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An analysis of the role of financialisation, China and stockholding in agricultural commodity price movements

A DISSERTATION SUBMITTED TO THE DOCTORAL PROGRAM IN ECONOMICS AND MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DOCTORAL DEGREE (PH.D) IN ECONOMICS AND MANAGEMENT

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Abstract

A wide range of commodity prices experienced a large peak in 2007/08, including many agricultural commodities. Since then agricultural commodity prices have remained at relatively high levels compared to the recent past and several agricultural commodities (e.g. maize and sugar) have experienced further, although smaller peaks. Studies of the recent commodity price movements have focused on financialisation, China, low stocks and biofuels. This thesis explores the role of three of these factors in agricultural commodity price formation, namely, financialisation, China and stockholding. Biofuels were analysed in work for my previous employer.

The second chapter uses Granger-causality methods to assess whether index investor positions influence agricultural futures prices. Four extensions are explored that might overcome the limitations of Granger-causality tests in this context. Firstly, the analysis is extended to less liquid markets. Liquid markets tend to be relatively efficient and for those markets the semi-strong form of the Efficient Market Hypothesis suggests that prices should not be forecastable as new information is swiftly impounded in prices. Even if index investment had price impact finding Granger-causality based on weekly data would be surprising. In less liquid markets prices are likely to adjust more slowly to new information.

Three further extensions are examined: long-horizon tests, using relative returns instead of returns and an index of positions instead of positions in individual markets. The analysis supports the conclusion that no impacts are discernible for liquid markets. However, Granger-causality is established in the less liquid soybean oil and livestock markets. Thus, there is clear evidence that index investment has been a factor influencing the level of grains and livestock prices in illiquid markets over the five years 2006-11.These results lead to the conjecture that index investment does also have price impact in liquid markets but that market efficiency prevents the detection of this impact using Granger-causality tests.

Chapter 3 investigates the potential impacts of changes in Chinese stockholding and self-sufficiency policies on world wheat prices. Whether or not the decrease in world grain stocks around the middle of the 2000s has had a significant impact on world prices in the last decade is controversial. Since most of the decrease in stocks was due to decreases in China, the main issue is the role that China has played on world markets. So far most studies that address this question have relied on informal arguments rather than formal modelling of the stocks-trade-price relationships. More recently the impact of possible changes to China’s self-sufficiency policy on world markets has become the focus of attention.

Trade and other grains policies are closely linked. Any impact of changes in grain policy in China will be transmitted to the world market through changing trade patterns. The model shows that a move away from autarky reduces stock levels in China and in the rest of

the world resulting in lower global stock levels. In the two scenarios where China imports but does not export global stocks decline by 23 and 32 per cent, respectively, compared to autarky. In the two free trade scenarios, global stocks reduce by 38 and 44 per cent, respectively, compared to autarky. These reductions in stock levels when a country moves from autarky to trading with the rest of the world do not lead to an increase in price variation and, more importantly for policy-makers, do not lead to increases in extreme price movements. In the free trade scenarios, extreme price movements are even reduced despite much lower stock levels.

Chapter 4 introduces a new approach to testing the competitive storage model which has been the main workhorse of the analysis of the role of storage in commodity price formation over the last decades. The relationship between storage and prices is complex. Stock levels depend on current prices and expected future prices. At the same time, the current prices and the futures expected price depend on the level of stocks carried forward from the current period to future periods.

The main approach to testing the competitive storage model has been the comparison of the characteristics of the predicted price series with actual commodity price series. In this study a different approach is taken. A relatively simple model is taken to the experimental laboratory. Participants in the experiment are asked to make storage decisions within a competitive storage model framework. Participants' behaviour in the experiment deviated from the behaviour predicted by the competitive storage model in a number of ways. The predicted relationship between the amount of wheat available and storage is non-linear in the model but is linear in the experiment. In addition, storage is more sensitive to "wheat" in storage than "wheat" harvested when the model suggests that the effect of wheat in storage and wheat from harvest should the same. Furthermore, average storage tends below the optimal level and storage does not vary as much as predicted by the competitive storage model. The resulting price series tend to be more variable than would be the case if stockholders behaved according to the competitive storage model.

Keywords: commodity markets, prices, index investment, storage, experiment
JEL classification: C61, C92, D84, Q02, Q11

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List of Acronyms

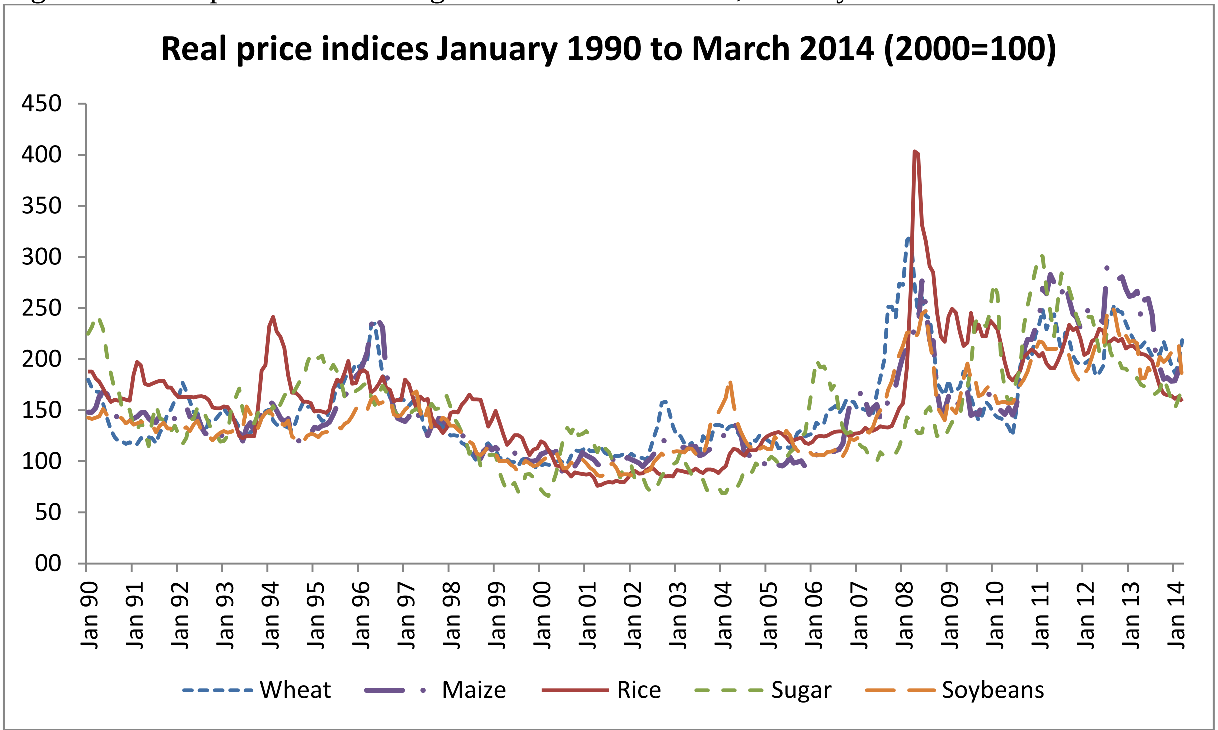
ADF	Augmented Dickey Fuller
ADL	Autoregressive Distributed Lag
AIC	Akaike Information Criterion
AMIS	Agricultural Market Information System
BEA	US Bureau of Economic Analysis
CBOT	Chicago Board of Trade
BIC	Bayesian Information Criterion
BPEX	British Pig Executive
CEEL	Cognitive and Experimental Economics Laboratory
CIT	Commodity Index Trader
CFTC	Commodity Futures Trading Commission
CME	Chicago Mercantile Exchange
COT	Commitment of Traders
ECU	Experimental Currency Unit
EMH	Efficient Market Hypothesis
FAPRI	Food and Agricultural Policy Research Institute
FAO	Food and Agriculture Organization of the United Nations
G20	Group of 20 major economies
GDP	Gross Domestic Product
HM Government	Her Majesty's Government
IFPRI	International Food Policy Research Institute
IOSCO	International Organization of Securities Commissions
IV	Instrumental Variables
KCBT	Kansas City Board of Change
MT	Million Tonnes
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PSD	Production, Supply and Distribution
RECS	Rational Expectations Complementarity Solver
RESET	Regression Equation Specification Error Test
ROW	Rest of the World
S&P GSCI	Standard and Poor's Commodity Index
SUR	Seemingly Unrelated Regression
UNCTAD	United Nations Conference on Trade and Development
USD	U.S Dollar
USDA	United States Department of Agriculture
WTI	West Texas Intermediate

1 Introduction

1.1 Context

A wide range of commodity prices experienced a large peak in 2007/08, including many agricultural commodities (see Figure 1.1). Since then agricultural commodity prices have remained at relatively high levels compared to the preceding two decades and several agricultural commodities (e.g. maize[1] and sugar) have experienced further, although smaller peaks. Understanding the factors that are driving these prices, especially those factors that are driving them to peak values, is not just an interesting academic question; changes in commodity prices lead to shifts in purchasing power. Households that are net consumers and countries that are net importers lose purchasing power whilst households that are net producers and countries that are net exporters gain purchasing power.

Figure 1.1 Real price indices of agricultural commodities, January 1990 to March 2014



Sources: UNCTAD (nominal prices) and BEA (implicit GDP deflator)

Especially for the poorest households, the impacts are severe. Net food and energy purchasing households experience a decrease in real income with the largest relative impact on the poorest households. Many of these poor households are rural households that need to purchase food in addition to what they produce. Anderson et al. (2013) show that in the 30

[1] Maize and corn are equivalent. In this thesis, maize, the term commonly used in Europe, is used unless specific reference is made to the US Chicago Board of Trade corn futures contract, which is the case for all of Chapter 2.

countries for which they have data food expenditure accounts for just over 60 per cent of total expenditure of the poor. Expenditure on the main four agricultural commodities, rice, wheat, maize and oilseeds, constitutes a substantial part of expenditure for the poor households. Because low-income households purchase basic food, such as wheat rather than bread or pasta, the price of the products that they buy is to a larger degree driven by commodity prices than is the case for richer households whose purchases are often in form of processed food.

Higher food prices, therefore, lead to a fall in real income of especially poor net food consuming households, reduce their standard of living and increase poverty. The impact of increases in food prices in the mid-2000s has reversed the progress made in reducing poverty in the previous decade (World Bank, 2008). Balagtas et al. (2014) for example find that in Bangladesh between 2000 and 2008 the price of a balanced basket of food rose by over 50 per cent while incomes only increased by 15 per cent. They estimate that in rural Bangladesh the price spike of 2007/08 contributed to pushing 13 million people into poverty. Hernandez et al. (2011) study the impact of the food price spike on urban households in El Salvador, Guatemala, Honduras and Nicaragua. They find that households replaced some more expensive food items with cheaper ones and also cut expenditure on other goods and services.

In addition, price spikes can lead to substantial changes in a country's balance of payments. For the same exports, energy and food importing countries get fewer imports. This reduction in purchasing power generally results in a reduction in consumption. Increasing food and energy prices are also a source of inflation, which can have additional negative macro-economic impacts (IMF, 2008). In extreme situations, such as during 2008, food commodity price spikes can lead to instability, jeopardising social cohesion and political stability (World Bank, 2008).

Following the 2007/08 price spike, agricultural commodity prices have remained above the average of the previous two decades which has led to a renewed interest in food security, also from policy makers. Food prices and food security were on the agenda of, for example, the 2009 G8 Summit in L'Aquila 8th to 10th July 2009 and the G20 Summit in Cannes 3rd to 4th November 2011. However, as for example, Miao et al. (2011) note, despite the crucial importance of food prices to both the public and policy-makers agricultural commodity prices and the main factors driving them are still poorly understood.

1.2 Motivation

Many studies have been carried out that try to establish the main factors driving commodity price spikes (e.g. Abbott et al., 2008, 2011; Gilbert, 2010a; HM Government, 2010; Prakash, 2011; World Bank, 2008). Factors that are thought to have contributed to the price spikes are increased production of biofuels, financial market impacts, often referred to simply as "speculation", stockholding policies, changes in trade policies, loose monetary policies, exchange rates and increased demand due to economic growth (Tadesse et al., 2013). Nevertheless as Headey and Fan (2010, p. x) note: "Many possible causes have been identified, but their relative importance is uncertain".

This study investigates the role of two of the factors often cited in commodity price spike analyses, namely, the impacts of financial markets and of stockholding on agricultural prices. These areas have two characteristics in common. Firstly, they are of interest to policy-makers and, secondly, their impacts on commodity prices are still disputed.

At the meeting of G20 Agriculture Ministers in Paris in June 2011, the Ministerial Declaration "Action Plan on Food Price Volatility and Agriculture" states: "We strongly encourage G20 Finance Ministers and Central Bank Governors to take the appropriate decisions for a better regulation and supervision of agricultural financial markets."[2] However, tighter regulation of trading of commodity futures markets will only be effective in preventing price spikes, reducing price levels or price variation, if financial markets have had, and are likely to continue to have, a substantial effect on prices. The extent of the impact of financial markets on price movements since 2007 is one of the most controversial issues with respect to recent price developments. Tadesse et al. (2013, p.2) note that "While there is a certain consensus regarding the effects of weather, biofuel production, and export restrictions on food commodity markets, the dispute surrounding speculation is far from settled". While some suggest that financial markets have had an important impact on commodity prices (e.g. Piesse and Thirtle, 2009; Robles et al., 2009; Suppan, 2008), others find no evidence that financial markets did influence price movements (e.g. IOSCO, 2009; Irwin, 2013; Irwin and Sanders, 2012). The second chapter of this thesis contributes to the evidence on the impact of a specific type of financial market players, so-called index investors, on agricultural commodity prices.

Stockholding and its impact on agricultural commodity prices and possible policy measures also remains widely discussed. The "L'Aquila" Joint Statement on Global Food Security included the recommendation that the "feasibility, effectiveness and administrative modalities of a system of stockholding in dealing with humanitarian food emergencies or as a

[2] Ministerial Declaration "Action Plan on Food Price Volatility and Agriculture" available at: http://www.g20.utoronto.ca/summits/2011cannes.html

means to limit price volatility need to be further explored”.[3] Some studies looking at agricultural prices suggest that low stocks had an important impact on prices (e.g. OECD, 2008; Wiggins and Keats, 2010) while others argue that the decrease in global cereal stocks was almost entirely due to a decline in Chinese inventories and it can be argued that stocks in China have a small influence on world prices (Dawe, 2009; Fuglie, 2008).

