed component to the cost of transfers given in Bryceson (1993). This included the cost of bags, loading costs etc.. The main part of the transfer costs, however, is the cost of transport. The average ratio of the geographical distance to the transport costs for the values given in Bryceson's study was calculated. This ratio was used to give a crude value to the inter-market transport costs where Dar es Salaam was not one of the markets[9]. The fixed costs were then added to this so that the overall cost can be calculated. These inter-market costs are given in table 2.

Table 2

Estimated Inter-Market Transfer Costs (TSh/tin[a])

	Arusha	Iringa	Mbeya	Shinyanga	Songea
Dar[b]	161	129	196	190	196
Arusha	-	159	234	209	265
Iringa		-	96	173	127
Mbeya			-	248	126
Shinyanga				-	279

Notes: [a] Tanzanian Shillings per 17 kg tin; [b]Dar es Salaam.

4.2 Price Spread over Time

One advantage of analysing inter-market spreads noted by Baulch (1996) is that the variable is likely to be stationary. This can be empirically tested and in this section some results will be indicated. However, it is worth noting the similarity between the analysis of the stationarity of the inter-market spread and the cointegration analysis that was performed in chapter 3. Cointegration analysis seeks to find a long-term equilibrium relationship between two

[9] Inter-market distances in kilometres

	Arusha	Iringa	Mbeya	Shinyanga	Songea
Dar	684	503	879	975	1033
Arusha	-	693	1069	940	1223
Iringa		-	376	761	530
Mbeya			-	1137	526
Shinyanga				-	1291

variables. While this relationship may not actually be observed due to short-term deviations from it, if the deviations from the long-run relationship are shown to be stationary, this is taken as evidence that there is a long-run equilibrium.

Table 4 of chapter 3 gives the long-run relationships of the various price pairs. It can be seen that, in general, the estimated relationship is insignificantly different from the inter-market spread. That is, the coefficient on the price of the other market is insignificantly different from one so that the simple difference is being modelled. Further, many of the market price pairs are cointegrated (see chapter 3, table 3). This means that the errors estimated by using the long-run relationship are stationary.

The results presented in table 3 bear out these earlier results. Table 3 gives the findings of the inter-market spread being tested for stationarity using a unit root test. The test for stationarity used is the Phillips-Perron nonparametric test (Phillips and Perron (1988)). Critical values are given in the table also. Where the test for stationarity of the inter-market spread proves insignificant, the first difference is calculated and this series is tested for stationarity. Thus, the inter-market spread between Dar es Salaam and Mbeya and Dar es Salaam and Songea is not stationary. However, both inter-market spreads, once differenced, are stationary. The analysis of Shinyanga and Mbeya gives a similar result.

Table 3

Stationarity of Inter-Market Spreads

	Arusha	Iringa	Mbeya	Shinyanga	Songea
Dar[a]	-4.44[b]	-4.02	-2.12	-5.52	-2.89
			-11.86[b,c]		-10.16
Arusha	-	-3.99	-3.75	-5.10	-3.36
Iringa		-	-5.60	-4.68	-3.86
Mbeya			-	-1.69	-3.33
				-7.32	
Shinyanga				-	-2.83

Notes: [a]Dar es Salaam; [b]Phillips-Perron tests significance levels are -3.54 (1%), -2.91 (5%) and -2.59 (10%); [c]Test result for stationarity of first difference in price spread.

Figures 3 and 4 plot out the price differentials over time. As tested later, the analysis of price spreads hypothesises that Dar es Salaam is a price leader. Thus the price level of the previous month is subtracted from the other markets when Dar es Salaam's market price is used. All other market pairs use contemporaneous data.

Figure 3 plots out the absolute inter-market spreads adjusted by transfer costs for the fifteen market pairs. The spreads between market pairs when plotted can be seen to be stationary. Most of the markets appear to be close to parity level - the absolute market spread less transfer costs is near zero. For example, the Arusha-Songea market spread appears to be very close to inter-market transfer costs during the entire five years. A few market spreads appear to exceed the cost of transfer for a number of months. Qualitatively, four market pairs - Dar es Salaam, Iringa and Mbeya with Songea and Dar-Iringa - seem to behave in this manner.

A general point is that the market spreads appear to be at or below market transfer costs. This is borne out by the plot of the average of all fifteen market pairs. In figure 4, the absolute inter-market spread, less the appropriate transfer costs, are plotted as an average. It can be seen that this plot is at or below zero in all but two months of the fifty-nine months considered. The standard errors across the fifteen market pairs can be calculated for each of the 59 months. The upper and lower bounds are plotted and indicate the high variation in inter-market spreads across market pairs that is exhibited. The upper bound is positive and the lower negative for all the months indicating that the negative average may prove insignificant.

5. Econometric Specification

5.1 Parity Bounds Model

The models discussed in chapter 3 largely assessed the validity of only one of the Takayama-Judge results - that when trade occurs, the prices in two markets would be correlated. The sophistication in the tests have improved, correcting some of the problems associated with the simple correlation tests. However, as noted in chapter 4, the Takayama-Judge model does not predict correlated price movements for all periods. Prices may be uncorrelated if the two markets clear at prices which differ by less than the cost of transfer between the markets. The cost of transfer includes the cost of transport, storage, packaging and some processing as well as the profit that the shipper makes. In many developing countries, these costs would not prove trivial. Transport infrastructure is often inadequate and the other activities also require capital which, as indicated in chapter 2, has a high rate of interest associated with it.

Baulch (1995) considers a test for market integration which models discontinuities in trade flows. His assessment also adds a third condition to Takayama-Judge's two - that price differentials may temporarily exceed transfer costs, violating spatial arbitrage rules, due to transportation bottlenecks, government controls or other impediments to trade flows. Baulch disaggregates the spatial price spread into four components: the average cost of transfer between the two markets, an error term associated with the measurement of this transfer cost (e_t) and then two further error terms. The first of the error terms (u_t) constitutes the extent to which price differentials in the market fall short of transfer costs. This occurs when trade is not taking place because market clearing prices in the markets mean that there is no opportunity for arbitrage. When arbitrage occurs, the price spread would equal transfer costs and so the error term would be bounded at zero. This error is therefore assumed to be half-normal in distribution. The second error term (v_t) is the amount price differential exceeds transfer costs when transportation bottlenecks or other impediments obstruct arbitrage. Again this error term is distributed as a half-normal; it is a positive addition to the transport costs.

In this specification, when trade takes place, the distribution of the error terms takes the standard normal density function. The distribution function of the sum of a symmetric normal random variable and a truncated normal random variable was first derived by Weinstein (1964). In Baulch (1995), two scenarios incorporate the Weinstein distribution. When there is no trade and inter-market spread is less than transfer costs, the total error term is $\varepsilon_t = e_t + u_t$, with $u_t \leq 0$. The density of the sum of the normal error term and a negative half normal term is given by Weinstein:

$$f(\varepsilon) = \frac{2}{\sqrt{\sigma_e^2 + \sigma_u^2}} \phi\left(\frac{\varepsilon}{\sqrt{\sigma_e^2 + \sigma_u^2}}\right)\left[1 - \Phi\left(\frac{\varepsilon \cdot \sigma_e / \sigma_v}{\sqrt{\sigma_e^2 + \sigma_u^2}}\right)\right] \quad (1)$$

where the σ terms are the standard errors of the error terms, $\phi(.)$ is the normal density function and $\Phi(.)$ is the cumulative normal distribution. Replacing u

with $-v$ in equation (1), allows the distribution of the third scenario to be expressed.

The present analysis assumes that the transfer cost is symmetrical. That is, the cost of transferring between two markets is independent of the direction of travel. This simplifies the model, allowing absolute differences to be used. Three regimes then isolate the main features of the trading/non-trading switch. When the two markets are trading:

REGIME 1: Price differential equals the cost of transfer, i.e.:

$$\log\left|p_i - p_j\right| = m_{ij} + e\,. \tag{2}$$

However, when there is no trade equation (2) is a strict inequality so that:

REGIME 2: Price difference is less than the cost of transfer, i.e.:

$$\log\left|p_i - p_j\right| < m_{ij} + e \tag{3}$$

The third regime occurs when there is some impediment to trade, stopping arbitrage and allowing price spreads to exceed transfer costs:

REGIME 3: Price difference exceeds the cost of transfer, i.e.:

$$\log\left|p_i - p_j\right| > m_{ij} + e \tag{4}$$

where p_i gives the price in a market i and m_{ij} is the average cost of transfer from market i to market j. It is assumed that the cost of transfer is stochastic, deviating from the mean value by an error, $e \sim N(0, \sigma_e)$.

The stochastic frontier literature proceeds by integrating a further term to capture to what extent an economy is within the frontier. This allows (2) and (3) to be combined to give:

$$\log\left|p_i - p_j\right| = m_{ij} + e - u\,. \tag{5}$$

where u would take the value zero in the first regime, equation (1), a positive value in regime 2, equation (2) and zero in regime (3). It is assumed that u is normally distributed, truncated to the left at zero, with standard deviation σ_v. The distribution of v assumed is again 'half-normal' (Baulch (1997)). Further,

(2) and (4) can be combined by introducing a third error term, v, again with a half-normal distribution but this time the error is added to the transfer cost:

$$\log\left|p_i - p_j\right| = m_{ij} + e + v\,. \tag{6}$$

The error v would take the value zero in the first regime and second regimes and a positive value in regime 3.

Assuming that the probability of regime 2 occurring is λ_1 and of regime 3 is λ_2, so that regime 1 occurs with probability $(1\text{-}\lambda_1\text{-}\lambda_2)$ and incorporating Weinstein's (1968) result regarding the density of the half-normal distribution, a log-likelihood function can be written down. Following Sexton et al. (1991), the likelihood function for the parity bounds model may be specified using these results as:

$$L = \prod_{t=1}^{T}[(1-\lambda_1-\lambda_2)f_t^{\,1} + \lambda_1 f_t^{\,2} + \lambda_2 f_t^{\,3}] \qquad \lambda_1, \lambda_2 \in [0,1] \tag{7}$$

where

REGIME 1: Trade as price difference equals transfer costs

$$f_t^{\,1} = \frac{1}{\sigma_e}\phi\left[\frac{d_t - m}{\sigma_e}\right]$$

REGIME 2: Price differentials inside the transfer costs

$$f_t^{\,2} = \left[\frac{2}{\left(\sigma_e^2 + \sigma_u^2\right)^{1/2}}\right]\phi\left[\frac{d_t - m}{\left(\sigma_e^2 + \sigma_u^2\right)^{1/2}}\right]\left[1 - \Phi\left[\frac{(d_t - m)\sigma_u/\sigma_e}{\left(\sigma_e^2 + \sigma_u^2\right)^{1/2}}\right]\right]$$

Regime 3: Price differential exceeds transfer costs

$$f_t^{\,3} = \left[\frac{2}{\left(\sigma_e^2 + \sigma_v^2\right)^{1/2}}\right]\phi\left[\frac{d_t - m}{\left(\sigma_e^2 + \sigma_v^2\right)^{1/2}}\right]\left[1 - \Phi\left[\frac{-(d_t - m)\sigma_v/\sigma_e}{\left(\sigma_e^2 + \sigma_v^2\right)^{1/2}}\right]\right]$$

Here, $(1\text{-}\lambda_1\text{-}\lambda_2)$ and λ_1 denote the probabilities for regimes 1 and 2, those which the Takayama-Judge model highlighted. The cost of transfer between the two markets is m. The absolute price differential between the two markets is denoted by d_t. The σ terms are each the standard errors of the three error terms, e_t, u_t and v_t.

The likelihood function combines the probability of falling within one of the three regimes and the density function of the observed price differential. Within the first regime, the density function is simply that of a normal distribution. However, in the other two regimes, Weinstein's result, equation (1), regarding the density of a truncated normal distribution function is used (Weinstein (1964)).

5.2 Stochastic switching models

Chapter 4 highlights how pairs of regions can be expected to switch between periods of trade and non-trade. In the model, trade with another region, stored grain and sourcing grain from an external market are all substitutes in meeting the consumption needs of a region. A model more simple than Baulch's Parity Bounds model, switching between two regimes - inter-regional trade and no inter-regional trade - can also applied to the data. This applies the stochastic frontier model of Aigner et al. (1977) (ALS) to food market price data. The ALS model is 'nested' within the PBM model as it merely contains two of the three PBM regimes. The two regimes are those already given as equations (2) and (3) above.

In the ALS specification, the extent to which an economy is within a production frontier is modelled in terms of two stochastic components. One is the uncertainty about the actual position of the frontier; a second component is an economy's inefficiency in not reaching the frontier of production. An economy can either lie on the frontier, in which case the latter component is zero, or it may be 'inefficient' in which case this latter component is negative. A similar method is applied in this section to model the switch between trading (when the inter-market spread is at the frontier of the transfer cost) and non-trading (when the inter-market spread is below the cost of transfer).

$$L = \prod_{t=1}^{T} [\lambda f_t^1 + (1-\lambda) f_t^2] \qquad . \qquad \lambda \in [0,1] \tag{8}$$

where

REGIME 1: Trade as price difference equals transfer costs

$$f_t^1 = \frac{1}{\sigma_e} \phi \left[\frac{d_t - m}{\sigma_e} \right]$$

REGIME 2: Price differentials insider the transfer costs frontier

$$f_t^2 = \left[\frac{2}{\left(\sigma_e^2 + \sigma_u^2\right)^{1/2}} \right] \phi \left[\frac{d_t - m}{\left(\sigma_e^2 + \sigma_u^2\right)^{1/2}} \right] \left[1 - \Phi \left[\frac{(d_t - m)\sigma_u / \sigma_e}{\left(\sigma_e^2 + \sigma_u^2\right)^{1/2}} \right] \right]$$

where regional subscripts have been suppressed and $d = \log|p_i - p_j|$ and $m = \log m_{ij}$.

A similar specification to (8) can be derived by restricting the PBM model to regimes 1 and 3. In this specification, markets are either trading so that price spreads equal transfer costs or there is some impediment to trade allowing price spreads to be significantly above the cost of transfer. Under these conditions, the estimated log-likelihood function becomes:

$$L = \prod_{t=1}^{T} [\lambda' f_t^1 + (1-\lambda') f_t^3] \qquad \lambda^{\underline{o}} \in [0,1] \tag{9}$$

where

REGIME 1: Trade as price difference equals transfer costs

$$f_t^1 = \frac{1}{\sigma_e} \phi \left[\frac{d_t - m}{\sigma_e} \right]$$

REGIME 3: Price differentials outside the transfer costs frontier

$$f_t^3 = \left[\frac{2}{\left(\sigma_e^2 + \sigma_v^2\right)^{1/2}} \right] \phi \left[\frac{d_t - m}{\left(\sigma_e^2 + \sigma_v^2\right)^{1/2}} \right] \left[1 - \Phi \left[\frac{-(d_t - m)\sigma_v / \sigma_e}{\left(\sigma_e^2 + \sigma_v^2\right)^{1/2}} \right] \right].$$

6. Analysis of Maize Prices in Tanzania

6.1 Model Estimation

To estimate these models, the data are transformed by taking the absolute price difference between pairs of markets, adding one, then by taking logs and finally by subtracting the log of the cost of transfer. The addition of one to the absolute price spread ensures that the log of the absolute spread is always positive. A first issue to address is the lag structure on the price differencing operation. The price time-series is monthly and slowness in arbitrage may cause one market price to lag behind another. The literature (Bryceson, 1993) suggests that Dar es Salaam's size makes it a leading market so that *a priori* the market may be a price leader. Other markets would follow the port suggesting a period lag on Dar es Salaam's data. No similar hypothesis is made about the other markets.

The models are estimated in Limdep (Greene (1992)) where the 'minimize' function is used to give parameter estimates and measures of the standard error. However, the *t*-statistics for the parameters must be treated with caution. Firstly, the hypothesis that λ=0 or λ=1 would be a boundary restriction (Gourieroux et al. (1982)) so that *t*-values cannot be used to test for significance. Further, the tested hypothesis on λ would necessarily imply a particular value for the estimates of the standard errors (zero) and the effect on these 'nuisance' parameters invalidates the standard likelihood ratio tests. This can be seen when estimates of λ approach either one or zero as *t*-statistics or standard errors tend to infinity. In these circumstances, the model is assumed to be miss-specified and the model is reparameterised assuming fewer regimes. Even when sensible estimates of λ result, Baulch suggests that the standard error results are viewed with caution. Estimates are best seen in terms of the parameter estimates and not the distribution of estimated parameters. Then, the λ terms can be viewed as the proportion of time in a particular regime.

The AIC criterion is also used to test the switching model against an alternative non-switching specification. When the model was estimated without any switching, so that λ was set to one, it was effectively simplified into a model where the absolute price spread, less cost of transfer, is normally distributed with zero mean. The only estimated parameter becomes the standard deviation of the deviation of the price spread from transfer cost. An AIC criterion for model selection is offered in Judge et al. (1982) (chapter 21). Tables 5 through to 9, which present model estimation results, also indicate the extent to which the log-likelihood of the switching model exceeds that of the non-switching model. If this is greater than the number of additional parameters (two or four) for the switching models, this is evidence in support of the switching model.