Proposals for cereal stock have been suggested management (e.g. von Braun and Torero, 2009; Crola, 2011). However, any intervention by governments on stockholding with the aim of dampening price movements can only be effective if low cereal stocks have had, and are likely to continue to have, a substantial impact on prices during the peaks. Hence, in order to assess the potential effectiveness of the proposed policies, it is necessary to better understand the stockholding and its role in price formation.

The third and fourth chapters of this thesis study two aspects of the stock-price relationship. In the third chapter, the competitive storage model is used to assess the likely impact of changes in Chinese stockholding and self-sufficiency policies on world wheat prices. In the fourth chapter, an experimental approach is introduced to investigate stockholding behaviour and the resulting price impacts.

1.3 Research approach and innovative aspects

The second chapter uses Granger-causality methods to assess whether index investor positions influence agricultural futures prices. Sanders and Irwin (2011a) was the first comprehensive study of the impact of index investment on grains futures prices following on from less systematic analyses of the price impact of index investment in the grains markets (e.g. Gilbert, 2010a). Sanders and Irwin (2011a) was published when I started work on my thesis. Chapter 2 replicates, critically examines and extends the analysis in Sanders and Irwin (2011a). Four extensions are explored that might overcome the limitations of Granger-causality tests in this context. Firstly, the Granger-causality analysis is extended to less liquid markets. Liquid markets tend to be relatively efficient and for those markets the semi-strong form of the Efficient Market Hypothesis (EMH) suggests that prices should not be forecastable as new information is swiftly impounded in prices (Fama, 1965). Thus, even if index investment had price impact, it would be surprising to find Granger-causality based on weekly data. In less liquid markets prices are likely to adjust more slowly to new information. Therefore, the analysis is extended to less liquid agricultural futures markets.

Secondly, long-horizon tests are carried out because long-horizon impacts would be present if an accumulation of positions puts pressure on prices. Thirdly, Granger-causality tests have

[3] “L’Aquila” Joint Statement on Global Food Security L’Aquila Food Security Initiative (AFSI) available at: http://www.g8italia2009.it/static/G8_Allegato/LAquila_Joint_Statement_on_Global_Food_Security%5b1%5d%2c0.pdf

low power in the context of futures returns because returns are very volatile which is detrimental for the determination of the coefficients in the Granger-causality tests. Relative returns will be less volatile if two return series share some of the volatility. This approach is explored for pairs of agricultural markets that are linked through production processes. Finally, it is known that index positions as measured by the Commodity Futures Trading Commission differ from actual index investment. As a final extension, Granger-causality tests based on an index of positions across all markets are added. Due to measurement errors of index investment positions the index of positions across all markets might be closer to actual index investment in the individual markets.

The analysis supports the conclusion that no impacts are discernible for the four grains markets Sanders and Irwin (2011a) consider. The models including relative returns as dependent variable and those using an index of positions as dependent variable also suggest the absence of Granger-causality from index positions to prices. However, Granger-causality is established in the less liquid soybean oil and livestock markets. These latter results lead to the conjecture that index investment does also have price impact in liquid markets but that market efficiency prevents the detection of this impact using Granger-causality tests.

The work in chapter 2 was carried out in 2011 and early 2012. There has, subsequently, been a large volume of research on the price impact of index investors. This more recent literature, which post-dates my analysis, is reviewed at the end of chapter 2.

The analysis in chapter 2 formed the basis of a paper prepared for the workshop "Understanding Oil and Commodity Prices" organised by the Bank of England, the Centre for Applied Macroeconomic Analysis, Australian National University, and the Money, Macro and Finance Study Group (Gilbert and Pfuderer, 2012). Building on these results, a substantially revised version of chapter 2, which is in some respects narrower and some respects broader, has subsequently been published (Gilbert and Pfuderer, 2014a). It is narrower because it focuses on a smaller number of agricultural markets and broader because it also assesses index position impacts on non-agricultural commodity prices and analyses contemporaneous impacts using an instrumental variable approach.

Chapter 3 investigates the potential impacts of changes in Chinese stockholding and self-sufficiency policies on world wheat prices. Whether or not the decrease in world grain stocks around the middle of the 2000s has had a significant impact on world prices in the last decade is controversial. Since most of the decrease in stocks was due to decreases in China, the main issue is the role that China has played on world markets. Sometimes China is seen as disconnected from the world market and at other times as an integrated part of it. So far most studies that have addressed this question have relied on informal arguments rather than formal modelling of the stocks-trade-price relationships. More recently the impact of possible changes to China's self-sufficiency policy on world markets has become the focus of attention of market analysts and academics (e.g. Hornby, 2014; Zhang, 2014).

The question of the world price impact of changes in stockholding and self-sufficiency policies can be explored using the competitive storage model. In chapter 3, the question is asked what impact a large country has on global price dynamics in a competitive storage model framework under different trade scenarios. Trade and other grains policies are closely linked. For example, any autarky policy in the domestic grain market will have to be accompanied by relatively high stock levels to buffer harvest shortfalls. Also, any impact of changes in grain policy in China will be transmitted to the world market through changing trade patterns. The model shows that a move away from autarky reduces stock levels in China and in the rest of the world resulting in lower global stock levels.

In the two scenarios where China imports but does not export global stocks decline by 23 and 32 per cent, respectively, compared to autarky. In the two free trade scenarios, global stocks reduce by 38 and 44 per cent, respectively, compared to autarky. These reductions in stock levels that accompany the country's moves from autarky to trading with the rest of the world do not lead to an increase in price variation and more importantly for policy-makers, do not lead to increases in extreme price movements. In the free trade scenarios, extreme price movements are even reduced despite much lower stock levels.

Chapter 4 introduces a new approach to testing the competitive storage model. The competitive storage model has been the main workhorse of the analysis of the role of storage in commodity price formation since Gustafson first proposed his model in 1958. The relationship between storage and prices is complex. One of the difficulties in the analysis of the stock-price relationship is that causation is bi-directional. Stock levels depend on current prices and expected future prices. At the same time, the current price and the future expected price depend on the level to stocks carried forward from the current period to future periods. The competitive storage model is a rational expectations model which can only be solved numerically.

Testing the model is not straightforward. The main approach to testing the competitive storage model has been the comparison of the characteristics of the predicted prices series with actual commodity price series (e.g. Cafiero et al., 2011; Deaton and Laroque, 1992, 1996). In this chapter a different approach is taken. A relatively simple model is taken to the experimental laboratory. Participants in the experiment were asked to make storage decisions within a competitive storage model framework. The experiment was run at the University of Trento in April 2014. The results show that mean storage tends to be below the level predicted by the competitive storage model and storage does not vary as much as predicted. The resulting price series tend to be more variable than would be the case if stockholders behaved according to the competitive storage model.

1.4 Structure of the thesis

The introduction to chapter 2 (section 2.1) is followed by a literature review of theoretical models on price impact of financial market participants (section 2.2.1) and a review of empirical analyses of the link between financial market participants and prices with particular focus on a review of Sanders and Irwin (2011a) in section 2.2.2. Section 2.3 sets out the methodology applied in this analysis and section 2.4 describes the data used. Section 2.5 presents the results starting with updated results of the analysis in Sanders and Irwin (2011a) followed by results applying the same methodology to less liquid agricultural commodity futures markets, results of long-horizon tests, tests using relative returns and those using an index of agricultural positions. The results section ends with an examination of contemporaneous effects. Section 2.6 concludes and section 2.7 reviews the literature that post-dates the analysis in chapter 2, which was carried out in 2011 and early 2012.

The introduction to chapter 3 (section 3.1) is followed by a literature review (section 3.2). Section 3.3 sets out the competitive storage model used in the chapter. An outline of the model equations in autarky (section 3.3.1) is followed by the presentation of the model in the two trade scenarios – one-directional trade, where China imports wheat but does not export it, and free trade (section 3.3.2). Section 3.3.3 sets out the solution method and section 3.3.4 the calibration of the model. Section 3.4 presents the results for the three scenarios of autarky, one-directional trade and free trade under two market conditions, balanced and unbalanced markets. Section 3.5 discusses the results and section 3.6 concludes.

Chapter 4 starts with the introduction (section 4.1), which also includes an overview of the related literature. Section 4.2 introduces the simple version of the competitive storage model that was taken to the laboratory. Section 4.3 describes the experimental setting. It starts with a description of the participants and procedures (section 4.3.1), then describes the experimental setting (section 4.3.2). The final part of section 4.3 presents the predictions of the competitive storage model with respect to stock levels and price series. Section 4.4 sets out the hypotheses that the experiment aims to test. Section 4.5 compares the results of the experiment to the predictions and assumptions of the competitive storage model. Section 4.5.1 compares stock levels in the experiment to stock levels predicted by the model and section 4.5.2 makes a similar comparison with respect to the price series characteristics. The following two sections use regression analyses to analyse decisions at the group level (section 4.5.3) and at the individual level (section 4.5.4). Section 4.6 discusses and concludes. Chapter 5 concludes and sets out further research.

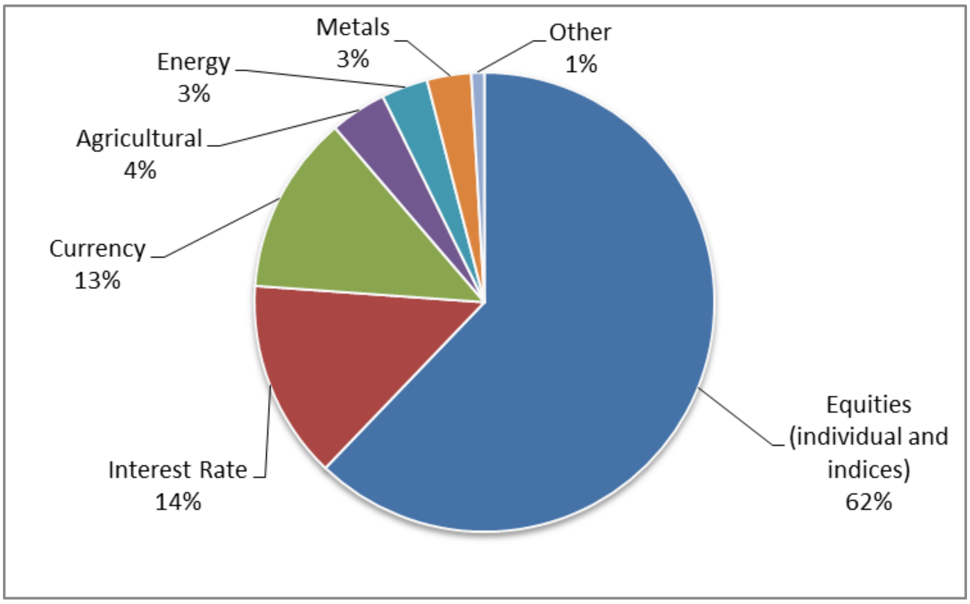
2 The Impact of Index Trader Positions on Agricultural Prices

2.1 Introduction

In this chapter, the impact of commodity index trader positions on agricultural futures prices is analysed. In its online glossary the Commodity Futures Trading Commission (CFTC) defines index trader as an "entity that conducts futures trades on behalf of a commodity index fund or to hedge commodity index swap positions".[4] The analysis builds on and extends previous research on the impact of financial markets on agricultural commodity prices. This strand of research can inform the current policy debates and initiatives aimed at improving the functioning of derivatives markets in general and agricultural commodity futures markets more specifically.

To put agricultural futures markets in the larger context of futures markets, Figure 2.1 shows the share of different categories of futures contracts in terms of the number of contracts traded and/or cleared at 81 exchanges that are covered by the Futures Industry Association Volume Survey 2011.

Figure 2.1 Shares of global futures and options volume by category in 2011



Source: Futures Industry Association, Annual Volume Survey 2011

Equity futures and options are by far the largest category with over 60 per cent of the volume of all futures. The share of all commodities is 10 percent and that of agricultural commodities 4 per cent.

[4] Available at: http://www.cftc.gov/consumerprotection/educationcenter/cftcglossary/index.htm#C

The United Nations Conference on Trade and Development (UNCTAD) defines financialisation of commodity markets as “the increasing role of financial motives, financial markets and financial actors in the operation of commodity markets” (UNCTAD, 2011, p. 13). Financialisation of commodity markets is perceived by policy-makers and market participants as a, possibly important, factor in the price movements of agricultural commodities from the mid-2000s onwards, thus, including the time of the 2008 price spike.

In the United States, Michael Masters, a hedge fund manager, stated that financialisation, in form of index investment, increased commodity prices (Masters, 2008). In 2009, a US Senate report investigated “excessive speculation” in the wheat market (United States Senate Permanent Subcommittee on Investigations, 2009). The report raised concerns about the impact of increasing volumes of index investment. In Europe, the French President between 2007 and 2012, Nicolas Sarkozy, is probably the most prominent politician to voice concerns about the price impact of financial market players. He has repeatedly stated that financial markets were pushing up food prices (Neate, 2011). Most of the focus of the discussions in relation to financial market impacts on commodity markets has been on the impact of the increase in index investment in commodity futures markets from the mid-2000s.

Index investment in commodity futures is motivated, at least in principle, by standard Markowitzian portfolio diversification arguments (Gilbert, 2010c; Stoll and Whaley, 2010). Gorton and Rouwenhorst (2006) show that, over the period from July 1957 to December 2004, returns on Standard & Poor’s commodity index (S&P GSCI) compare favourably with those on equities although with slightly greater risk, and dominate corporate bonds in terms of the Sharpe ratio. Over the period they consider, commodity returns have a statistically insignificant correlation with equities and a low but statistically significant negative correlation with bond returns. These calculations suggest that investment in a long passive commodity fund could have bought diversification of an equities portfolio at a lower cost than through bonds. Importantly, the S&P GSCI did not exist for much of the period Gorton and Rouwenhorst (2006) considered and there must be doubts that these returns continue to be available given the lower transaction costs now associated with commodity index trading.

Gilbert (2010c) argues that, if one takes the portfolio diversification motivation seriously, it is preferable to regard index investment as a separate category from hedging and speculation. For example, pension funds generally attempt to avoid speculative trades and many are statutorily required to do this. Index investors hold portfolios of commodity futures contracts with the aim of replicating returns on one of a small number of tradable commodity futures indices. The Standard & Poor’s (S&P) GSCI and the Dow Jones-UBS indices are the most important of these commodity futures indices. Index investors may either hold positions directly, as is the case with some large pension funds, or indirectly through fixed-floating swaps provided by “index providers” (typically investment banks). In the latter case, the index provider will offset the resulting short exposure by purchase of futures contracts, although not necessarily on an automatic (non-discretionary) basis.