The 'minimize' function in Limdep does not easily allow the inclusion of parameter constraints. In the present models, the term λ is a probability and must be between zero and one. In the PBM model, the sum of the two probabilities, $(\lambda_1+\lambda_2)$, as well as the individual probabilities must meet these conditions. The standard error estimates, meanwhile, are constrained to be positive. The latter constraints were met by using the substitution $\sigma_{\bullet} = s_{\bullet}^2$. For the other terms, the following substitutions were employed. In the simpler model with only two regimes, a standard econometric method for limiting the estimate of λ or λ' to being between zero and zero is used:

$$\lambda = 1/(1+e^{l}). \tag{10}$$

$$\lambda' = 1/(1+e^{l'}) \tag{11}$$

In the PBM model, λ_1 is first constrained to lie between zero and one. Then the λ_2 is constrained to be between zero and $(1-\lambda_1)$.

$$\lambda_1 = 1/(1+e^{l_1}); \tag{12}$$

$$\lambda_2 = (1-\lambda_1)/(1+e^{l_2}) = \frac{1-1/(1+e^{l_1})}{1+e^{l_2}} \qquad (13)$$

It must be noted that the parameters actually estimated in Limdep - l, l', l_1 and l_2 - can all lie anywhere in the real number set. To then estimate the actual parameters, these values can be substituted into equations (10)-(13) to give estimates, $\hat{\lambda}$, $\hat{\lambda}'$, $\hat{\lambda}_1$ and $\hat{\lambda}_2$. However, no simple substitution can give the standard errors of the parameter estimates. To calculate the standard errors of the parameters, the minimisation routine in Limdep is run for zero iterations using the actual likelihood functions (equations (7), (8) and (9) above) using the $\hat{\lambda}$, $\hat{\lambda}'$, $\hat{\lambda}_1$ and $\hat{\lambda}_2$.

6.2. The Parity Bounds Model (Baulch, 1994)

The parity bounds model of Baulch (1994) was estimated using the 'minimize' routine in Limdep. This model allows for three inter-market regimes. As well as regime 1, where there is trading so that price spread equals the cost of transfer, the second regime (no trade as price spread is less that transfer costs) and the third regime (no trade despite a significant price incentive) are allowed. This general model is here compared against one where no switching is allowed. The 'no switch' model is a maximum likelihood estimate with only regime 1. In this model, there are no λ to estimate and only one standard error, σ_e, to model. A summary of the results of this estimation is presented in table 5. The estimates of the standard error are all highly significant and vary from 0.77 to 1.12 for Dar es Salaam trading with the other five markets. In the other market pairs, where transfer costs were crudely estimated, the range of standard errors is 0.65 to 1.35. These are estimates of the standard error of the costs of transfer, a variable which will be used for analysis later.

The table also summarises the log-likelihoods of the PBM model. The addition of two regimes implies the estimation of four additional parameters - λ_1, λ_2, σ_u and σ_v - and the table presents the log-likelihood results of this. A likelihood ratio test can be performed using the 'no switch' model as a benchmark. An improvement in the log-likelihood of more than the number of additional parameters - four - would imply a significant improvement in model performance. Table 5 indicates that the PBM model is not an improvement in any of the market pairs. The results indicate that none of the market pairs switch between all three regimes. Full results are given in the appendix to this chapter. There it can be seen that the minimisation routine fails to identify the model and the covariance matrix becomes singular. This is an indication that the model is over-specified and the number of parameters needs to be reduced. This is done in the models switching between two regimes presented below.

Table 5

Results of Estimation of Model (8) for Dar es Salaam

	Dar ↔ Arusha	Dar ↔ Iringa	Dar ↔ Mbeya	Dar ↔ Shiny'ga	Dar ↔ Songea
σ_e	1.105	1.108	0.985	1.115	0.768
	(0.04)	(0.03)	(0.03)	(0.03)	(0.06)
No. of Obs.	59	59	59	59	59
Log-likelihood					
with switch	-95.4	-95.0	-82.0	-96.6	-52.8
with no switch	-95.4	-95.9	-82.0	-96.6	-52.8

	Arusha ↔ Iringa	Arusha ↔ Mbeya	Arusha ↔ Shiny'ga	Arusha ↔ Songea	Iringa ↔ Mbeya
σ_e	1.352	1.285	1.104	0.620	1.223
	(0.06)	(0.05)	(0.04)	(0.03)	(0.04)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-121.4	-115.2	-97.0	-27.8	-109.2
with no switch	-121.4	-115.2	-97.0	-27.8	-109.2

	Iringa ↔ Shinyanga	Iringa ↔ Songea	Mbeya ↔ Shinyanga	Mbeya ↔ Songea	Shiny'ga ↔Songea
σ_e	1.243	0.763	1.229	0.778	0.647
	(0.3)	(0.04)	(0.03)	(0.03)	(0.02)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-111.2	-52.6	-109.8	-55.0	-33.0
with no switch	-111.2	-52.6	-109.8	-55.0	-33.0

Note: standard errors in parenthesis.

6.3 The Stochastic Frontier Model

Tables 6 to 9 indicate the model estimates for Dar es Salaam and the other markets. Tables 6 and 7, which consider the nature of trading between Dar es Salaam and the five other markets, uses the cost of transfer as estimated by Bryceson through her survey work. The estimate of parameters λ and λ' indicate the extent of switching between regimes. Table 6 presents results of estimating the extent of switching between regimes 1 (trading) and 2 (no trading because the price difference is less than the cost of transfer). At the foot of the table, there is some evidence for the appropriateness of this model. The log-likelihood when there is no switching allowed is indicated and can be compared against the log-likelihood of the estimated equation (8). In all the markets except Songea, there is evidence in support of the model. The log-likelihood rises by more that 2, the number of additional parameters modelled when (8) is estimated rather than a model without regime switching. This is a likelihood ratio test with the likelihood ratio merely the difference in the log-likelihoods.

Table 6

Results of Estimation of Model (8) for Dar es Salaam

	Dar ↔ Arusha	Dar ↔ Iringa	Dar ↔ Mbeya	Dar ↔ Shinyanga	Dar ↔ Songea
λ	0.219	0.780	0.751	0.421	0.513
	(0.09)	(0.07)	(0.09)	(0.10)	(0.02)
σ_e	0.333	0.521	0.434	0.424	0.592
	(0.07)	(0.07)	(0.06)	(0.08)	(0.13)
σ_u	1.328	2.371	1.741	1.536	0.000
	(0.140)	(0.58)	(0.74)	(0.23)	(14798)
No. of Obs.	59	59	59	59	59
Log-likelihood					
with switch	-73.0	-76.8	-65.0	-77.8	-52.8
with no switch	-95.4	-95.9	-82.0	-96.6	-52.8

Note: standard errors in parenthesis.

The proportion of the sample time where there is trading varies considerably across market pairs. In Iringa and Mbeya, for more than 70% of the time, the price differences in the market are equal to transfer costs suggesting that regime 1 dominates in trade between Dar es Salaam and these markets. This implies that the variation in inter-market spread is explained by the variation in the cost of transfer between the market and not by long periods where the markets are not trading. Between Dar es Salaam and Arusha and Shinyanga, the extent of trading is much lower: Arusha trades for approximately 22% of the time while Shinyanga trades 42%.

For a market analyst, the results in table 6 indicate that four of the five markets are integrated with the central market of Dar es Salaam. The markets spend significant amounts of time trading with the Dar es Salaam. When there is no trading, this is not because of any impediments to trade which would be a cause for concern. Rather, the markets are not trading because equilibrium prices in each market make inter-market transfers unprofitable. This is not the case in the Dar-Songea pair. Table 6 indicates that a model which allows for switching between regimes 1 and 2 is no better at explaining the observed behaviour than one with no switching. Table 7, meanwhile, indicates results of estimating a model which allows for switches between regime 1 (trading) and regime 3 (impediments to trade allow price spreads to exceed transfer costs).

Firstly, it is worth noting that in the other four market pairs, the introduction of regime 3 does not add explanatory power. The likelihood ratio test gives a figure close to zero. Also, the parameter estimate of σ_v is zero in all four market pairs. This signifies that the addition of a positive, half-normally distributed error term, v, to the non-switching model is a miss-specification. However, with Dar es Salaam and Songea, the estimation results are an improvement on the model with no switching. This result indicates that when the Songea-Dar pair is not trading, the periods of non-trade have price spreads which *exceed* transfer costs. There clearly is some impediment to trade as, under such circumstances, arbitrage should ensue.

Table 7

Results of Estimation of Model (9) for Dar es Salaam

	Dar ↔ Arusha	Dar ↔ Iringa	Dar ↔ Mbeya	Dar ↔ Shinyanga	Dar ↔ Songea
λ'	0.536	0.479	0.435	0.534	0.000
	(1.00)	($9\text{x}10^7$)	(1.00)	(1.00)	(0.19)
σ_e	1.220	1.229	0.971	1.243	0.233
	(1.00)	(0.35)	(1.00)	(1.00)	(0.06)
σ_v	0.000	0.000	0.000	0.000	0.545
	(1.00)	(17314)	(1.00)	(1.00)	(0.139)
No. of Obs.	59	59	59	59	59
Log-likelihood					
with switch	-95.4	-95.9	-82.0	-96.6	-23.6
with no switch	-95.4	-95.9	-82.0	-96.6	-52.8

Note: standard errors in parenthesis.

A similar analysis was performed on the remaining market pairs. Tables 8 and 9 indicates the results of this analysis. In this analysis, crude estimates of inter-market transfer costs, based on Bryceson's survey work and geographical distances, were employed. No lag structure was assumed so that contemporaneous data was used in calculating market differences (see table 2)[10]. Consider table 8 which presents the results of the model which has switching between regimes 1 and 2. In three market pairs - Arusha-Songea, Iringa-Songea and Mbeya-Songea - the model does not add explanatory model in comparison to the model with no switching. As with the results of Dar es Salaam, it is Songea town which proves problematic.

[10] A variety of lag structures were tested but no consistent behaviour could be identified.

In the other market pairs the model performs better. However, the probability of market trading is highly variable, with λ, the proportion of time in regime 1, being near zero in many market pairs. Arusha appears to trade very rarely with the other markets. It is a northern market and so one of the more remote markets. This contrasts with Iringa, a central market. Iringa is trading with its neighbours for nearly half the time.

Table 8

Results of Estimation of Model (8) for Regional Markets

	Arusha ↔ Iringa	Arusha ↔ Mbeya	Arusha ↔ Shiny'ga	Arusha ↔ Songea	Iringa ↔ Mbeya
λ	0.000	0.215	0.001	0.002	0.503
	(0.21)	(0.09)	(0.20)	(27.19)	(0.12)
σ_e	0.793	0.365	0.533	0.369	0.722
	(0.33)	(0.08)	(0.169)	(0.40)	(0.12)
σ_u	1.648	1.818	1.097	0.107	1.855
	(0.33)	(0.23)	(0.19)	(2.94)	(0.31)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-97.5	-88.5	-74.3	-26.3	-95.4
with no switch	-121.4	-115.2	-97.0	-27.8	-109.2

	Iringa ↔ Shiny'ga	Iringa ↔ Songea	Mbeya ↔ Shiny'ga	Mbeya ↔ Songea	Shiny'ga ↔Songea
λ	0.495	0.509	0.219	0.526	0.905
	(0.01)	(10^7)	(0.11)	(10^7)	(10^7)
σ_e	0.454	0.581	0.412	0.605	0.333
	(0.06)	(0.63)	(0.10)	(0.04)	(0.03)
σ_u	2.076	0.000	1.643	0.000	0.826
	(0.25)	(22225)	(0.13)	(331)	(0.51)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-86.0	-52.6	-83.6	-55.0	-28.3
with no switch	-111.2	-52.6	-109.8	-55.0	-33.0

Note: standard errors in parenthesis.

The market at Songea, which is the southernmost, is the least likely to be trading with the other markets. Its behaviour with Shinyanga, in the extreme north is curious in this regard. While this is the longest distance between markets, the markets are trading nearly 87% of the time. Songea's trade with the other markets is very low and table 9 explores whether some impediment to trade may explain the behaviour. Songea is located on the other side of the Rubeho mountains. The mountains stretch east-west separating the southern part of Tanzania, south of Iringa, from the rest of the country. The only pass is the Songea-Mbeya road and this road has only recently (in 1995) been surfaced. The costs of transfer estimates may be too low or there may be some impediments to trade. This would explain the results of estimating the model with regimes 1 and 3 presented in table 9. With the Iringa market, market spreads are above transfer costs for almost all of the time. For the Mbeya-Songea pair, the inclusion of regime 3 improves the explanatory power of the models but not significantly.

In two market pairs - Arusha-Songea and Mbeya-Songea - the inclusion of switching into the model is not appropriate. Allowing the markets to switch between regimes 1 and 2 and between 1 and 3 does not add significantly to explanatory power. This implies that the simple 'no switch' model gives the best estimate of the standard error of transfer costs. In the next section, the estimates of the standard errors for the 15 market pairs will be used.

Table 9

Results of Estimation of Model (9) for Regional Markets

	Arusha ↔ Iringa	Arusha ↔ Mbeya	Arusha ↔ Shiny'ga	Arusha ↔ Songea	Iringa ↔ Mbeya
λ^{o}	0.489	0.497	0.537	0.534	0.489
	(10^7)	(10^7)	(10^7)	(10^7)	(1.00)
σ_e	1.832	1.656	1.219	0.384	1.494
	(0.24)	(0.22)	(0.16)	(0.04)	(1.00)
σ_v	0.000	0.000	0.000	0.000	0.000
	(2890)	(1964)	(1458)	(1237)	(1.00)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-121.4	-115.2	-97.0	-27.8	-109.2
with no switch	-121.4	-115.2	-97.0	-27.8	-109.2

	Iringa ↔ Shiny'ga	Iringa ↔ Songea	Mbeya ↔ Shiny'ga	Mbeya ↔ Songea	Shiny'ga ↔Songea
λ^{o}	0.486	0.000	0.496	0.000	0.543
	(10^7)	(0.32)	(10^7)	(9.69)	(1.00)
σ_e	1.546	0.332	1.511	0.578	0.419
	(0.17)	(0.06)	(0.17)	(0.25)	(1.00)
σ_v	0.000	0.477	0.000	0.180	0.000
	(724)	(0.14)	(750)	(1.70)	(1.00)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-111.2	-32.4	-109.8	-53.2	-33.0
with no switch	-111.2	-52.6	-109.8	-55.0	-33.0

Note: standard errors in parenthesis.

6.4 Seasonality in Trade Switching

The results of the previous analysis are now used to analyse the seasonality in the regime switches. This is achieved through looking at the behaviour of market spreads in all the market pairs. For each month, whether the absolute difference in market prices less the cost of transfer between the markets is significantly different from zero can be calculated. The upper and lower bound on the market spread less transfer cost was calculated using the estimate of the standard deviation of the error *e*. This measure was taken either from estimates provided by switching models or from the 'no switch' model. Table 10 indicates the estimates used.

Table 10

Results of Estimation of Model (8) for Dar es Salaam

	Dar ↔ Arusha	Dar ↔ Iringa	Dar ↔ Mbeya	Dar ↔ Shinyanga	Dar ↔ Songea
σ_e	0.333	0.521	0.434	0.424	0.233
Model	Switch Regime 1&2	Switch Regime 1&2	Switch Regime 1&2	Switch Regime 1&2	Switch Regime 1&3

	Arusha ↔ Iringa	Arusha ↔ Mbeya	Arusha ↔ Shiny'ga	Arusha ↔ Songea	Iringa ↔ Mbeya
σ_e	0.793	0.365	0.533	1.104	0.722
Model	Switch Regime 1&2	Switch Regime 1&2	Switch Regime 1&2	No switch	Switch Regime 1&2

	Iringa ↔ Shiny'ga	Iringa ↔ Songea	Mbeya ↔ Shiny'ga	Mbeya ↔ Songea	Shinyanga ↔Songea
σ_e	0.454	0.332	0.412	0.778	0.333
Model	Switch Regime 1&2	Switch Regime 1&3	Switch Regime 1&2	No switch	Switch Regime 1&2

Table 11 presents the analysis of the seasonality in price spreads. For each market pair, the individual monthly spreads, adjusted by the cost of transfer, was considered. If the value vas significantly below zero (at 5 %), the month was considered to be one where the price spread was significantly negative. This meant that the market pair was in regime 2 in this particular month. If, again at 5%, the price spread less than the transfer costs was positive, this was taken to mean the market pair were in regime 3. All other observations meant the market was in regime 1, i.e. trading was occurring. Price spread is significantly positive on one occasion across all the market pair observations and significantly negative 67 times (out of a total of 895 market spread observations). Thus, it is uncommon for price differences to *exceed* the cost of transfer significantly. This may be viewed as a sign that markets are working efficiently as it indicates that excessive price spreads are attracting arbitrage.

When the price spread is significantly below parity level, regime 2 is prevalent; trade is not taking place because the clearing prices in each market differ too little to attract arbitrage. The number of times this is observed has been noted in table 11 by month. In total, for Dar es Salaam, there were 295 market price differences (59 observations for each of the five regional markets). Twenty-three of the observed months gave evidence that trade did not take place. In the regional markets, the ten possible market pairs were considered. Of the 600 price differences, forty-four provided evidence that trade was not taking place. The percentage were 7.7 and 7.4 respectively.