The S&P GSCI is probably the most widely tracked tradable commodity futures index. This index gives a very high weight to energy commodities, in particular crude oil and natural gas. Agricultural commodities have only a small weight – of the order of 10 per cent of the total for grains and vegetable oils.[5] The Dow Jones UBS index caps the energy weight at one third leaving more space for agricultural futures – of the order of 20 per cent for grains and vegetable oils (see e.g. Gilbert, 2010c). As a consequence, only a small proportion of commodity index investment finds its way to agricultural markets.

Despite this, Commodity Futures Trading Commission figures show that index investment accounts for a large proportion of long-side open interest in many U.S. agricultural futures markets. Table 2.1 reports net index positions, both in terms of contracts and as a percentage of total outstanding long positions, for the eight U.S. agricultural commodities analysed below. The shares vary from the high teens to just over 50 per cent. For the two later dates, the share is above 20 per cent for all commodities. The share is highest for Chicago Board of Trade (CBOT) wheat where index investment accounts for 45 per cent to 50 per cent of all long positions.

Table 2.1. Commodity index trader (CIT) positions and shares of total long positions

	3 January 2006		1 September 2009		27 December 2011	
	Contracts (thousands)	Share of total	Contracts (thousands)	Share of total	Contracts (thousands)	Share of total
CBOT wheat	168	50.6%	175	50.1%	186	46.9%
KCBT wheat	22	15.3%	32	31.7%	34	26.2%
CBOT corn	265	28.1%	338	30.1%	364	28.2%
CBOT soybeans	87	24.9%	147	29.4%	162	29.8%
CBOT soybean oil	51	26.3%	65	26.3%	90	30.3%
CME live cattle	61	27.6%	101	35.0%	124	33.6%
CME feeder cattle	5	14.1%	6	25.6%	8	22.4%
CME lean hogs	55	41.7%	67	40.4%	87	33.6%

Notes: The table reports the net commodity index trader (CIT) position (thousands of contracts) and the net CIT position as a share of total long positions on three dates: 3/1/06 (the initial date of the sample available for this analysis), 1/9/09 (the final date of the sample employed by Sanders and Irwin (2011a)) and 27/12/11 (the final date of the sample used in this analysis). CBOT stands for Chicago Board of Trade, KCBT for Kansas City Board of Trade and CME for Chicago Mercantile Exchange.

Source: CFTC, Supplemental Commitments of Traders Reports.

[5] Changes in prices and periodic rebalancing result in changes in index weights over time.

The CFTC also reports the number of commodity index traders. This number, typically between 20 and 30, is fairly consistent over time and over commodities, in line with the fact that CITs are all tracking the same indices. Individual CITs will therefore only account for a small proportion of total trades on any market. However, because the CITs will all invest new money in approximately the same proportions and will all roll expiring contracts on or around the same dates, they will tend to act collectively as if they were a single large trader.

The increasing importance of financial players on commodity futures markets has led to extensive policy debates. Policy proposals to limit the market impact of financial players have been discussed in both the United States and in Europe. In July 2010, President Barack Obama signed the *Dodd-Frank Wall Street Reform and Consumer Protection Act* (for short Dodd-Frank Act) which includes, among many other measures, provisions for the Commodity Futures Trading Commission (CFTC) to set position limits as

(i) to diminish, eliminate, or prevent excessive speculation;
(ii) to deter and prevent market manipulation, squeezes, and corners;
(iii) to ensure sufficient market liquidity for bona fide hedgers; and
(iv) to ensure that the price discovery function of the underlying market is not disrupted.

In the Commodity Exchange Act excessive speculation is described as speculation "causing sudden or unreasonable fluctuations or unwarranted changes in the price of such a commodity".[6] Following the Dodd-Frank Act, the CFTC proposed limits for positions in the U.S. agricultural futures markets in October 2011 and amendments in May 2012. However, the International Swaps and Derivatives Association and the Securities Industry and Financial Markets Association together challenged the position limits suggested by the CFTC. As a result, the implementation was halted in September 2012. On 15th November 2013 and 12th December 2013, the CFTC published new proposals with respect to the limits for positions to be discussed at a round table in June 2014.[7]

In the European Union, the European Commission published proposals for a review of the Markets in Financial Instruments Directive (MiFID) and a new regulation the Markets in Financial Instruments Regulation (MiFIR) in October 2011. Agreement on the high level (Level 1) texts was reached in January 2014. Adoption of the Level 1 texts by European Parliament followed in April 2014 and that by the Council in May 2014. The Level 1 text includes a provision for position limits and reporting of positions but the details will be

[6] Commodity Exchange Act available at: http://www.cftc.gov/files/ogc/comex060601.pdf
[7] Federal Register / Vol. 79, No. 103 / Thursday, May 29, 2014 / Proposed Rules available at: http://www.cftc.gov/ucm/groups/public/@lrfederalregister/documents/file/2014-12427a.pdf

finalised in the Level 2 phase. The European Securities and Markets Authority started the consultation process on the Level 2 phase in May 2014.[8]

However, tighter regulation of positions held by different categories of traders in commodity futures markets will only be effective in reducing fluctuations and unwarranted price movements, including price spikes, if positions of financial market players have had, and are likely to continue to have, a substantial effect on prices.

The analysis presented provides new evidence on the impact of index trader positions. These results make an important contribution to the better understanding of the role of financial markets in agricultural price formation and can inform the current policy debate.

The chapter proceeds as follows: section 2.2 reviews the literature up until the time the analysis was carried out with particular focus on the paper by Sanders and Irwin (2011a) that is critically examined and extended in this chapter. Section 2.3 outlines the methodology and section 2.4 the data sources. Results are presented in section 2.5 and section 2.6 concludes. Section 2.7 reviews the literature that post-dates the analysis in chapter 2.

2.2 Literature review

2.2.1 Theoretical models

A number of theoretical models that link behaviour of financial market participants and commodity prices have been developed. Their predictions as to whether financial market participants can move prices away from fundamentals differ. Testing these models empirically is challenging, though.

Traditionally, participants in futures markets have been split into three main categories: hedgers, speculators and arbitrageurs (Hull, 2008). Hedgers participate in futures markets to reduce the risk that they are exposed to through their commercial activities. Unlike hedgers, speculators do not have commercial activities that are linked to the underlying assets of the futures contracts. Speculators are betting on price movements and thus are assuming risk by entering into financial market transactions. Arbitrageurs take advantage of riskless profit opportunities when prices in two markets differ.

Price movements away from fundamental values that are caused by speculators are sometimes referred to as excessive speculation (Szado, 2011) or a bubble (Irwin and Sanders, 2011; Barlevy, 2007). There is no agreement on the definition of either speculation or bubble, even among economists (Barlevy, 2007).

Friedman (1953) argued that profit-maximising speculators stabilise rather than destabilise prices. According to his view, speculators' participation in the market incorporates

[8] European Securities and Markets Authority information on MiFID/MiFIR available at: http://www.esma.europa.eu/page/MiFID-II-application

new information into the price. He argued that if this were not the case then speculators would lose money and eventually find better ways to spend their time and resources. In this world, speculators help price discovery based on fundamentals and stabilise prices. One of Friedman's crucial assumptions is that speculators are well-informed while another is that speculators lose money and would find better ways to spend their resources.

The assumption that all speculation is informed may not be satisfied. Indeed, if markets are efficient and gathering information about market fundamentals is costly, there is no incentive to gather information (Grossman, 1976, 1995; Grossman and Stiglitz, 1976, 1980). Therefore, finance theory generally distinguishes between informed and uninformed speculators (O'Hara, 1995; de Jong and Rindi 2009). Informed speculators hold private information about market fundamentals and base their market decisions on their private knowledge of fundamental changes in the markets. Informed speculation is the means through which private information is included in publicly quoted prices. Uninformed speculators do not hold private information. Noise traders, one type of uninformed traders, base their market decisions on considerations that are unrelated to the fundamental price, for example, portfolio diversification. In the absence of noise traders, other uninformed speculators could infer the private information of informed speculators from price movements (Grossman and Stiglitz, 1980).

In practice, uninformed traders do not know whether any given price movement is the result of informed or uninformed trades. They therefore attach a probability to trades being informed based on the noise-to-signal ratio in the market – see Kyle (1985). Informed purchases will result in a rise in the market price but of a smaller order than the amount by which the informed traders estimate the fundamental to have risen. Partial impounding maintains the profitability of market research thereby finessing the Grossman and Stiglitz (1980) paradox.

The assumption by Friedman that speculators would eventually leave the market was challenged in a number of subsequent papers. Black (1986) suggests two possible reasons why noise traders might trade even when objectively they should not. Firstly, traders might enjoy the trading activity and, therefore, continue even if they are not making money. Secondly, traders might wrongly believe that they are trading on information that gives them an advantage when they are actually trading on noise. Although as a group noise traders will tend to lose money and informed speculators will tend to make money due to the noisiness of the actual returns, it is not obvious to determine if an individual is trading on noise or information. Noise traders therefore persist in the market and events that have no information content can affect prices because the underlying value of the asset cannot be directly observed.

De Long et al. (1991) raise further doubt about Friedman's assumption that noise traders would lose money and leave the markets. They show that under certain circumstances it is possible that noise traders trading on bullish noise or pseudo-signals can outperform rational investors in terms of average returns and not only survive in the market but dominate it.

In a series of papers, de Long et al. (1989, 1990a, 1990b) investigate the possible welfare and price effects of noise traders. Using a two-period overlapping-generation model, de Long et al. (1989) show that noise traders increase the riskiness of investments by increasing the price variability for rational investors which can lead to welfare losses. Under many circumstances, this negative effect of noise traders on rational investors can outweigh the benefit for rational investors, namely, that they can make money trading with noise traders. Thus, noise traders not only make consumption more volatile for rational investors but, in addition, can also reduce investment and capital stock and thus average consumption.

The possibility of the market price to diverge from its fundamental value is investigated in de Long et al. (1990a). Again, using an overlapping-generation model with informed investors and noise traders, the authors show that if informed investors have short horizons, they might not aggressively pursue arbitrage opportunities because arbitrage is risky even in the absence of fundamental risk. With arbitrage by informed investors limited, it is possible that the price significantly diverges from its fundamental value.

If positive feedback strategies are followed by some market participants and informed speculators have short horizons, it may be rational for informed speculators to even follow the trend away from fundamentals (de Long et al., 1990b). The presence of traders that follow positive feedback strategies makes arbitrage expensive, which can lead to price movements that are not justified by fundamental changes. As a consequence, price signals are distorted and resources are misallocated. In this case, even rational speculation is destabilising. For a more detailed review, see Mayer (2011).

In addition, especially in less liquid markets large purchases on futures market can push up the price if they "eat into the market order book" (see Holthausen et al., 1987; Scholes, 1972; Shleifer, 1986). These price effects should be relatively short-lived unless, in a market with relatively few informed speculators, the uninformed speculators interpret the price increase as conveying information about fundamental market developments (see, for example, de Jong and Rindi, 2009; O'Hara, 1995; Stoll, 2000).

2.2.2 Empirical analysis of prices and financial market participants

As seen in the previous section, theory allows for financial markets to move prices away from fundamentals at least in the short to medium term. However, it is difficult to test these theories empirically due to data limitations. On the one hand, fundamental values of commodities cannot be observed. In finance theory, the fundamental value equals the discounted value of convenience yields, which cannot be directly observed and are difficult to model. On the other hand, many variables related to financial markets – e.g. the number of informed and uninformed speculators and the strategies they follow – are usually not observed and often also not observable.

Empirical work has focused on three different approaches for assessing the impact of financial markets on recent commodity price spikes:

- Looking for mildly explosive behaviour in prices
- Modelling price movements based on fundamentals
- Studying the relationship between prices and financial positions

2.2.2.1 Looking for mildly explosive behaviour in price movements

When financial market participants move prices away from fundamentals, the stochastic price behaviour may change. Several theoretical models suggest that when prices are driven away from fundamentals, price movements can be characterised as an explosive autoregressive process, i.e. an autoregressive process where the root is greater than unity (Phillips et al., 2011a). Rational bubble models and herd behaviour models, for example, are consistent with mildly explosive price movements. Mildly explosive processes are characterised by autoregressive coefficient in an explosive region of unity. The divergence of autoregressive coefficient is $o(1/T)$, where T is the sample size, and, thus, goes as $T \rightarrow \infty$ the divergence goes to zero.

Phillips et al. (2011a) introduced a recursive regression methodology to identify periods of time when the evolution of prices of an asset deviates from its normal stochastic behaviour. Price series are tested for the presence of exponential growth and non-linear curvature, which indicate explosive behaviour. The requirement that the series be only mildly explosive, in the sense defined above, ensures consistency of these estimates.

Applying this method to commodity futures price series, Phillips and Yu (2010) find evidence of mildly explosive price behaviour in the West Texas Intermediate (WTI) crude oil market between March and August 2008 and in the platinum market between January and July 2008. By contrast, using the same techniques, Gilbert (2010b) obtained a negative result.

Gilbert (2010b) also failed to find evidence of bubbles of this narrowly defined type in U.S. agricultural markets, with the exception of a brief bubble in soybean oil prices in early 2007.

This econometric literature, which is based on univariate time series analysis, does not make any reference to financial market participants, in general, and index investment, more specifically. Hence, it does not allow any conclusions to be drawn directly regarding the reasons for mildly explosive behaviour since this behaviour is consistent with rational bubble and herd behaviour models but under certain conditions it is also consistent with rational or exuberant adjustments to fundamental changes in the market (Phillips et al., 2011b). One example of rational adjustments that lead to bubble type price movements is given in Bobenrieth et al. (2002). In a rational expectations storage model, price rises that revert sharply can occur when there is a non-zero probability of zero output and the price becomes infinite at zero consumption, the former of which seems unrealistic though for global grains markets.[9] However, it would be possible to see index investment as a potential mechanism by which such bubbles, if present, materialise.

2.2.2.2 Modelling price movements based on fundamentals

The basic reasoning underlying the second approach to empirically assessing the question if financial markets move prices away from fundamentals examines the question from a different angle. If fundamentals can explain all price movements, there is little room for financial markets to have contributed to price movements away from fundamentals. If, however, fundamentals cannot explain price movements on commodity futures markets, financial market impacts are one of the possible explanations.

Robles et al. (2009, p. 2), for example, state that “changes in supply and demand fundamentals cannot fully explain the recent drastic increase in food prices. Rising expectations, speculation, hoarding, and hysteria also played a role in the increasing level and volatility of food prices”. A number of other studies argue that fundamentals cannot explain price movements in food commodities (Piesse and Thirtle, 2009) or in the crude oil market (Eckaus, 2008) and conclude, therefore, that financial markets have moved prices away from fundamentals. By contrast, some studies conclude that changes in fundamentals can fully explain commodity price changes since 2007 and that there is no room for any impacts by financial markets (IOSCO, 2009; HM Government, 2010).