It is the seasonal patterns which is most interest. Table 3 indicates the frequency of the months where market prices differ by less than the cost of transfer. It is noticeable that such months are concentrated in the pre-harvest period October to February. Inter-regional trade becomes less likely in the later part of the agricultural year. This is consistent with the model in chapter 4 summarised earlier in this chapter. Storing grain within a region for sale later in the year incurs storage costs so that external markets may become cheaper sources for grain later in the year as the next harvest approaches.

Table 11

Frequency of Within Bounds Observations

Month	Agricultural Season	Dar es Salaam	Regional Markets	Total Observations inside Parity Bounds
January		1	7	8
February		4	8	12
March	Harvest	1	2	3
April	Harvest	1	4	5
May	Harvest	1	3	4
June		0	2	2
July		1	4	5
August		0	3	3
September		1	3	4
October		3	3	6
November		4	2	6
December		6	2	8
Total		23	44	67
Observations		295	600	895

Also, there is no some evidence of a lull in trading in the harvest period itself. In the model set out earlier, the harvest months saw a replenishment of regional stocks of grain and during this initial period, regions can consume from own harvest. However, as noted earlier, this period could be quite short if harvest levels were low in one of the market pairs. Thus, these results are more consistent with regional markets being linked with an urban area where there is no significant harvest or stocks of grain making T_1 closer to zero.

7. Concluding Remarks

A model is presented in chapter 4 which highlights that trading is seasonal in the market for grains when there is significant storage. Prior to liberalisation, data on government purchases and sales of foodgrains certainly bore out seasonal peaks in marketing. However, price analysts working in developing country food markets rarely integrate seasonality into their analyses of market efficiency. One of the consequences of seasonality is that it is optimal to be consuming stored grains or switching to external markets rather than trading with a neighbouring region. Baulch (1997) identifies that when breaks of trade are significant, this may invalidate the use of the most common tests of food market integration.

Using Tanzanian price data, this issue is explored further in this chapter. Price spreads between pairs of rural markets are analysed to identify whether there were periods without trade. The analysis uses a stochastic frontier modelling approach and the use of such a model was generally borne out as providing a better explanation of observed data than a model without switching. In most of the market pairs, trade occurs for most of the sample period. The probability that a market is trading is estimated at above 50% for most market pairs. Trade is shown to be least likely with the most remote market.

When looking at the timing of breaks in inter-regional trade, some tentative conclusions can be drawn. It should be noted that, though some seasonality is apparent, the frequency of non-trading months is low. Post-harvest, there is some evidence of a lull in trading; trade begins in June. As the year progresses, inter-regional market trading becomes less significant. These two findings are consistent with the model. Section 2 indicates that the model predicts that inter-regional trade becomes less likely at the start of the agricultural year because stocks have been replenished. Later in the agricultural year, the external market supplies a region. This is because storing grain within a region for sale later in the year incurs storage costs so that external market becomes the cheaper source for grain.

Appendix to Chapter 7

Table A1

Results of Estimation of PBM Model for Dar es Salaam

	Dar ↔ Arusha	Dar ↔ Iringa	Dar ↔ Mbeya	Dar ↔ Shinyanga	Dar ↔ Songea
λ_1	0.000	0.000	0.000	0.000	0.000
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
λ_2	0.000	0.000	0.000	0.000	0.000
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_e	1.220	1.210	0.990	1.338	0.346
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_u	9.382	18.240	0.692	3.494	1.083
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_v	9.382	15.945	0.634	9.280	1.062
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
No. of Obs.	59	59	59	59	59
Log-likelihood					
with switch	-95.4	-95.0	-82.0	-96.6	-52.8
with no switch	-95.4	-95.9	-82.0	-96.6	-52.8

Note: standard errors in parenthesis.

Table A2

Results of Estimation of PBM Model for Regional Markets

	Arusha ↔ Iringa	Arusha ↔ Mbeya	Arusha ↔ Shinyanga	Arusha ↔ Songea	Iringa ↔ Mbeya
λ_1	0.000	0.000	0.000	0.000	0.000
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
λ_2	0.000	0.000	0.000	0.000	0.000
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_e	1.829	1.652	1.219	0.385	1.495
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_u	1.011	0.954	6.608	4.276	0.829
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_v	1.011	0.866	27.036	4.610	0.693
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-121.4	-115.2	-97.0	-27.8	-109.2
with no switch	-121.4	-115.2	-97.0	-27.8	-109.2

	Iringa ↔ Shinyanga	Iringa ↔ Songea	Mbeya ↔ Shinyanga	Mbeya ↔ Songea	Shinyanga ↔Songea
λ_1	0.000	0.000	0.000	0.000	0.000
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
λ_2	0.000	0.000	0.000	0.000	0.000
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_e	1.545	0.581	1.510	0.606	0.419
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_u	0.822	0.647	0.849	0.650	15.267
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
σ_v	0.667	0.768	0.620	0.708	16.213
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
No. of Obs.	60	60	60	60	60
Log-likelihood					
with switch	-111.2	-52.6	-109.8	-55.0	-33.0
with no switch	-111.2	-52.6	-109.8	-55.0	-33.0

Note: standard errors in parenthesis.

CHAPTER 8:

Conclusions

1. Overview

The marketing systems of Tanzania and Zimbabwe have undergone enormous reform in the last two decades. State-owned marketing boards dominated the grain markets of both countries in the early 1980s. Private trade was suppressed with the private movement of large quantities of maize prohibited. The processing of grains was highly regulated. By 1995, both countries had allowed the role of the private sector to increase by removing the restrictions on private trade. At the same time, subsidies given to the food marketing system have been withdrawn.

This thesis has modelled and empirically analysed the staple grain marketing systems of Tanzania and Zimbabwe. The two countries have much in common with other countries of sub-Saharan Africa, such as Zambia, Malawi, South Africa and Kenya, so that the findings will have a wider relevance. All six countries grow and consume white maize with the crop being the main staple both in terms of production and consumption. White maize production and consumption outside of these countries is very rare so that international markets in the crop are thin. The countries also share a common colonial past so that the government institutions acting in the food markets have a similar structure and history.

The need to measure the performance of the newly liberalised marketing system has spurred an interest in empirical tests of market behaviour. The most common tests have used time-series data regarding the market price of maize. If the price movements across markets are correlated, then this is evidence that arbitrage is occurring and the markets are performing 'well'. When prices are moving apart, inter-regional transfers of grain are not occurring despite the existence of price incentives and there may be some impediment to trade.

The thesis begins by characterising the economics of the white maize market. There is a single annual harvest across southern Africa with all the main producers harvesting sometime in April-May. The single harvest implies that grain stocks must be maintained, by households, private companies and/or governments, so that consumption needs are met for the year until the following harvest. The costs of storage - both the physical cost of maintaining storage systems and the capital costs of tying up resources in grain - are high. Research cited in chapter 2 highlights that capital markets remain under-developed and so the rate of discount is very high.

Food marketing in the region is further complicated by the poor transport infrastructure of the countries. Some countries have invested in the road and rail system, e.g. South Africa. However, Tanzania especially and Zimbabwe to a lesser extent has a high proportion of producers in remote areas. Grain movements involve transfers across long distances using poor quality roads and vehicles. Transport costs are very high.

Food market analysts have concerned themselves with both grain trade and the storage of grain. Inter-regional trade has been researched, looking into the extent to which transfers across countries could off-set localised production failures. Also, the extent to which storage of grains could be used to spread the effects of a production shortfall in a particular year has also been explored. This thesis has combined the two aspects and investigate how they interact. A central finding of the research is that storage and inter-regional trade may be substitutes in meeting consumer needs. Further, this research has explored the dynamics of the substitution between the various sources for grain.

In January 1998, there were food riots in Harare. Maize flour prices had been raised as the grain millers passed on to consumers the rise in the cost of white maize grain. The following year saw further price rises amidst a flurry of activity by all the main actors in the food marketing system: producer groups, marketing agencies, government etc.. Reform of food markets has remained politically contentious and the conclusions of this thesis must be taken with a caution: political climate also affects food markets. Given the socio-political importance of the market for staples, the effect of the actions of key stakeholders is sometimes greater in magnitude than the economic aspects that have been modelled and analysed in this research.

2. Research Answers

The introductory chapter posed two questions. The first asked if storage and trade interacted in meeting food needs. The thesis confirms that this interaction takes place and is significant. The intuition behind the result is that storage and trade can substitute for each other as sources of grain. In countries where there is a single annual harvest and high costs to storage and inter-regional trade, this will result in consumption needs being met through different sources at different times in the year. The mathematical program analyses the optimal behaviour. The empirical chapters verify that the predicted seasonality is observed.

The second question asks whether the interaction is important. The way trade and storage combine proves to be important because it undermines a very common belief: that inter-market trade should occur continuously over the year for marketing systems to be functioning 'well'. Such an expectation has been assumed in common tests of market integration. However, the optimal program proves that trade would be intermittent even in a well-functioning market. This seasonality in trade implies that price co-movements need not be observed year-round, though price differences will never exceed the cost of transfer. Hence, the observation that markets are integrated in the long-run but not integrated in the short-run is entirely consistent with a marketing system with significant seasonality.

The switching between trade and storage results in a further caution for policy: there is a need to ask what market prices are telling us. Market analysts have used time-series price information to measure market performance. Plotting out the inter-market spread over time (the absolute difference in market prices) offers a quick summary of the functioning of the marketing system. However, if there is seasonality in inter-regional transfers, the volume and direction of market trades becomes relevant. At times when trading levels are high, the inter-market spread should equal the cost of transfer. However, when a regional market is being supplied by either stores or the external market, this variable is less significant. Therefore, the inter-market spread is only useful with more information about flows of trade.

A similar problem may affect a second common summary variable, the average price level over the year. This variable is very useful for measuring the effects of reform but only for certain groups within the population. In the cities, households do not produce any grain but purchase from the market at a steady rate throughout the year. A lower average market price will unambiguously reduce annual expenditure on maize. A fall in the average price level would therefore translate into welfare gains for the urban households.

However, the average price is less informative when considering rural areas where households produce their own grains and so do not wholly rely on the market. Consider two different situations, but which result in the same average price level. In the first situation, maize prices are constant throughout the year; in the second, there is a low price level after harvest and a high price during the lean period ahead of the harvest. This second scenario is very common in rural markets. Now consider grain flows: post-harvest, a rural market is selling grains while later in the year it is often drawing in supplies from other markets.

Seasonality in trade makes welfare assessments on the basis of the average price problematic.

3. Specific Conclusions

1) Chapter 4 models two regions which can store or trade their harvested grains. Further, to capture the government marketing boards, which have played a significant role post-reform, an external market is modelled. Some conclusions of the model can be highlighted:

> In a model of inter-regional trade where there is a single harvest at the start of the period and an external market which fixes a low buying and a high selling price, it is proven that trade may be intermittent. In particular, regions would first source consumption from own stocks, then trade and finally purchase grain from the external market until the following years' harvest.

2) The model is analysed using an optimal control framework. The results provided therefore indicate the optimal storage and trade decisions over a year to meet the consumption needs of a pair of regions. The dynamic behaviour observed is predicated on an important underlying pricing rule:

> The cost of transferring grain between markets is constant. The price of stored grain rises over time due to storage costs. As the absolute price rise in a period is less in areas where grain stocks are high than in areas with low stocks, the price spread between two such regions will rise over time. A region with less grain will therefore buy from its neighbour, incurring the constant transfer costs, later in the year when the price spread equals the cost of transfer.

3) The price of grain in the two markets is given by costate variables so that the inter-market spread over the year after harvest can be given:

> The price level in the markets generally rise. When both regions have stores of grain, the inter-market spread is below the cost of transfer. When one region exhausts its stock and the other still has grain, trading may occur between the markets. Price spreads equal transfer costs. When either or both regions buy from the external market, the price spread falls below the cost of transfer.

4) The model is first investigated using household survey data collected in 1994-95 from 356 households in Buhera Communal Area, Zimbabwe. The dynamics of rural household maize stocks were evaluated during an entire year. The year's harvest was particularly poor so that the average household was grain deficit. The poor harvest was the first since the grain markets had been liberalised and the private traders used their new freedoms:

> Private traders had, for the first time since liberalisation, established direct trade links between food deficit parts of Buhera and surplus neighbouring areas.

5) As the data was collected from households which were remote as well as the more accessible households, chapter 5 also investigates the behaviour of the food marketing system across space taking access into account. The findings give the first indication of the role of the Grain Marketing Board post-reform:

> The marketing board appears to anchor the market for grains. Price rises with distance from the marketing board depot. Traders are pricing as if they are selling grain sourced from the depot. However, traders procure grain from a variety of sources. An explanation for the pricing behaviour is that traders realise that this is the maximum price the purchaser would accept.

Households know the price of marketing board grain and a trader who charges over this price by more than the cost of transfer would merely mean purchasers going directly to the marketing board. It can be noted that direct purchases from the depot did not give a significant discount for the household.

6) The purchase price was analysed to measure the impact of the channel of procurement.

Private traders appeared to base their prices on the c.i.f. price of marketing board maize. When a household used motorised transport to move the grain from the market, thereby accessing markets beyond the local trader's shop, the price discount was less than the cost of transport. Only when the household bought from a neighbour was there a price discount.

7) An important aspect of the model presented in chapter 4 is the role played by grain stocks. Chapter 6 uses the household survey data to explore this. The decision to buy grain is econometrically estimated and the determinants of household purchasing decisions evaluated:

Households were found to purchase grain as their grain stocks became low. Thus, the general results of inter-regional trade model presented in chapter 4 are borne out: households purchase after their own stocks are exhausted.

8) The chapter used parametric and semiparametric estimation techniques to exhaustively evaluate the determinants of grain purchases. It finds that the quantity of grain purchased is determined in two stages:

Households first decided whether to buy grain. This decision was made on the basis of household stocks levels. The quantity purchased was decided in a second stage and this was determined by the household's consumption needs. Households with a high consumption need bought more grain.

9) In chapter 7, tests of market performance are explored in more detail and the implications of the inter-regional trade model analysed. The model in chapter 4 predicts that trade is intermittent and that there may be a lull in trading in the months before and after harvest. To identify when trade is taking place, the spatial arbitrage rule is utilised. This states that when inter-market trade is occurring, the price spread across the markets would equal the cost of transfer between the markets. When there is no trade, the two markets clear at price levels so that the price spread is less than or equal to the cost of transfer. This property can to used to model econometrically the switching between trading and non-trading. Such modelling uses a stochastic switching framework on time series data of grain prices from Tanzania. The price time-series of six markets for the period 1986 to 1990 are used as well as a point estimate for the cost of transfer between each of the fifteen market pairs. The times when trading takes place can be identified:

In Tanzania, the markets were most likely not to trade in the months leading up to harvest, November to March. This is evidence that there is seasonality in inter-market trading. Further, the timing of the trading suggests that trading is concentrated post-harvest.

10) The model presented in chapter 4 suggested that inter-regional trade would only happen after the exhaustion of the grain stocks in one of the regions. It was noted this period could be short especially if the harvest in one of the two regions was small. This would clearly be the case if one of the markets was not an agricultural area, such as a city:

The timing of trade in the Tanzanian market pairs was consistent with some of the regions being urban or being dominated by producers of crops other than white maize.

4. Further Research

This research has focused on the interaction of trade and storage in regional grain markets. The thesis has provided both a model and empirical evidence in support of the model. This has added to current knowledge by highlighting that storage and trade are used to meet food consumption needs. However, the research motivates some future work. Firstly, the model presented in chapter 4 does not look at uncertainty. Clearly, rural food systems are prone to weather shocks and the optimal behaviour of regions would take this into account. Optimal control models which take uncertainty into account are beyond the scope of the present research but would be a sensible next step.

The thesis has identified that trade and storage interact but has said little about the relative importance of the two aspects. There may be welfare improvements to be had by development agencies tackling shortcomings in one of the two. However, further research may show that policy should be combining improvements to inter-regional grain transfer infrastructure with improvements to storage systems. An empirical assessment of the relative importance of the two may involve simply asking households directly. A more complex research agenda which models the food marketing system explicitly integrating storage and transport could also be instigated.

The role of the external market remains in a state of flux. An interesting counter-factual would be to consider how food markets would have evolved had they not been historically burdened by state controls. However, as governments are under pressure to withdraw from food markets, the most obvious conception of the external market - the marketing board - may soon be out-of-date.

Increasingly, it will be the international markets, perhaps at an Africa level, which will become the buyer or seller of last resort. This thesis has shown the significance of the external market. An area of more urgent research must be the transition of the food marketing system as the state withdraws.

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APPENDIX 1:

Survey Details

1. Background

Zimbabwe is a landlocked country in Southern Africa. North of South Africa, the country borders Mozambique (east of Zimbabwe), Zambia (north) and Botswana (to the west). The country has ten provinces, of which two, Harare and Bulawayo, are metropolitan. The non-metropolitan provinces are increasingly fertile and populated to the east of the country but all maintain a primarily agrarian nature. Manicaland Province has 42 people per square mile and is the most densely populated of the non-metros. Matabeleland North, the most western, has a population density of 9 (CSO, 1993).