There are few studies in this category that employ formal economic modelling of prices based on fundamentals. One of the few is Kaufmann (2011) who models oil prices as a function of a number of fundamental variables such as capacity utilisation and inventories and

[9] In a recent paper Figuerola-Ferretti et al. (2014) argue that mildly explosive price behaviour in metals markets can be due to non-linearities in the price reaction to market fundamentals, such as stock-outs and capacity constraints.

uses two measures to assess the model's ability to simulate oil price changes. The two measures are the stability of the cointegration relationship and the performance of one step-ahead out-of-sample forecasts. The model performs much worse in the period from 2007 to 2009, which indicates that there might have been factors other than fundamentals driving the price during this period.[10]

This argument is 'residual' and the analysis does not test directly for financial market impacts. A failure of fundamentals to explain price movements is taken as an indication that financial markets have moved the price away from fundamentals.

2.2.2.3 Studying the relationship between prices and financial positions

The two approaches discussed so far do not use any information about activities on financial markets. By contrast, the third category of empirical research directly investigates the relationship between financial market variables and commodity prices.

The question of whether index investors have impacted prices can be studied in cross-sectional or in time series frameworks. Fama-Beth cross-sectional regressions (Fama and MacBeth, 1973) and traditional cross-sectional regressions can be used to study the relationship between returns on commodity futures and index investment. Sanders and Irwin (2010) use both the cross-sectional regression approaches and several measures for index investment: the notional value of index funds in the market, the percentage of index investment of all long positions and the change in the percentage of index investment of all long positions. A total of twelve models are analysed in Sanders and Irwin (2010) with only one of them showing a statistically significant effect of index investment on prices.

In time series analysis, most studies use Granger-causality tests, which have become established as the standard econometric methodology to analyse the impact of positions on futures market prices. In the following, the most important studies are reviewed that have tested for Granger-causality from index investors positions to agricultural futures prices.

Brunetti and Büyüksahin (2009) use daily data on positions that are not publicly available to test for Granger-causality from daily position of commodity index traders in the corn market to daily corn futures. They do not find any evidence of Granger-causality in the corn market. Most other studies use the CFTC weekly data on positions which are publicly available from January 2006.

Stoll and Whaley (2010) include all twelve agricultural markets for which index position data are published on a weekly basis by the CFTC. Their study covers the period

[10] There are number of recent studies that focus on the impact of individual factors on annual prices (e.g. Bobenrieth et al., 2014; Martin and Anderson, 2012; Roberts and Schlenker, 2013) but none takes into account a wider range of fundamental factors and none looks at prices with lower than annual frequency.

from 2006 to 2009. They do not find any evidence of Granger-causality except in the case of cotton.

Sanders and Irwin (2011a) analyse U.S. grain prices. They use CFTC data to examine whether index funds impacted U.S. grains futures prices over the period 2004 to 2009, thus including 2004 and 2005 for which position data of index traders are not publicly available. They fail to establish any Granger-causal link from changes in the futures positions attributed by the CFTC to index providers to the returns on nearby grains futures prices.

Sanders and Irwin (2011b) use a Seemingly Unrelated Regression (SUR) system framework to test for Granger-causality from swap dealer positions to futures prices in the period from 2006 to 2009. In agricultural markets swap dealer positions are a good proxy for commodity index trader positions because the majority of commodity index positions are those of swap dealers hedging over-the-counter exposure (Irwin and Sanders, 2010). Using the SUR approach, Sanders and Irwin (2011b) do not find any evidence of Granger-causality.

Capelle-Blancard and Coulibaly (2011) apply a similar method but use the CIT position data over the period 2006 to 2010. They only find evidence of Granger-causality from index positions to prices in the live cattle market before September 2008 and cocoa for the period between September 2008 and December 2010. To sum up, studies using Granger-causality tests predominantly fail to reject Granger-non-causality.

The advantage of this approach is that it directly links price movements to financial market variables. However, even if Granger-causality is found to be present, no conclusions can be drawn, based on Granger-causality analysis, on the nature of these price movements i.e. if they are fundamentally-based or not. In the following sub-section, Sanders and Irwin (2011a) is reviewed in more detail as a case study. It is the first systematic analysis focused on the grains market. The analysis in this chapter re-examines and extends their analysis.

2.2.2.4 Review of Sanders and Irwin (2011a)

Sanders and Irwin (2011a) is the first study that focuses on the grains and oilseeds markets. They analyse U.S. agricultural futures prices of Chicago Board of Trade (CBOT) corn, CBOT wheat, CBOT soybeans and Kansas City Board of Trade (KCBT) wheat. They use CFTC data to examine whether index investors impacted U.S. grains futures prices over the period from 2004 to 2009, a period which includes the 2007/08 price spike. Their analysis is largely based on Granger-causality tests, all of which fail to establish any Granger-causal link from changes in the futures positions attributed by the CFTC to index providers (CIT positions) to the returns on nearby grains futures prices. They conclude that their analysis “casts serious doubt on the hypothesis that commodity index speculation drove the 2007/08 commodity price increase” (Sanders and Irwin, 2011a, p. 530).

Sanders and Irwin (2011a) run the risk of confounding the question of whether CIT activity impacted grains prices with the issue of whether or not grains price movements in 2007/08 were fundamentally based. They suggest, for example, that “there were other macroeconomic factors potentially influencing commodity prices” (Sanders and Irwin, 2011a, p. 532). Their contraposition of index trading and fundamentally-based trades supposes that index investment is not fundamentally based. That would be true if indeed index-based investment is purely motivated by portfolio diversification concerns, but not if it forms a component of a macroeconomic investment strategy. In that case, index investment should be seen as the channel by which macroeconomic information or forecasts becomes impounded in commodity prices. Gilbert (2010b) emphasises Chinese growth as the major driver of commodity price movements, including movements of agricultural prices, over 2007/08. Given the difficulties associated with direct portfolio investment in China, investors may find it attractive to invest in commodity futures since these prices are likely to appreciate in line with Chinese growth.

Sanders and Irwin (2011a) analyse Tuesday-to-Tuesday log returns for nearby futures contracts on the Chicago Board of Trade (CBOT) corn, soybeans and wheat markets and the Kansas City Board of Trade (KCBT) wheat market. Returns on these markets are related to CIT positions as published in the CFTC’s weekly *Supplemental Commitments of Traders* reports (the *Supplementals*). For the most part, their methodology is to regress weekly returns on returns in the previous week and the changes in CIT positions over the previous week. The Student t test on the lagged position change variable provides the test for Granger-causality. A significant t value rejects the hypothesis of Granger-non-causality allowing the investigator to assert that Granger-causality has been established.

The Sanders and Irwin (2011a) sample is weekly (Tuesdays) from 6 January 2004 to 1 September 2009. They measure CIT positions, which relate to the same dates, in two ways: an absolute measure, as the net long position held by CITs, and a normalised measure, long positions held by CITs divided by total long positions.

Sanders and Irwin start from an autoregressive distributed lag model (ADL(4,4)) relating the commodity return to four lags of itself and to four lags of the change in the relevant CIT position variable as set out in Equation (2.1).

$$r_{j,t} = \kappa_j + \sum_{i=1}^{4} \alpha_{j,i} r_{j,t-i} + \sum_{i=1}^{4} \beta_{j,i} x_{j,t-i} + u_{j,t} \quad (2.1)$$

where $r_{j,t}$ is the logarithmic price return for commodity j, $x_{j,t}$ is the change in index positions and u_{jt} is a disturbance.

They then test down to more parsimonious specifications using the Bayesian (Schwartz) Information Criterion (BIC). In each case they find that a single lag of each variable is sufficient. The single lag Granger-causality test is given by the *t*-statistic $|t_\beta|$ for hypothesis H_0: $\beta_j=0$ against the alternative H_1: $\beta_j\neq0$ in Equation (2.2):

$$r_{j,t} \ = \kappa_j + \alpha_j r_{j,t-1} + \beta_j x_{j,t-1} + \ u_{j,t} \tag{2.2}$$

where $r_{j,t}$ is the logarithmic price return for commodity j, $x_{j,t}$ is the change in index positions and $u_{j,t}$ is a disturbance. Their results are reproduced in Table 2.2. In each of the eight cases they consider (four grains, two position variable definitions), they are unable to reject the hypothesis of no Granger-causal impact.

Table 2.2 Sanders and Irwin (2011a) Granger-causality analysis (sample 6 January 2004 to 1 September 2009)

	Positions	p-values
CBOT corn	Absolute	[0.413]
	Normalised	[0.103]
CBOT soybeans	Absolute	[0.446]
	Normalised	[0.171]
CBOT wheat	Absolute	[0.841]
	Normalised	[0.402]
KCBT wheat	Absolute	[0.895]
	Normalised	[0.384]

Notes: The table reports p-values for the Granger-non-causality tests that index returns do not Granger-cause price returns.

To sum up, theoretical models allow for price impacts of financial market participants that move prices away from fundamentals. Index investment has been identified as a possible factor in the price spikes of the last decade. The most direct approach to assessing the impact of index investment on commodity prices is by studying the relationship between commodity returns and index investment. In this chapter, a Granger-causality approach is employed to test the hypothesis that index investors' positions do not impact prices. To alleviate short-comings of Granger-causality analysis in existing empirical studies, the analysis is extended to less liquid markets, relative returns, long-horizons tests and a different measure of index investor positions.

The analysis narrowly focuses on the question of whether or not CIT activity impacted U.S. agricultural prices but does not attempt to evaluate whether any such impact, if present, contributed to the 2007/08 price spike or indeed whether that spike may be legitimately classified as a bubble. Granger-causality analysis is appropriate for examining whether a specific group of financial transactors, here CIT traders, had price impact but not for quantifying the extent of that impact or establishing the nature of the price impact.

2.3 Methodology

2.3.1 Granger-causality analysis

In many situations it is difficult to establish the direction of causation between two variables. This is also the case for the relationship between prices and positions in futures markets. If traders react to price movements by changing their positions prices might cause changes in positions. At the same time, changes in positions might cause price movements.

Granger-causality is based on two components (Granger, 1969). First, the cause appears before the effect. For one variable to cause another, the causal variable has to precede the effect variable because the future cannot influence the past. Second, the causal variable contains information related to the effect variable that is not available elsewhere. Granger-causality is used to examine causal relationships because it a pragmatic and testable definition of causality.

Granger-causality is testable in the framework of a regression model. The effect variable is regressed on the candidate causal variable. As a consequence of the first component of Granger-causality, the causal variable enters the regression model with lags. The second component requires that other possible explanations for the causal variable are included in the model, usually this means, as a minimum, inclusion of the own history of the effect variable. In such a regression model, the null hypothesis that the causal variable does not Granger-cause the effect variable can be tested using standard F-tests. The null hypothesis tested is that the coefficient of the candidate causal variable is zero. Thus, the null hypothesis is that the lagged candidate causal variable does not have any explanatory power – i.e. that it does not Granger-cause the dependent variable. If the null-hypothesis of Granger-non-causality is rejected, the candidate causal variable is said to Granger-cause the effect variable.

The model, in its general form testing whether index positions Granger-cause prices is set out in Equation (2.3):

$$r_{kt} = \kappa_j + \sum_{i=1}^{m} \alpha_{ki} r_{ki,t-i} + \sum_{j=1}^{n} \beta_{kj} x_{kj,t-j} + u_{kt} \tag{2.3}$$

where r_{kt} is a measure of the price variable of commodity k in period t and $x_{j,t-j}$ is a measure of index positions in period t-j and u_{kt} is a disturbance. The Granger-causality test is the test of $H_0 : \beta_{k1} = \beta_{k2} = \ldots = \beta_{kn} = 0$ based on the F-statistic.

2.3.2 Limitations of Granger-causality analysis

In the context of commodity futures prices and trader positions, Granger-causality analysis has important limitations.[11]

2.3.2.1 Efficient markets

One limitation of Granger-causality analysis for the markets examined by Sanders and Irwin (2011a) is that these markets are liquid and competitive and as a consequence relatively efficient.

Of the three main versions of the Efficient Market Hypothesis (EMH), the semi-strong form is the accepted paradigm (Jensen, 1978). The semi-strong form of the Efficient Markets Hypothesis (EMH) implies that prices should not be forecastable from publicly available information because all publicly available information is impounded in the price (Fama, 1965). It is reasonable to suppose that market participants have an accurate impression of the scale of index trading activity at any point of time. Thus, although information on index investment is not available to those outside the market, it is publicly available to those involved in the market. The EMH therefore implies that lagged CIT position changes should not predict current futures price changes.

One would therefore not expect to find Granger-causality on these markets even if CIT activity does have a contemporaneous price impact. The negative Sanders and Irwin (2011a) results might therefore be viewed as tests of the semi-strong form of efficiency rather than CIT price impact. More generally, a finding of Granger-causality in an efficient and liquid market must be seen as a surprising result. The analysis is therefore extended to less liquid markets where price adjustments can be expected to happen over a longer period.

2.3.2.2 Low power due to long-horizon impacts

If a build-up of positions over a period of time puts pressure on prices over time, then tests based on Equation (2.3) have low power (Summers, 1986). Jegadeesh (1991) shows that tests based on the model set out in Equation (2.4) have higher power.

$$r_{kt} = \kappa_k + \sum_{i=1}^{m} \alpha_{ki} r_{ki,t-i} + \beta_k \sum_{j=1}^{n} \frac{x_{kj,t-j}}{n} + u_{kt} \qquad (2.4)$$

where r_{kt} is a measure of the price variable of commodity k in period t and $x_{j,t-j}$ is a measure of index positions in period t-j, n is the number of lags of the candidate causal variable included

[11] A recent review of the conceptual interpretability of Granger-causality analysis in the context of the price impact of index investment in agricultural markets can be found in Grosche (2014). A brief review of Grosche (2014) is included in section 2.7.

in the model and u_{kt} is a disturbance.[12] This model is a "fads" type of model where changes happen slowly over time and the candidate causal variable enters the model as a moving average.

2.3.2.3 Low power due to volatility of the dependent variable

Returns are very volatile, which makes the determination of coefficients in the Granger-causality model difficult and standard errors high resulting in low power of the tests. Using relative returns can reduce the volatility of the dependent variable. If some of the volatility is common across commodities, then relative returns will be less volatile. Commodities that are linked through production processes or consumption substitutability might have a common element of volatility. Therefore, relative returns of the following commodity markets are examined:

i) relative returns of feeder cattle and live cattle

Feeder cattle and live cattle are different stages in the same production process and thus likely to be subject to a common component of return volatility.

ii) relative returns of lean hogs and corn

Pig feed contains a high percentage of cereals. In the US, the main cereal-based feed is corn and thus an important input into the production process of pigs. One can expect a share of return volatility to be common to the lean pig contract and the corn contract.

iii) relative returns of lean hogs and soybeans

The second most important element of pig feed is soymeal.