The survey took place in Buhera District, Manicaland Province between November 1994 and December 1995 with planning and preliminary work taking place in the four months prior to this. Choice of district was finalised in June 1994 and firstly based on logistical priorities. Buhera is four hours' drive from Harare. University of Zimbabwe (UZ), who provided institutional support for the research, is based in Harare and has chosen the District in previous work. UZ's familiarity and extensive prior contact with district officials made the district a practical choice. The inset of map 1 indicates the districts of Zimbabwe and the position of Buhera.

A second feature of Buhera District is that it is entirely communal in its tenure arrangements. The focus of the research - poor rural households - are concentrated in this, the largest (by area), agricultural sector. Buhera's thirty wards of equal size each have approximately 1,200 households and 6,500 people.[11]

2. Sampling strategy

The first stratification used the agroecological zones in the district. The Ministry of Agriculture has divided the country into five zones depending on several variables important to agricultural production including altitude and rainfall. Buhera District straddles the three worst zones, III to V. Map 1 shows how the northern third of the district is in zone III, the central belt is zone IV, while the southern third lies in the 'semi-arid' region (zone V). However, as can be seen in the map, agroecological zone and ward boundaries do not match. Therefore, the average agroecological zone was calculated for each ward using a Geographical Information System operation called overlay[12]. This gave thirteen wards in zone III, nine in zone IV and 8 in zone V. The wards are all of approximately equal population, so sampling in proportion to distribution of wards across the zones was followed. To adequately represent the differing agroecological characteristics of the district, four, three and three wards were randomly selected from the wards in zones III, IV and V respectively. These are a lighter shade of grey in the map and the numbers correspond to the Ministry of Agriculture's ward numbering.

Wards are disaggregated further into enumeration areas. The sampled enumeration areas were selected on the basis of accessibility to facilities. The location of health facilities in the district were used as the basis for accessibility. Other indicators, such as markets, were found to be problematic as there were

[11] The ward boundaries were redrawn by the Central Statistical Office for the 1992 Census. However, all other government agencies continue to use 1982 boundaries. Here, the 30 wards that resulted from the old boundaries are used, rather than the 36 of the new Census map.

[12] Overlay allows the boundaries of the ward to be used to average a geographical characteristic which differs from point to point.

not up-to-date maps of the location of markets. Also, it was clear that some markets were larger than others and factoring this into the map design was not possible. The quality of health facility was largely dictated by the type. In Buhera, there are four types of health facility: hospital, rural hospital, clinic and outreach centre. Both the location and type of all health facilities were provided by the Ministry of Health.

First, a difficulty of movement map was created for the district. This is a standard starting point for calculating distances in GIS. The district is split into 1 km by 1 km squares. Using maps of the road network, the squares which contained a road were valued at 0.2 (tarmac road), 0.3 (non-tarmac provincial road), 0.4 (non-tarmac, maintained by district) and 0.5 (other roads). For the remaining squares, the terrain was integrated into the value. A relief map gave the slope of each square. This was the difference in height in metres between the highest and lowest edge of a particular square. The value given to the squares without roads was then: 1+0.01*(slope)2.

The second stage was preparing maps of the access to individual health facilities types. Four maps, one for each type of facility, were made. The push-broom algorithm was used to find the accessibility of each square to the nearest hospital. Nearness was determined by summing the difficulty of movement value for each square crossed in a particular route. The lowest value possible was entered into the relevant square of the hospital accessibility map. Squares with a hospital registered a zero. A histogram of the values for each square indicated a normal distribution. The map values were then converted into the number of standard deviations from the district mean of a particular square. This entire procedure was repeated for the other three types of facility. The four maps were added using the weights 7 (hospital), 5 (rural hospital), 3.7 (clinic) and 0.033 (outreach centre). The ratings were offered by Ministry of Health staff based on the services each facility could provide and the number of days in a month they were open[13].

The combined map, weighting all four types of health facility, was overlaid with a map of enumeration area boundaries. The average accessibility was derived for each enumeration area and this took a value averaging approximately zero (not exactly zero due to the standardisation that took place). Those with a negative value were deemed to have good access, those with above zero values were defined as having poor access. Ministry of Health officials were asked for feedback at various stages in the procedure so that anomalies were picked out (the most significant problem was that one of the clinics was used entirely by the workers in a private mine; this clinic had to be deleted from the map). It must be noted that access to markets was very similar to access to health facilities as markets were often located near to the facilities.

Sampling of enumeration areas from the selected ward took place using the following rules. When a ward was entirely good or poor, two enumeration areas were chosen entirely at random. Where there was a mix, one poor access area was chosen randomly from the poor access enumeration areas and one area with good access was chosen randomly from the remaining enumeration areas.

From each enumeration area, six villages were chosen at random. From a complete list of households in each of the villages, six households were selected at random. The sample of 360 households that resulted had two significant adjustments so that the number of sample households was 404:

a) One village had to be discounted as it consisted of households benefiting from irrigation. The introduction of households with quite different production systems would have greatly complicated data collection. In particular, inclusion

[13] Hospitals and rural hospitals are open every day, clinics close at the weekend. Outreach centres are mobile facilities spending a specified day each month in each of 22 locations (they do not operate at weekends).

of the village would have necessitated the design of new questions regarding agricultural production. As only six households would be considered, any meaningful statistical analysis would have been impossible from this data, so the households were not surveyed;

b) A number of polygamous households were surveyed. Where a man had more than one wife, each wife usually had a separate kitchen, separate food stocks and owned their own livestock. As with other surveys, these wives were deemed to be running separate households for most food decisions. The main exception was crop production. After completing the survey, these households were amalgamated with the head household.

3. Completion of questionnaires

3.1 General details

Surveying was undertaken by ten trained enumerators (one for each ward) through monthly visits to each household. The survey formed part of a large research project into economic and health aspects of the households[14]. Here, data from the economic surveys has been used.

In October 1994, the survey began with a preliminary questionnaire. This asked about household composition - age, gender, education and economic activity of each member - and about housing and domestic assets. This questionnaire was repeated at the end of surveying to gauge the change in the household over the survey period. In November, the level of household food stocks was ascertained. For staples, the main grain was white maize.

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[14] Survey undertaken as part of a project under the Commission of the European Communities DGXII, Science and Technology for Developing Countries Programme, contract reference TS3*-CT92-0048.

In February, the enumerators again asked households about the quantity of grains in store, but probed further about the causes of stock changes. The main out-flow of grain from the stores was household grain consumption. The household was asked to estimate its annual consumption of grains. Other out-flows over the previous four months were also quantified:

1) Sale

2) Loans/Repayment of debt

3) Other, including animal feed and brewing.

At the same time, the in-flows into the household granary were measured:

1) Purchases

2) Borrowings/Repayments by borrowers

3) Other, including gifts.

This survey combined with the food stock data collected in November captured the change in food stocks over the four month period, November 1994 to February 1995. In the first four month period, in-flows of grain greatly exceeded the non-consumption out-flows. The largest in-flow was the purchase of grain.

In June 1995, when the households were asked about stocks and flows of grain during the second four month period, purchases again were significant. The period, however, covered the household grain harvest which was the largest in-flow of grain. An additional survey, in May, recorded the level of crop production for each household. Poor rains meant that harvest levels were very low and barely exceeded purchased grain as the most important in-flow of grain. In a normal year, own production would meet the needs of the households and provide some surplus for sale. Low yields meant that sales of grain were negligible.

By the third round, July to September 1995, the government had initiated a drought relief programme so that purchases ceased to be the most significant source of grain.

3.2 Attrition of households

As the survey progressed, some households failed to be enumerated. Further, due to amount of data that was collected from each household, interviews were split into two sittings. This meant that a complex picture of attrition could be envisaged. Table 1 indicates the number of households where there is complete data in the first round and each round of the survey over the three rounds where food in-flows and out-flows were enumerated. The 354 households were initially enumerated so that the demographic details of the households as well as the assets of the households were collected for 353 participating households (1 household dropped out after sampling). After this, over the year that followed, the number of households that participated in the survey generally fell.

The picture by wards (and so enumerator) gives some indication of the locations where the attrition was severest. The spread is somewhat uneven suggesting some enumerator bias may be apparent. In the third round especially, where enumerators were facing the termination of employment, the attrition is particularly severe. The last round occurred in the last month of enumerator contracts. This was an unfortunate budgetary restriction as it meant that an interview could not be rescheduled into a later month. This was possible in the earlier two rounds so that with some households, the interview would have taken place in the first week of the following month.