The Granger-causality test for relative returns is based on the following equation:

$$r_{jt} - r_{kt} = \kappa + \sum_{i=1}^{m} \alpha_i \left(r_{j,t-1} - r_{k,t-i}\right) + \sum_{i=1}^{m} \beta_{ji} x_{j,t-i} + \sum_{i=1}^{m} \beta_{ki} x_{k,t-i} + v_{jkt} \quad (2.5)$$

where r_{jt} is the logarithm of the return of commodity j and r_{kt} the logarithm of the return of commodity k, $x_{j,t-i}$ is a measure of index positions for commodity j, $x_{k,t-i}$ a measure of index positions for commodity k and v_{jkt} a disturbance. The Granger-causality test is the test of the hypothesis $H_0 : \beta_{j1} = \cdots = \beta_{jm} = \beta_{k1} = \beta_{km} = 0$.

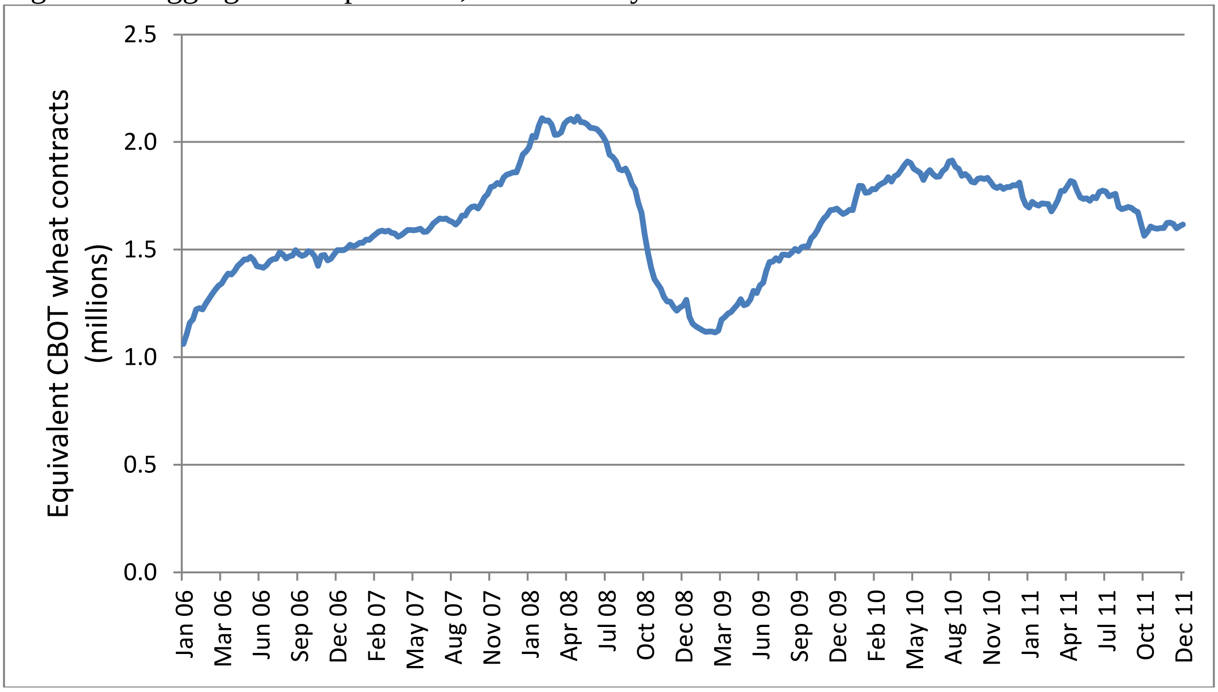
[12] Jegadeesh (1991) uses Monte Carlo simulations to derive critical values. In contrast to both the models in this paper and Sanders and Irwin (2011a), Jegadeesh estimates a purely autoregressive model with a latent independent variable Z. In a model where Z, the index position variable, is observed and if one is interested in the coefficients of the independent variable standard critical values can be employed.

2.3.2.4 Errors in measurement of index investment

The independent variable measures actual index investment with an error. Many index investors do not invest directly in futures contracts but go through investment banks. Investment banks do not automatically offset the positions on the futures market but do so on a discretionary basis. The index investment measured on futures markets, therefore, differs from actual index investment (the issues are set out in more detail in section 2.4.1). Commodity indices do not change composition and the discretionary behaviour is likely to be less than perfectly correlated between individual contracts. If the original investment in commodity indices impacts prices, the measurement based on position in futures markets contains an error. This error is likely to be larger for index positions of individual commodity contracts than for total index positions.

Therefore, index positions are aggregated for the entire range of twelve agricultural commodity futures – see Gilbert (2010a,b,c) and Stoll and Whaley (2010). Because index weights for different commodity futures are revised infrequently and since roll dates and trading opportunities differ across commodity futures, it is possible that this aggregate measure more accurately reflects underlying index investment than the commodity-specific CIT measures. Granger-causality analysis using as candidate causal variable a weighted index of the total quantity of CIT net positions across all twelve reporting markets is, therefore, additionally carried out. The unit of measurement of this index can be interpreted as "equivalent CBOT wheat contracts" (with base 6 January 2006).

Figure 2.2 Aggregate CIT positions, from January 2006 to December 2011



Source: Own calculation based on CFTC data.

2.4 Data

2.4.1 Index position variables

Weekly data on index investor positions are available from the CFTC. Since 2000, the CFTC has published the *Commitment of Traders* (COT) report on a weekly basis (CFTC, n.d.). The reports are published each Friday, 3.30 pm Eastern Time, and show open interest on the previous Tuesday. The information published in the COT reports is based on data collected under the CFTC's market surveillance program under which exchanges and large traders have to report information on a daily basis. The COT report includes information on open interest for two categories of traders – commercial and non-commercial traders. The aim of the categorisation was to group traders according to their general purpose for trading in futures markets, commercials being hedgers with exposure in the physical market and non-commercials all traders with no such exposure to hedge (CFTC, 2006). Over time, non-traditional hedgers have become more important. Non-traditional hedgers have no direct exposure in the physical market but hedge over-the-counter index-related transactions.

With the increase in this long-only index investment, the information provided in the main report was judged to have lost some of its relevance as traders in the same category could not be considered to have a similar general purpose for trading. Index investors differ from traditional non-commercial and from commercial traders and therefore should be considered a different category of traders (e.g. Gilbert, 2010c). As a consequence, on January 5, 2007 the CFTC started to publish a Supplemental report (*Supplementals*) that shows positions for three categories of traders – commercials, non-commercials and index traders.

The classification of traders into the commodity index trader category was based on the analysis of futures position of traders, information provided by traders in their use of futures markets which is part of the reporting requirement to the CFTC and more than 30 interviews with traders thought to be involved in index trading (CFTC, 2006).

The report covers the twelve main U.S. agricultural futures markets including the eight commodity futures markets included in this analysis. Comparable data for 2006 was published with the first report in January 2007. Sanders and Irwin's (2011a) sample covers the period from 6 January 2004 to 1 September 2009. The data from 2004-05 are not publicly available and so the sample used in this chapter starts on 3 January 2006. The sample is extended to the end of 2011.

The index trader category in the *Supplementals* contains traders that are included in the commercial category of the COT report (e.g. swap dealers) and in the non-commercial categories of the main COT report (e.g. managed funds, pension funds and other institutional investors). Thus, index providers fall into two categories – positions taken by institutions, typically investment banks, which offer fixed-floating swaps in which the floating leg is linked to a tradable commodity futures index, and positions taken by institutions, typically pension funds, which invest directly in futures to replicate a tradable index. In relation to the former, the index swap provider category, the CIT measure is therefore a measure of offsetting futures positions and not directly of the index investment itself.

The two would only be equal if all providers were to offset their positions on an automatic, non-discretionary, basis. This is unlikely to be a profit-maximising strategy for the index providers. Firstly, the index roll dates are known to market participants and provide attractive profit opportunities for the commodity trading community who can exploit the inflexibility of non-discretionary index providers. Secondly, the short position established through index provision can be offset through other means, most obviously by writing options. More generally, this short position constitutes a basis for trading opportunities. Offsetting on the futures market will form only a (possibly large) residual component of the offsetting strategy. For these reasons, one should beware of interpreting CIT positions as directly measuring index investment.

The *Supplementals* are the best available data source for index investor positions but have important shortcomings.[13] In addition to the above mentioned limitations, data are only available on a weekly basis which has serious limitations because index positions and prices can experience significant changes within a week, or even within a day. However, no data at a higher frequency are available. In addition, the *Supplementals* classify traders as “index traders” if index related trading is the main trading strategy of that trader. The report includes all positions held by those traders in the index trader category. As a consequence, the measure published in the *Supplementals* might under- or over-report index trading. It might over-report positions as not all positions by the traders classified as “index traders” are index-related. It might under-report index trading as the position on the futures market is the residual after internal netting of positions by the traders (CFTC, 2006).

Following Sanders and Irwin (2011a) two measures of index investment positions are constructed based on the CFTC data – an absolute measure and a normalised measure of index investment. The absolute measure is net long positions held by commodity index traders in the individual markets. It is calculated as long positions minus short positions by index traders and scaled by 1/1,000,000. The normalised measure is the percentage of total long positions held by commodity index traders. This variable is calculated as long positions held by index traders divided by the total long positions in the market.

Augmented Dickey Fuller (ADF) tests were used to test the position variable series for non-stationarity. The null-hypothesis of non-stationarity could not be rejected for the absolute

[13] The CFTC also publish Index Investment Data. These data are in some respects more accurate. However, the available data series are much shorter because publication started on a quarterly basis in December 2007 and only became monthly in June 2010 towards the end of the sample used in this chapter.

measure of index positions in any of the markets under consideration. The ADF tests indicated that the normalised measures of index investment in the feeder cattle, lean hogs and CBOT wheat markets are stationary. ADF tests for the first differences of the absolute and normalised measures of index investment suggest that all first difference series are stationary (see Table 2.II in the appendix for ADF test results). For consistency and for comparability with Sanders and Irwin's results, first differences of the index position variables are used throughout the analysis in this chapter.

The aggregate index of agricultural positions, shown in Figure 2.1 and used in section 2.5.5, is formed from the twelve contracts included in the *Supplementals*. Because the contracts are not of equal size, the index is constructed as the weighted sum of the positions. The weights are chosen so that each weighted contract has the same value as one CBOT wheat contract on the initial date in the sample (3 January 2006). The index can be interpreted as showing the number of "equivalent CBOT wheat contracts".

2.4.2 Price variable

Commodity futures prices are available from the futures exchanges and from other data providers. Futures price data were sourced from Norma's Historical Data[14]. Price data are available on a daily basis for the period for which index trader position data are available (and beyond). The datasets include daily closing prices for all open contracts for each of the eight markets included in this study.

Sanders and Irwin (2011a) state that they use returns on the nearby future but are not explicit on their roll convention i.e. the date on which they move from the expiring contract to the next nearby. Index investors roll their positions from 5th to 9th business day of the month preceding the contract months (Stoll and Whaley, 2010). This implies that they only rarely use the nearby contract i.e. the contract closest to expiry. By contrast, price reference is mostly with regards to nearby contracts. Therefore, the nearby prices are of most relevance for the question of whether index investor impact important agricultural commodity prices.

However, rolling on expiry could be problematic because often there is little trading on the last contract days and a number of different conventions are used in the futures literature. The five grains contracts considered in this chapter all expire on the 14th of the expiry month or the immediately prior trading day if the 14th falls on a weekend or on a holiday. Contracts are rolled on the first trading day of the month in which a contract expires. Livestock contracts differ with regards to the expiry date. In line with grains contracts, the livestock contracts are rolled approximately two weeks before expiry. Other roll conventions exist, such as rolling when volume or open interest of the expiring contract drops below that

[14] Norma's Historical Data is no longer active.

of contracts with longer maturities. Several complications can arise with these roll conventions. The contract with the highest volume or open interest does not necessarily have to be the contract with the next shortest maturity. Also, it is possible that volume or open interest of the expiring contract only drops temporarily below that of a contract with longer maturity which would require more frequently rolling from one contract to another. These roll conventions potentially introduce additional noise into the data.

Prices on Tuesdays are analysed to tie in with the position data. Following Sanders and Irwin (2011a), Tuesday-to-Tuesday log returns are analysed (i.e. log(closing price on Tuesday/closing price on previous Tuesday)). If a Tuesday is not a trading day, the closing price on the trading day preceding Tuesday is used. Log returns over the roll date are defined to be contract-consistent, i.e. they exclude roll returns. ADF tests are used to test the return series for non-stationarity. The null-hypothesis of non-stationarity is rejected in all cases. (See Table 2.II in the appendix for the results of the ADF tests).

2.4.3 Futures contracts details

The characteristics of the eight futures contracts for which index trader position impacts are analysed are set out in Table 2.3. Average prices of the contracts and average margins, which are regularly adjusted given price level and volatilities, are given for the first and the last months in our sample, namely, January 2006 and December 2007.

At the start of the sample, the average price of a contract and the maintenance margins were lowest for corn and wheat, in line with the generally low prices for those two grains at the time. The average price of a contract and the maintenance margin for the soybean and livestock contracts were of similar order. The maintenance margin for the non-grain contracts were all in the range between 700 and 1,000 thousand USD.

At the end of the sample, the prices and margins had increased for all contracts. In December 2011, the maintenance margin was lowest for the soybean oil contract and highest for the soybean contract. The soybean oil contract also had the lowest average price in December 2011 with 3,008 thousand USD and five contracts were priced in the range between 3,000 and 3,500 thousand USD, namely CBOT corn, CBOT soybean oil, CBOT wheat, KCBT wheat and CME lean hogs. The highest average prices in December 2011 were recorded for the CME feeder cattle contract, followed by the CBOT soybean contract.

Table 2.3 Futures contract characteristics

	Contract size	Maintenance Margin (USD)		Average price of contract ('000 USD)		Contract months
		January 2006	December 2011	January 2006	December 2011	
CBOT corn	5,000 bushel	250	1,750	1,067	3,030	Mar, May, Jul, Sep, Dec
CBOT soybeans	5,000 bushel	820	2500	2,936	5,765	Jan, Mar, May, Jul, Aug, Sep, Nov
CBOT wheat	5,000 bushel	375	2,250	1,675	3,062	Mar, May, Jul, Sep, Dec
KCBT wheat	5,000 bushel	n/a	n/a	1,921	3,347	Mar, May, Jul, Sep, Dec
CBOT soybean oil	60,000 pounds	725	1,000	1,323	3,008	Jan, Mar, May, Jul, Aug, Sep, Oct, Dec
CME live cattle	50,000 pounds	700	1,200	3,817	4.821	Feb, Apr, Jun, Aug, Oct, Dec
CME feeder cattle	40,000 pounds	1,000	1,500	5,613	7,238	Jan, Mar, Apr, May, Aug, Sep, Oct, Nov
CME Lean hogs	40,000 pounds	800	1,250	2,400	3,445	Feb, Apr, May, Jun, Jul, Aug, Oct, Dec

Note: Maintenance margin data for KCBT wheat not available; n/a stands for not available.

Source: CME for futures contract information, Norma's Historical Database for price information.

2.5 Results

2.5.1 Sanders and Irwin revisited

As an initial exercise, the analysis in Sanders and Irwin (2011a) is reproduced using the same approach. The starting point is an autoregressive distributed lag model (ADL(4,4)) relating the commodity return to four lags of itself and to four lags of the change in the relevant CIT position variable as set out in Equation (2.1). For this initial exercise, Sanders and Irwin (2011a) are followed and the Bayesian (Schwarz) Information Criterion (BIC) is used for model selection to facilitate comparison of the results. In the following sections, results based on the Akaike Information Criterion (AIC) are reported instead of the BIC. The BIC is based on Bayesian arguments. The AIC is consistent with the classical approach to statistical testing employed in this analysis.

The sample used differs from the sample used in Sanders and Irwin (2011a). The analysis in this chapter uses a sample that is based on publicly available data from 3 January 2006 onwards whilst Sanders and Irwin's sample starts on 6 January 2004. The 2004 and

2005 data are only available to researchers if the analysis takes place on the premises of the CFTC. The final date included in the sample for this initial exercise is 1 September 2009 to make this analysis as similar as possible to Sanders and Irwin's. Ordinary least squares (OLS) are used to estimate the models. Robust standard errors are reported where White's test for heteroscedasticity suggests that the error terms are heteroscedastic. The results are presented in Table 2.4.[15] The results are broadly similar to Sanders and Irwin's (2011a) and support their conclusions. However, unlike Sanders and Irwin, the analysis in this chapter finds some evidence that index positions Granger-cause corn prices (using the normalised measure of index investment). This result is further discussed later in this section.

Table 2.4 Sanders and Irwin (2011a) Granger-causality analysis revisited

		3 Jan 2006 to 1 Sep 2009			Sanders and Irwin (2011a) 6 Jan 2004 to 1 Sep 2009
	positions	coefficient	|t-statistic|	p-value	p-value
CBOT corn	Absolute	-0.508	1.07	0.284	0.413
	Normalised	-1.046**	2.29	0.023	0.103
CBOT soybeans	Absolute	1.363	1.25	0.215	0.446
	Normalised	0.453	1.56	0.121	0.171
CBOT wheat	Absolute	0.037	0.03	0.974	0.841
	Normalised	-0.163	0.72	0.474	0.402
KCBT wheat	Absolute	-1.563	0.50	0.618	0.895
	Normalised	-0.218	0.70	0.486	0.384

Notes: The table reports the estimated β coefficient, the *t*-statistic $|t_\beta|$ for the Granger-non-causality tests that index returns do not Granger-cause price returns (robust standard errors when required) and p-values. Rejections at the 5% level are denoted by **.

Table 2.5 reports the results for the larger sample starting on 3 January 2006 and ending on 27 December 2011. This is the sample used in the remainder of this analysis. Using the Akaike Information Criterion (AIC), the model with one lag is selected for all commodities and for both the absolute and normalised measure of index positions. There is evidence that index investment Granger-causes corn and soybean prices.

In both Tables 2.4 and 2.5, rejections of Granger non-causality are reported for the CBOT corn market. However, in each case, these rejections are associated with negative estimated coefficients on the lagged CIT position change, apparently implying that an increase in CIT positions reduces corn prices. These negative signs might be seen as problematic if the hypothesis of interest is the claim that index investment causes an increase in prices, as distinct from simply a change in prices.

[15] The estimated coefficients, t-statistics and associated p-values for the lagged CIT position variable are reported. For brevity, the estimated intercept and lagged return coefficients are omitted.

Table 2.5 Granger-causality test results (CIT positions) for grains for the sample 3 January 2006 to 27 December 2011

	positions	coefficient	|t-statistics|	p-value
CBOT corn	Absolute	-0.625**	1.99	0.048
	Normalised	-0.665**	2.12	0.035
CBOT soybeans	Absolute	1.034	1.37	0.171
	Normalised	0.382*	1.83	0.068
CBOT wheat	Absolute	-1.007	1.20	0.232
	Normalised	-0.067	0.38	0.703
KCBT wheat	Absolute	0.972	0.40	0.689
	Normalised	-0.124	0.50	0.616

Notes: The table reports the estimated β coefficient, the *t*-statistic $|t_\beta|$ for the Granger-non-causality tests that index returns do not Granger-cause price returns (robust standard errors when required) and p-values. Rejections at the 5% level are denoted by ** and those at the 10% level by *.

However, Granger-causality tests answer the question whether there is a causal relationship between the candidate causal variable and the effect variable. Granger-causality differs from structural causation (Hoover, 2001) and Granger-causality tests cannot directly be interpreted with regards to the structural form of the causal relationship. There are a number of different ways in which a positive structural causal relationship might manifest itself in a negative coefficient in a single-lag Granger-causality framework.[16] Two specific possibilities arise in the current context in which the EMH implies that any price impact from CIT trading should be contemporaneous.

The first possibility is that the candidate causal variable is negatively autocorrelated. In this case, a decrease in CIT positions in week 1 will predict an increase in week 2. If the week 2 increase is associated with a price increase, omitted variable bias will translate a positive structural coefficient on the omitted unlagged position change into an estimated negative coefficient on the lagged position change in the Granger-causality regression. A second possibility is that futures price changes are negatively autocorrelated. This might arise as the consequence of illiquidity such that a large volume of CIT purchases in week 1 eats into the market order book resulting in price “slippage”, reversed over subsequent trading. In this case, the Granger-causality test might pick up the bounce back from the previous week’s trades. In fact, neither corn CIT positions nor corn futures prices are statistically significantly negatively autocorrelated over our sample. CIT positions are statistically significantly positively autocorrelated whilst the one lag autocorrelation of returns is negative but not statistically significant (see Table 2.III in the appendix).

[16] When Granger-causality is tested using multiple lags the resulting F-statistic is necessarily positively signed and so this interpretation issue does not directly arise.

Bivariate Granger-causality tests are always subject to the qualification that an apparent causal link may be via a third variable: variable C causes effect variable *E* but *C* is also causally related to candidate causal variable *X*. In such a case, a bivariate test might show that *X* Granger-causes *E* while a trivariate test, in which *E* is regressed on lagged *C* as well as lagged *X* and lagged *E*, would show that the causal relationship is in fact from *C* to *E*. Given the problematic nature of the corn test results reported in Tables 2.4 and 2.5, it is worth asking whether such a third variable may indeed be responsible for this result.

All futures market transactions involve two parties. If CIT traders are buying, some other group of transactors must be selling. In an auction market, it is never straightforward to determine which party has initiated a trade and which is the counterparty, whose role is that of liquidity provision. The negative estimated coefficients in the corn regressions reported in Tables 2.4 and 2.5 might result if CIT traders were liquidity providers to a second group of traders who wished to establish short positions. The sample evidence suggests that this was indeed the case for the non-reporting group of traders.[17] In a trivariate Granger causality regression, the lagged change in CIT positions is estimated with a negative coefficient (-0.648, *t*-statistic 1.82, p-value 0.0692) while the lagged change in non-reporting positions is estimated with a nearly equal positive coefficient (0.753, *t-statistic* 1.40 p-value 0.1613).[18]

In summary, the evidence reported in this section supports Sanders and Irwin's (2011a) conclusion that CIT investment did not Granger-cause movements in futures prices in the four important and liquid grains markets that they investigated. However, the discussion in the Methodology section suggests that the lack of evidence of Granger-causality might be due to the limitations of the tools and the data. It may be more fruitful to look for the possible impact of CIT trading in less liquid markets, to use long-horizon tests, to analyse relative returns and to use an index of positions to overcome some of these limitations.

2.5.2 Less liquid markets

Granger-causality tests rely on lagged effects and may, therefore, not pick up the effects in liquid markets, such as those analysed by Sanders and Irwin (2011a). Liquid markets are relatively efficient and price impacts are likely to happen within a short period of time. If this hypothesis is correct, then clearer evidence that index positions Granger-cause prices might be found in less liquid market. Therefore less liquid agricultural contracts that are included in the in the S&P GSCI and/or the Dow Jones-UBS indices are additionally analysed. These are the CBOT soybean oil contract, the least liquid of the CBOT grains

[17] The non-reporting group are traditionally identified as "small speculators". Brokers are required to report small positions in aggregate and not by client. The CFTC's *Commitments of Traders* reports give these aggregate non-reporting positions.
[18] Sample 27 June 2006 to 27 December 2011.

complex, and the Chicago Mercantile Exchange (CME) livestock contracts: live cattle, feeder cattle and lean hogs.

Table 2.6 shows total open interest for the contracts analysed by Sanders and Irwin (2011a) and the additional four contracts included in our analysis. Open interest is one indicator of market liquidity. The data show that open interest in the four contracts that are additionally analysed is below that of the three CBOT contracts analysed by Sanders and Irwin (though not the KCBT wheat contract). As seen in Table 2.3, average margin and price of the contracts are not systematically different for the livestock and soybean oil contract. While the CBOT soybean oil contract is at the low end of the average price and margin of the contracts analysed, the CME feeder cattle contract tends to be at the high end compared to the other contracts with CME live cattle and lean hogs generally in the middle range.

Table 2.6 All open interest for grain and livestock contracts

Contracts included in Sanders and Irwin (2011a)				
	CBOT corn	CBOT soybeans	CBOT wheat	KCBT wheat
3 January 2006	996,901	364,625	339,284	143,580
1 September 2009	1,262,635	526,575	390,847	103,026
27 December 2011	1,558,918	639,929	451,421	141,900
Additional contracts analysed				
	CBOT soybean oil	CME feeder cattle	CME live cattle	CME lean hogs
3 January 2006	195,952	38,228	225,130	132,415
1 September 2009	269,212	32,245	292,765	175,218
27 December 2011	334,218	37,346	396,315	281,093

Notes: The table reports all open interest on three dates: 3 January 2006 (the initial date of the sample available to us), 1 September 2009 (the final date in the sample employed by Sanders and Irwin (2011a)) and 27 December 2011 (the final date of our sample).

Source: CFTC Supplemental Commitments of Traders Reports.

The soybean and soybean oil contracts are closely linked. Soybean oil is a stable proportion of soybeans and the relativity between the two prices defines the “crush” arbitrage. Thus, arbitrage opportunities lead to a close link between the two contracts. Furthermore, Table 2.1 shows that CIT positions in the soybean market are up to twice as large as those in the smaller soybean oil market. For these reasons, index positions in the soybean market are included in the soybean oil Granger-causality tests. Table 2.7 shows the results of Granger-causality tests for the soybean oil contract including as candidate causal variables the change in soybean oil and soybean CIT positions both individually and jointly.

The results show that changes in commodity index positions Granger-cause soybean oil price returns, with stronger evidence for a causal relationship between soybean positions and soybean oil price returns than soybean oil positions and soybean oil price returns. The results do not throw up any sign issues. Although there is always the possibility that the apparent causal relationship is explained by an unspecified third variable, it seems reasonable to conclude, at least provisionally, that CIT activity has impacted soybean oil prices.

Table 2.7 Granger-causality test results (CIT positions) for the CBOT soybean oil contract

Positions	Lag 1	Lag 2	Lag 3	F-statistic [p-value]
Absolute soybean oil	1.209 {1.42} [0.157]	0.015 {0.02} [0.986]	-2.115*** {2.68} [0.008]	3.06** [0.028]
Normalised soybean oil	0.023 {1.21} [0.229]			
Absolute soybean	1.328* {1.74} [0.084]	1.368* {1.92} [0.084]		3.71** [0.0255]
Normalised soybean	0.618*** {2.85} [0.005]			

	Lag	soybeans	soybean oil	Joint
Absolute CIT positions	3	3.40** [0.018]	2.99** [0.031]	2.84** [0.011]
Normalised CIT positions	1	2.63*** [0.009]	0.23 [0.821]	4.07** [0.018]

Notes: The table reports the estimated β coefficient, the t-statistic $|t_\beta|$ for the Granger-non-causality tests that index returns do not Granger-cause price returns (in round brackets OLS standard errors and in curly brackets robust standard errors) and p-values in square brackets for individual lags. The F-statistic for the Granger-causality tests that index returns to not Granger-cause price returns with p-values in square brackets. Rejections at the 1% level are denoted by ***, at the 5% level are denoted by ** and those at the 10% level by *. Sample 3 January 2006 to 27 December 2011.

The analysis is extended to the three CME livestock contracts included in the in the S&P GSCI and/or the Dow Jones-UBS indices and for which the CFTC *Supplementals* report CIT positions. Whereas for the grains markets the U.S. futures prices are world reference prices, this role is less pronounced for the U.S. livestock contracts which are more domestically focused. Results are given in Table 2.8. The AIC-determined lag structure is generally more complex than in the liquid grains markets. The Granger-causality test is the *F* test for exclusion of the entire distributed lag.

Table 2.8 Granger-causality test results for livestock contracts (CIT positions)

		1 lag	2 lag	3 lag	4 lag	F statistic [p-value]
Feeder cattle	Absolute	-1.957				
		(0.64)				
	Normalised	-0.069	-0.107			1.48
		{0.70}	{1.29}			[0.229]
Live cattle	Absolute	-0.197	1.333**			2.97*
		{0.30}	{2.43}			[0.053]
	Normalised	0.093	0.219**	-0.119		2.713**
		(0.99)	(2.32)	(1.26)		[0.045]
Lean hogs	Absolute	0.430				
		(0.46)				
	Normalised	-0.016	-0.296**	0.018	0.304**	2.494**
		(0.12)	(2.15)	(0.13)	(2.27)	[0.043]

Notes: The table reports the estimated β coefficient, the t-statistic $|t_\beta|$ for the Granger-non-causality tests that index returns do not Granger-cause price returns (in round brackets OLS standard errors and in curly brackets robust standard errors) and p-values in square brackets for individual lags. The F-statistic for the Granger-causality tests that index returns to not Granger-cause price returns. Rejections at the 5% level are denoted by **, and those at the 10% level are denoted by *. Sample 3 January 2006 to 27 December 2011.