Table 1:

Households Participating by Round

Ward	Number of Households Participating			
	Initial Round	Round 1	Round 2	Round 3
2	35	33	32	27
5	36	35	34	33
13	36	33	32	24
15	36	25	18	10
16	36	34	34	35
18	36	33	28	24
21	36	32	30	31
23	36	32	30	29
28	36	33	30	30
30	30	22	19	17
District	353	312	287	233

The characteristics of the households, however, on average, does not change over the round significantly. In the initial round, the variable WEALTH and CONS was collected. Table 2 indicates the average and standard deviations of these variables by round. There is not a significant change in the wealth or the food requirements of the households.

Table 2

Characteristics of Households by Round

Variable	Round 1	Round 2	Round 3
CONS	10.596	10.515	10.729
	(6.68)	(6.33)	(6.70)
ASSET	0.1565	0.1561	0.1585
	(0.118)	(0.115)	(0.113)

3.3 Variables selected

Summary data regarding selected variables are found in the thesis chapters. The first table is in chapter 5 and focuses on variables related to individual grain purchase transaction. The second such table, in chapter 6, lists the stock levels and flows of each of the 355 households. These variables are split into two types: continuous and binary.

The variable WEALTH needs some explanation. One means of measuring household wealth is to sum the resale value of domestic asset. However, in such a measure, there is firstly measurement error in assessing the assets a household owns and then a second source of error in estimating the resale value of an asset (given enumerators were unlikely to be allowed to see the assets for themselves). A 'rapid' method was therefore used instead. Enumerators collected whether a household owned a particular asset or not. Assets were then classified into groups. The proportion of total households not owning any of the assets in a particular group was used as a value for owning the asset, e.g. all households owned blankets so that its value was 0. The sum of these values for each household provides the series WEALTH.

The distance measure used does not provide the geographical measure of distance as D takes into account the terrain and road infrastructure between a household and the GMB depot. The difficulty of movement map created for the sampling plan was used to measure the shortest route from each point in a ward to the depot. As described above in the Sampling Strategy, the length of a route is given by the sum of the difficulty of movement of the squares crossed. Then, the GIS overlay operation was used to generate a ward average. The use of the difficulty of movement measure means that crossing a 1 km distance using tarmac road is only 0.2 units. If the most convenient route between a ward and the depot involves only flat ground, the measure will give the km distance between the centre of the ward and the depot. However, roads will be used to considerably ease the travel to the depot. Thus, while the distance between the furthest south ward, ward 30, and the depot is approximately 120 km, use of the unsurfaced road between the two has made the maximum of *D* forty-three.

APPENDIX 2

Computer Code

1. Background

This appendix provides the Gauss 386i (for DOS) code written by the author used to estimate models detailed in chapter 6.

2. Likelihood estimation of the Tobit model

This estimation used the Gauss gradient maximisation procedure, optmum. This is not included in the basic Gauss software, but available as an add-in. Olsen's reparametisation is used in the maximisation of the likelhood function. Towards the end of the routine, statistics for testing normality and homoskedasticity in the distribution of the disturbance term are computed.

```
/*              TOBIT Estimation

        y = dependent variable (censored)
        x = matrix of independent variables        */

#include gradient.ext;

/* create a dummy d for y>0 and i for y=0
  get ols estimates, set start estimate for sigma to 1   */

d=0 .lt y;
i=1-d;
{a0,a1,a2}=regress(x,y);
b0=a0|ones(1,1);
```

```
/* maximise log likelihood                          */

optset;
_opmiter=100;
_opusrgd=&gradfd;
_opalgr=5;
proc loglike(b);
retp(-d'(-.5*(ln(2*pi)-2*ln(b[6])+(b[6]*y-x*b[1:5])^2))-
i'(ln(cdfnc(x*b[1:5]))));
endp;
{a,fmin,c,r}=optmum(&loglike,b0);

s=1/(a[6]);                 /*  tobit parameter estimates   */
b=a[1:5]*s;

/* compute information matrix and retrieve standard errors */

h=hessp(&loglike,a);
j=zeros(6,6);
j[1:5,1:5]=eye(5)/a[6];
j[1:5,6]=-b/(a[6]^2);
j[6,6]=-1/(a[6]^2);
/* in the text minus hessian used, but loglike proc is -ive of tobit ll */
inf=j*inv(h)*j';
sd=sqrt(diag(inf));
emp={0};
print b0~(a1|emp)~(b|s)~sd;

/*  Breush-Pagan test for heteroskedasticity  */

lam=pdfn(x*b/s)./cdfnc(x*b/s);
```

```
aa=d.*((y-x*b)/s^2)-i.*lam/s;
bb=d.*(((y-x*b)/s)^2-1)/(2*s^2)+i.*(x*b).*lam/(2*s^3);
ee=d.*((y-x*b)/s)-i.*lam;
gg=aa.*x~bb~s^2*(bb.*x[.,1:3]);
ig=ones(rows(gg),1);
lmstat=(ig'gg)*inv(gg'gg)*(gg'ig);

/* Chesher-Irish residuals test for normality */
g2=aa.*x~bb;
mm=ee.^3~(ee.^4-3*ee.^2);
aa=g2~mm;
lmstat2=ig'aa*inv(aa'aa)*aa'ig;
lmstat3=ig'mm*inv(mm'mm-mm'g2*inv(g2'g2)*g2'mm)*mm'ig;
print "Homoskedasticity   " lmstat;
print "Normality          " lmstat2~lmstat3;
```

2. CLAD estimation

The Nelder and Mead algorithm is used in the estimation of the censored least absolute deviations model. The procedure “sumabmax” is the value function which is equation (14) in chapter 6. The main procedure first runs some code to order the three estimates by the value function so that the three initial estimates of b_{max} are ordered. This is the procedure “cladord”. Then the various rules are observed indicated above are then used so that a new estimate can be chosen. The main procedure repeats until a maximum number of iterations (set by the variable itmax) is reached. A covariance matrix is estimated using the formulae (15) and (16) and the smoothing parameter c. The procedure returns this estimate as well as the parameter estimate.

Gauss code for the estimation of the CLAD model and covariance matrix.

```
/* Censored Least Absolute Deviation estimator (Powell, 1984):

            {b, v} = CLAD (b1,b2,b3,y,x,c,itmax,)

   where b     vector of CLAD parameter estimates
         v     covariance matrix
         b1-b3  three estimators of b (eg. OLS, Tobit etc.)
         y     dependent variable
         x     independent variable(s)
         c     smoothing parameter on covariance matrix
         itmax  maximum iterations for estimation

*/

proc (2) = clad (b1,b2,b3,y,x,c0,itmax);
local v,iter,cnv,t,a,b,c,d,e,g,h,j,ad,m,cc;
iter={0};
cnv={1};

/* Order points */
{b1,b2,b3}=cladord(b1,b2,b3,y,x);

do while iter<itmax;

/* Construct points */
d=0.5*(b2+b3);
ad=d-b1;
g=a+.5*ad;
h=a+1.5*ad;
e=a+2*ad;
j=a+3*ad;
```

```
if sumabmax(e,y,x)>sumabmax(b1,y,x);
 h=g;
endif;
if sumabmax(e,y,x)<sumabmax(b3,y,x);
 if sumabmax(e,y,x)>sumabmax(j,y,x);
  e=j;
 endif;
endif;
if sumabmax(e,y,x)>sumabmax(b2,y,x);
 e=h;
endif;
b1=e;
{b1,b2,b3}=cladord(b1,b2,b3,y,x);
cnv=sumabmax(b2,y,x)-sumabmax(b3,y,x);
iter=iter+1;
endo;

/* Calculation of coavariance matrix (eqns (5.1) and (5.6) in Powell */
t=sumc(0 .lt x*c);
m=(t/rows(y))*x'*x;
t=(0 .lt x*c)'(((y-x*b) .ge 0) .and ((y-x*b) .le c0));
cc=(2/(rows(y)*c0))*t*x'x;
v=invpd(cc)*m*invpd(cc);
retp (b3,v);
endp;

/* Procedure to calculate the sum of the censored least abs dev */
proc sumabmax(beta,y,x);
retp(ones(1,rows(x))*abs(y-maxc(zeros(1,rows(x))|(beta'x'))));
endp;
```

```
/* Procedure to order three points by sum of CLAD */
proc (3)=cladord(b1,b2,b3,y,x);
local b,s,n,m,f;
s=zeros(3,1);
b=b1~b2~b3;
f=sumabmax(b1,y,x);
s[1]=f;
f=sumabmax(b2,y,x);
s[2]=f;
f=sumabmax(b3,y,x);
s[3]=f;
n=maxindc(s);
m=minindc(s);
retp(b[.,n],b[.,6-n-m],b[.,m]);
endp;
```