The results yield strong evidence that index positions Granger-cause live cattle returns and weaker evidence that they Granger-cause lean hog returns. In half of the livestock Granger-causality tests in Table 2.8 the null hypothesis that index positions do not Granger-cause price returns is rejected.

To summarise, there is strong evidence that in the less liquid soybean oil and livestock markets index positions do impact prices. These results support the hypothesis that one reason for the lack of evidence of Granger-causality in Sanders and Irwin’s (2011a) analysis is due to the difficulty of isolating the effects of index positions in liquid markets rather than the lack of such effects.

2.5.3 Long-horizon tests

Long-horizon regressions were carried out to test for "fads" type effects. The results are presented in Table 2.9. As in Sanders and Irwin (2011a), a significant long-term effect is only found in the soybean market. The results indicate that absolute index positions have an impact on prices in the soybean market over an 11 week horizon. The weakly significant results in the corn market and normalised soybean positions are for model specifications with one lag only and thus do not indicate any longer horizon impacts.

Table 2.9 Long-horizon tests for liquid markets

		Return	Position variable			
		lag	lag	coefficient	|t-statistic|	p-value
CBOT corn	Absolute	1	1	-0.608*	-1.96	0.051
	Normalised	1	1	-0.665**	-2.13	0.015
CBOT wheat	Absolute	1	1	-0.969	-1.17	0.243
	Normalised	1	5	0.390	1.06	0.290
KCBT wheat	Absolute	1	2	1.504	0.48	0.633
	Normalised	1	12	-0.934	-1.12	0.262
CBOT soybeans	Absolute	1	11	3.990**	2.09	0.038
	Normalised	1	1	0.378*	1.81	0.071

Notes: The table reports the estimated β coefficient, the *t*-statistic $|t_{\beta}|$ for the long-horizon regression (robust standard errors when required) and p-values. Rejections at the 5% level are denoted by ** and those at the 10% level by *. Sample 3 January 2006 to 27 December 2011.

Table 2.10 Long-horizon tests for less liquid markets

		Return	Position variable			
	Position variable	lag	lag	coefficient	t-statistic	p-value
Feeder cattle	Absolute	3	11	11.159	1.20	0.230
	Normalised	3	5	-0.264	-1.72	0.090 *
Live cattle	Absolute	3	2	0.951	1.14	0.254
	Normalised	2	2	0.304	2.43	0.016 *
Lean hogs	Absolute	1	4	0.985	0.66	0.510
	Normalised	1	2	-0.363	-1.91	0.058 *
Soybean oil	Absolute sbo	3	1	1.171	1.44	0.152
	Normalised sbo	3	5	0.455	1.03	0.302
	Absolute sb	3	3	3.111	2.71	0.007 ***
	Normalised sb	3	1	0.600	2.76	0.006 ***
		return lag	sb lag	sbo lag	F-statistic	p-value
Soybean oil	Absolute	3	3	3	5.29	0.006 ***
	Normalised	3	1	5	4.15	0.017 **

Notes: Sb stands for soybeans and sbo for soybean oil. The table reports the estimated β coefficient, the *t*-statistic $|t_{\beta}|$ for the long-horizon regression (robust standard errors when required) and p-values. Rejections at the 1% level are denoted by ***, at the 5% level are denoted by ** and those at the 10% level by *. Sample 3 January 2006 to 27 December 2011.

Table 2.10 presents the results of the long-horizons tests in the less liquid markets. The results support the findings of the standard Granger-causality tests but do not suggest any long horizon impacts. There is strong evidence that soybean and soybean oil index positions of the previous three weeks impact soybean oil prices. In addition, weak evidence is found that normalised index positions impact livestock prices with the longest horizon for feeder cattle with a five week horizon and two week horizon for live cattle and lean hogs. There is no evidence of any impact beyond five weeks. These results confirm those from the standard Granger-causality test but do not suggest any impact from a longer-term build-up of pressure from index positions.

2.5.4 Relative returns

If the dependent variable is volatile and if a large proportion of this volatility cannot be explained by the independent variable, the Granger-causality tests lack power. This is likely to be the case with respect to returns and index positions. Returns are very volatile and, if at all, only a small fraction of this volatility is likely to be explained by changes in index positions. Therefore, the standard error of the coefficient on index positions will be large. As a consequence, the Granger-causality tests have low power. If returns for different commodities move together, their relative returns will be less volatile and Granger-causality tests will have more power.

Table 2.11 shows the results of Granger-causality tests for relative returns of CME feeder cattle and CME live cattle, CME lean hogs and CBOT corn, and CME lean hogs and CBOT soybeans. There is weak evidence that (normalised) index positions Granger-cause relative returns of CME feeder cattle and CME live cattle as well as those of CME lean hogs and CBOT soybeans. The results are only significant at the 10 per cent level and both weakly significant results relate to the normalised measure of index positions. The normalised measure is less straightforward to interpret as the results can be due to either changes in the numerator (i.e. long index positions) or the denominator (i.e. total long positions).

Granger-causality tests using relative returns only provide weak evidence that index positions Granger-cause returns. One possible reason for the lack of strong evidence of Granger-causality, other than a lack of such an effect, is that relative returns are not substantially less volatile than the individual returns which, indeed, seems to be the case here (see Table 2.I in the appendix for descriptive statistics). Other sources also suggest that the links between the lean hog market and the corn and soybean markets are not strong with only partial price transmission and relatively long lags (see e.g. BPEX, 2012; Meyer, 2009).

Table 2.11 Granger-causality tests – relative returns

			Lags	Position change		
			m	Left	Right	Joint
CME live cattle	CME feeder cattle	Absolute	1	0.070	0.123	0.020
				(0.17)	(0.06)	[0.980]
		Normalised	1	0.147**	0.111	2.612*
				(2.20)	(0.22)	[0.075]
CME lean hogs	CBOT corn	Absolute	1	-1.724	0.628	1.365
				(0.76)	(1.34)	[0.257]
		Normalised	1	0.089	0.383	0.603
				(0.37)	(1.02)	[0.548]
CME lean hogs	CBOT soybeans	Absolute	1	-0.274	-0.955	0.720
				(0.16)	(1.01)	[0.488]
		Normalised	2	2.94*	0.711	2.276*
				[0.054]	[0.491]	[0.061]

Notes: The table reports the test statistics for the hypothesis that index returns do not Granger-cause spread returns. Spreads returns are the return of the column 1 (left) contract price less that of the column 2 (right) contract price. Lag length m (column 4) is chosen by minimization of the Akaike Information Criterion (AIC). Where m = 1, columns 5 and 6 report the estimated β coefficients and, in round parentheses, the absolute values of the t-statistics on the lagged position change variable. When m = 2, columns 5 and 6 report the F-statistic for exclusion of the entire distributed lag and, in square parentheses, the associated tail probability. Column 7 reports F-statistics for exclusion of both lagged position variables with tail probabilities are given in square parentheses. Rejections at the 5% level are denoted by ** and those at the 10% level by *. Sample 3 January 2006 to 27 December 2011.

2.5.5 Index of agricultural positions

Table 2.12 shows results of the Granger-causality tests based on regression models where log returns are regressed on lagged log returns and the lagged index of positions held by index traders in twelve agricultural futures markets. Using the AIC, models with only one lag are chosen for all but two of the commodities, namely soybean oil and live cattle. The results provide little evidence that the index of position Granger-causes returns. The only rejection of Granger-non-causality is found in the soybean oil market.

A possible explanation for the significant result in the soybean market is the fact that the soybean complex is an important element in the index, especially through soybean positions. Results in section 2.5.2 suggest that soybean positions Granger-cause soybean oil returns. It is likely that the significant result with respect of the index of agricultural positions is mainly based on the fact that the soybean complex represents a substantial part of the index. Overall, the analysis using an index of positions across twelve agricultural commodities does not improve the tests. These results suggest that the activity by index investors in the individual markets rather than the original index investment impacts prices.

Table 2.12 Granger-causality tests – index of agricultural positions			
	1 lag	2 lag	p-value of F-statistic
CBOT corn	0.037		
	{0.25}		
CBOT soybeans	0.136		
	{1.16}		
CBOT wheat	0.116		
	{0.77}		
CBOT soybean oil	0.262**	0.205	4.7 ***
	{2.11}	{1.64}	[0.010]
KCBT wheat	0.119		
	{0.85}		
Feeder cattle	0.054		
	(1.05)		
Live cattle	0.045	0.042	0.72
	{0.80}	{0.68}	[0.486]
Lean hogs	-0.043		
	(0.53)		

Notes: The table reports the estimated β coefficient and the t-statistic $|t_\beta|$ for the Granger-non-causality tests that index returns do not Granger-cause price returns in round brackets for OLS standard errors when tests suggest that errors are homoscedastic and in in curly brackets if heteroscedasticity robust standard errors are used. The candidate causal variable is the change in the number of CIT contracts in the row commodity contract. Rejections the 5% level are denoted by and those at the 1% level are denoted by ***. Sample 3 January 2006 to 27 December 2011.

2.5.6 Contemporaneous effects

The results in the preceding sections demonstrate Granger-causation from changes in CIT positions to changes in futures prices in the relatively illiquid soybean oil, live cattle and lean hogs markets. The predictability, which underlies the Granger-causality testing methodology, most likely arises out of the relative illiquidity of these markets. This predictability is absent in more liquid markets. This suggests the conjecture that the failure to establish a causal link in these more liquid markets may reflect a deficiency of the Granger-causality methodology and not the absence of any CIT price impact.

That conjecture is not provable. It is nevertheless worth considering contemporaneous interactions. Consider the simple contemporaneous correlations between futures returns and CIT position changes and also the simple regressions

$$r_{j,t} = \kappa + \beta x_{j,t} + u_{j,t} \qquad (2.6).$$

The t-statistics relating to the estimated slope coefficient in these regressions are simply transformations of the F tests on significance of the correlation between the returns and the position changes. These correlations and the t-statistics associated with the tests that the associated population correlations are zero, are given in Table 2.13. The correlations are all positive for the absolute measure of position changes and, apart from the case of lean hogs, are all statistically significant.

Two conclusions can be drawn from Table 2.13. First, it is undeniable that there is an association between CIT positions and futures returns. Causation could run either way or a third variable could be an unseen joint cause of both returns and CIT position changes. However, if these positive associations arise from a causal link from returns to position changes, this would require that CIT traders are trend followers. If instead, CIT traders are seeking to buy low and sell high, the causal link from returns to position changes should be negative and would offset the positive link from position changes to returns.

Table 2.13 Contemporaneous correlations of absolute positions and returns

	correlation coefficient	*t*-statistic	p-value
CBOT corn	0.145**	2.58	0.0103
CBOT soybeans	0.368***	6.97	0.0000
CBOT soybean oil	0.170***	3.04	0.0026
CBOT wheat	0.179***	3.20	0.0015
KCBT wheat	0.201***	3.61	0.0004
CME feeder cattle	0.132**	2.35	0.0193
CME live cattle	0.221***	4.01	0.0001
CME lean hogs	0.044	0.79	0.4319

Notes: The table reports the correlation coefficient, the t-statistics and the p-value testing zero correlation between price returns and contemporaneous index position changes. Rejection at the 1% level are denote by ***, those at the 5% level by ** and those at the 10% level by*. Sample 3 January 2006 to 27 December 2011.

Second, the correlations reported in Table 2.13 for the three commodities for which Granger causality has been established (soybean oil, live cattle and lean hogs) are similar to the five contracts where this link was not established. This suggests that the failure to find Granger-causality may indeed be because the methodology is insufficiently powerful in the context of an efficiently traded market and not because CIT position changes lack price impact.

2.6 Conclusions from this study

The casual reader of Sanders and Irwin (2011a) and other studies using Granger-causality analysis might come away with the impression that commodity index investment has no impact on U.S. grains market prices. Sanders and Irwin themselves are judiciously cautious in the interpretation of their results. They emphasise, for example, that their Granger-causality tests, which rely on the ability of lagged position changes to predict price changes, lack statistical power. This lack of power is particularly acute in the analysis of asset returns since, if markets are efficient, predictability should be non-existent or at least be limited. To counter this problem less liquid markets (soybean oil, feeder cattle, live cattle and lean hogs) were included in the analysis. Doing this, clear evidence is found that index investment does affect returns in these less liquid markets.

If CIT activity impacts less liquid agricultural futures markets, it may also have an impact in the more liquid grains markets for which no evidence of Granger-causality was found, either in this chapter or by Sanders and Irwin (2011a). The semi-strong form of the EMH implies that any such impacts should be contemporaneous. The contemporaneous correlations between CIT position changes and futures price changes, which are positive and generally statistically significant, are similar for the liquid and less liquid markets. Although an unambiguous causal interpretation is unavailable for these contemporaneous correlations, they are consistent with the view that changes in CIT positions affect the entire range of grains and livestock futures prices. However, this remains a conjecture.

Other extensions do not improve the Granger-causality tests. Results of long-horizon tests confirm those from the standard Granger-causality test but do not suggest any impact from a longer-term build-up of pressure from index positions. Granger-causality tests using relative returns only provide weak evidence that index positions Granger-cause returns. One possible reason for the lack of strong evidence of Granger-causality in this context, other than a lack of such an effect, is that relative returns are not substantially less volatile than the individual returns which is backed up by descriptive statistics and evidence from the markets. Analysis using an index of positions across twelve agricultural commodities does not improve the tests, which suggests that the activity by index investors in the individual markets rather than the original index investment impacts prices.

The results do not imply that index investors were responsible for the high levels of grains prices observed in 2007/08 and 2010/11. The econometric methods needed for quantification of any price impact differ from those required to demonstrate causal impact. This chapter has relied on Granger-causality analysis, which is a bivariate technique. Since there are multiple potential causes of the high prices observed in 2007/08, any quantification exercise would need to employ a multivariate framework. Furthermore, since grains are traded on markets which are widely regarded as efficient, a quantification exercise would need to consider contemporaneous interactions which Granger-causality tests exclude.

In conclusion, irrespective of whether or not there was a bubble in grains prices in 2007/08, and whether or not index investors contributed to such a bubble, there is clear evidence that index investment has been a factor influencing the level of grains and livestock prices over the five years from 2006 to 2011. This is an important finding, especially given the current policy debate.

The results in this chapter call for a closer scrutiny of the generally negative results of studies analysing the link between financial markets and food prices in the academic literature and the conclusion that, therefore, there is no need for a policy debate on financial market regulation.[19] Given the weaknesses of the methods used in most empirical studies, a policy debate on possible regulations of futures markets is necessary as is further research going beyond the currently dominant research approaches.

Considering the particularly sensitive nature of food commodity prices from a political standpoint and the seriousness of the impact on the poor, this debate is particularly important with regards to possible stricter regulation of agricultural commodities markets. In this context, consideration should also be given to policies that break the link between food and non-food commodities to limit possible spill-over effects to agricultural markets. One way to achieve this, which falls short of outright prohibition of index trading in agricultural futures, would be to unbundle agricultural and non-agricultural indices and, at the same time, for the index reporting companies (Dow Jones and Standard and Poors) to separate out agriculture from their published commodity indices.

2.7 Review of the literature after 2011

A large volume of research on the price impact of index investment has been carried out and published since the analysis in this chapter was carried out up until early 2012. The most important recent studies are briefly reviewed in this section.

Irwin and Sanders (2012) use a cross-sectional approach based on CFTC's quarterly Index Investment Data (IID) report which covers 19 markets, including the twelve of the COT *Supplementals*. They employ cross-sectional Fama–MacBeth regression tests on three different models that link commodity returns to index investment (Fama and MacBeth, 1973). The three different models use different specifications of the index position variable. The only

[19] See also Bozorgmehr et al. (2013) who “conclude that it is not justified to reject the hypothesis that financial speculation might have adverse effects on food prices/price volatility. We hope to initiate reflections about scientific standards beyond the boundaries of disciplines and call for high quality, rigorous systematic reviews on the effects of financial speculation on food prices or price volatility.”

model with a statistically significant result indicates that commodity index investment reduced returns, contrary to model predictions and market expert expectations.

A number of studies test for Granger-causality from index investment to agricultural futures prices. Over the period 2006 to 2010, Rouwenhorst and Tang (2012) find that changes in index investor positions do not Granger-cause returns in eleven of the twelve agricultural commodities studied. For the single commodity for which Granger-causality is found, the relevant coefficient is estimated as negative.

Mayer (2012) analyses the wheat, corn (maize)[20], soybeans and soybean oil markets as well as four non-agricultural markets. He includes index positions and money manager positions in the model to test for Granger-causality. Between June 2006 and June 2009, Granger-causality from index positions to prices is established in four of the eight markets (soybeans, soybean oil, copper and crude oil). For money managers, Granger-causality from positions to prices is established only in the corn market.

Aulerich et al. (2013) use the SUR framework with data over the period from January 2004 to September 2009 from the Large Traders Reporting System database. Out of the twelve markets they study, Granger-non-causality from index positions to prices is rejected in three markets (feeder cattle, lean hogs, Kansas City Board of Trade wheat).

Hamilton and Wu (2013) test if notional exposure in the previous period predicts prices. They do not find any evidence in the markets they study. Overall, the results in the literature based on Granger-causality analysis continue to be predominantly negative.

Tang and Xiong (2012) take a different approach. They analyse return correlations of non-energy commodities with oil. They find that the correlation of oil returns with those commodities that are not included in the two most important commodity indices increased significantly less than those of the commodities in the indices. Their results suggest that index investment impacted prices.

Gilbert and Pfuderer (2014a) include Granger-causality tests but also an instrumental variables (IV) approach to examine the price impact of index investment on the main US grains and soybean markets. The Granger-causality analysis results are in line with the negative results of other studies. IV-based tests for contemporaneous causality provide evidence of price impact for the soybean complex and the KCBT wheat market. Granger-causality tests based on a regression of IMF commodity price indices on a weighted index of the total quantity of CIT net positions across all twelve reporting markets find Granger-causality for all but the beverage price index. The latter two papers suggest that the largely negative results of Granger-causality tests in individual commodity markets might be more due to a lack of power of Granger-causality tests than to a lack of such an impact.

[20] Mayer (2012) refers to maize but the analysis is based on the CBOT corn contract.

Grosche (2014) reviews the evidence to Granger-causality analysis from index investment to agricultural commodity prices and also finds that there is little evidence of Granger-causality from index positions to agricultural commodity prices. The paper then goes on to critically examine the interpretation of Granger-causality results in this context. Three interpretations of positive Granger-causality tests are reviewed: the interpretation as prima facie causal evidence, as a test of informational efficiency of the markets analysed and as a test of improved forecasts. The paper argues that none of these possible interpretations of Granger-causality admits direct inference about the existence of a price impact of index investment and calls for alternative approaches to complement Granger-causality analysis.

Appendix

Table 2.I Descriptive statistics

Log prices					
	Observations	Mean	Standard Deviation	Minimum	Maximum
CBOT corn	313	6.034	0.336	5.341	6.642
CBOT soybeans	313	6.881	0.288	6.286	7.392
CBOT soybean oil	313	3.671	0.293	3.055	4.231
CBOT wheat	313	6.377	0.282	5.795	7.109
KCBT wheat	313	6.449	0.268	5.919	7.140
CME feeder cattle	313	4.697	0.117	4.461	5.000
CME live cattle	313	4.545	0.112	4.298	4.815
CME lean hogs	313	4.237	0.166	3.792	4.635
Log returns					
	Observations	Mean	Standard Deviation	Minimum	Maximum
CBOT corn	312	5.82E-04	0.051	-0.165	0.184
CBOT soybeans	312	1.87E-03	0.039	-0.127	0.113
CBOT soybean oil	312	1.15E-03	0.039	-0.116	0.140
CBOT wheat	312	-1.42E-03	0.053	-0.176	0.147
KCBT wheat	312	2.65E-05	0.048	-0.164	0.148
CME feeder cattle	312	-4.80E-04	0.021	-0.067	0.080
CME live cattle	312	-6.70E-04	0.020	-0.057	0.071
CME lean hogs	312	-3.04E-03	0.034	-0.122	0.089
Absolute measure of index positions					
	Observations	Mean	Standard Deviation	Minimum	Maximum
CBOT corn	313	0.377	0.068	0.224	0.504
CBOT soybeans	313	0.149	0.028	0.087	0.201
CBOT soybean oil	313	0.075	0.017	0.037	0.114
CBOT wheat	313	0.187	0.024	0.127	0.230
KCBT wheat	313	0.032	0.008	0.016	0.053
CME feeder cattle	313	0.008	0.002	0.005	0.011
CME live cattle	313	0.117	0.023	0.061	0.157
CME lean hogs	313	0.084	0.016	0.046	0.127
Index of positions	313	1.631	0.244	1.061	2.118
First difference of absolute measure of index positions					
	Observations	Mean	Standard Deviation	Minimum	Maximum
CBOT corn	312	3.17E-04	9.05E-03	-0.037	0.045
CBOT soybeans	312	2.40E-04	3.61E-03	-0.014	0.011
CBOT soybean oil	312	1.25E-04	2.59E-03	-0.011	0.011
CBOT wheat	312	5.98E-05	3.73E-03	-0.011	0.015
KCBT wheat	312	4.06E-05	1.16E-03	-0.006	0.005
CME feeder cattle	312	7.68E-06	3.99E-04	-0.003	0.001
CME live cattle	312	2.04E-04	2.10E-03	-0.011	0.008
CME lean hogs	312	1.04E-04	2.13E-03	-0.011	0.012
Index of positions	312	1.78E-03	2.37E-02	-0.102	0.059

Normalised measure of index positions					
	Observations	Mean	Standard Deviation	Minimum	Maximum
CBOT corn	313	0.247	0.042	0.167	0.348
CBOT soybeans	313	0.263	0.030	0.198	0.349
CBOT soybean oil	313	0.256	0.044	0.178	0.405
CBOT wheat	313	0.422	0.043	0.320	0.518
KCBT wheat	313	0.236	0.052	0.123	0.346
CME feeder cattle	313	0.247	0.047	0.141	0.352
CME live cattle	313	0.370	0.050	0.272	0.472
CME lean hogs	313	0.410	0.042	0.289	0.514
First difference of normalised measure of index positions					
	Observations	Mean	Standard Deviation	Minimum	Maximum
CBOT corn	312	2.53E-06	0.009	-0.029	0.043
CBOT soybeans	312	1.56E-04	0.012	-0.025	0.042
CBOT soybean oil	312	1.29E-04	0.012	-0.034	0.039
CBOT wheat	312	-1.15E-04	0.017	-0.055	0.090
KCBT wheat	312	3.48E-04	0.011	-0.042	0.044
CME feeder cattle	312	2.66E-04	0.016	-0.050	0.072
CME live cattle	312	1.91E-04	0.012	-0.032	0.040
CME lean hogs	312	-2.62E-04	0.015	-0.052	0.061

Table 2.II Unit root tests

Price variables

Log prices	lag	t-adf	Log returns	lag	t-adf
CBOT corn	1	-1.77	CBOT corn	0	-18.77 **
CBOT soybeans	0	-1.77	CBOT soybeans	0	-17.58 **
CBOT soybean oil	0	-2.30	CBOT soybean oil	2	-9.50 **
CBOT wheat	0	-2.30	CBOT wheat	0	-17.48 **
KCBT wheat	0	-2.11	KCBT wheat	0	-17.02 **
CME feeder cattle	0	-0.79	CME feeder cattle	2	-9.66 **
CME live cattle	4	-2.00	CME live cattle	2	-10.00 **
CME lean hogs	4	-1.95	CME lean hogs	0	-16.98 **

Relative returns		lag	t-adf
CME lean hogs	CBOT corn	4	-9.55 **
CME lean hogs	CBOT soybeans	4	-9.16 **
CME live cattle	CME feeder cattle	0	-18.97 **

Absolute measure of index positions

Levels	lag	t-adf	First difference	lag	t-adf
CBOT corn	4	-1.95	CBOT corn	0	-13.52 **
CBOT soybeans	1	-1.86	CBOT soybeans	0	-13.59 **
CBOT soybean oil	1	-1.64	CBOT soybean oil	0	-14.10 **
CBOT wheat	4	-1.90	CBOT wheat	0	-14.99 **
KCBT wheat	2	-1.77	KCBT wheat	1	-10.27 **
CME feeder cattle	1	-2.77	CME feeder cattle	0	-15.50 **
CME live cattle	4	-1.81	CME live cattle	3	-6.08 **
CME lean hogs	3	-1.76	CME lean hogs	2	-7.35 **
Index of positions	4	-2.09	index of positions	3	-5.56

Normalised measure of index positions

Levels	lag	t-adf	First difference	lag	t-adf
CBOT corn	4	-2.15	CBOT corn	1	-12.77 **
CBOT soybeans	3	-2.83	CBOT soybeans	2	-12.65 **
CBOT soybean oil	3	-1.98	CBOT soybean oil	2	-12.95 **
CBOT wheat	1	-4.69 **	CBOT wheat	3	-10.12 **
KCBT wheat	1	-2.48	KCBT wheat	0	-15.52 **
CME feeder cattle	3	-4.13 **	CME feeder cattle	0	-16.02 **
CME live cattle	1	-2.52	CME live cattle	4	-10.47 **
CME lean hogs	0	-3.11 *	CME lean hogs	4	-10.05 **

Notes: t-adf stands for the t-statistics for the Augmented Dickey-Fuller test. Rejection at the 1% level are denote by ** and those at the 5% level by *.

Table 2.III One lag autocorrelations

	Absolute index positions		Normalised index positions		Returns	
	auto-correlation	p-value	auto-correlation	p-value	auto-correlation	p-value
CBOT corn	0.2602	0.000	0.1715	0.002	-0.0718	0.203
CBOT soybeans	0.2517	0.000	0.1320	0.017	-0.0056	0.921
CBOT soybean oil	0.2230	0.000	0.1792	0.007	0.0207	0.713
CBOT wheat	0.1846	0.001	0.1749	0.001	-0.0009	0.987
KCBT wheat	0.1289	0.021	0.1160	0.045	0.0278	0.622
CME feeder cattle	0.1187	0.033	0.0887	0.111	0.0270	0.630
CME live cattle	0.3074	0.000	0.1062	0.056	-0.0670	0.232
CME lean hogs	0.1982	0.000	-0.0294	0.597	0.0361	0.520

3 Impacts of China on Global Grain Prices – Insights from the Competitive Storage Model

3.1 Introduction

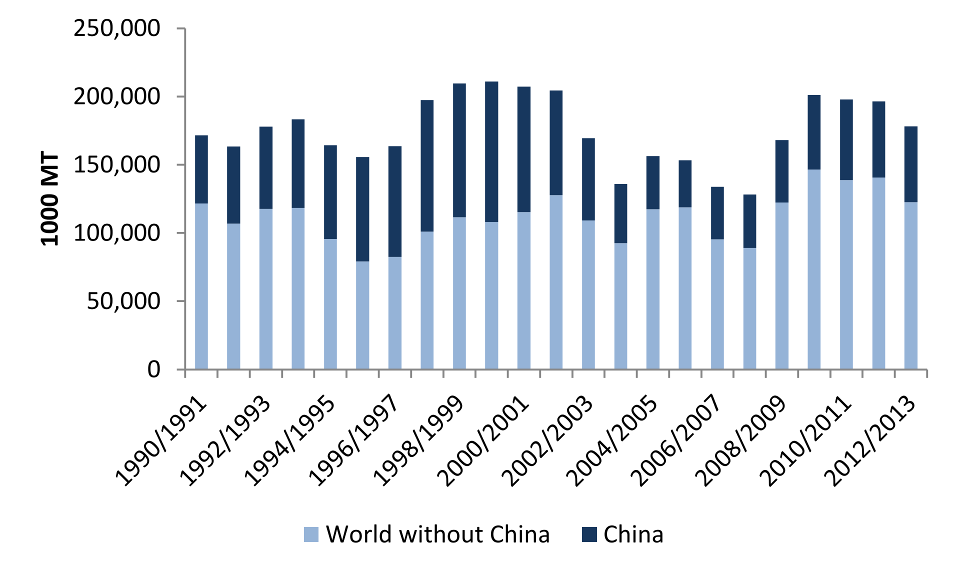
Agricultural commodity prices have been at the centre of an intense public and academic debate since the price increases in the late 2000s. After several decades of low and relatively stable agricultural commodity prices, the price spike of 2007/08 came as a surprise to industry experts, policy-makers and academics alike. Even now our understanding of the price spike in particular, but also commodity price movements more generally, is rather limited despite the crucial importance of food commodity prices. In the preface to their comprehensive study of the causes and consequences of the price spike, Headey and Fan (2010, p. x) note: “Many possible causes have been identified, but their relative importance is uncertain.” Similarly, Miao et al. (2011) note that despite the crucial importance of food prices to both the public and policy-makers agricultural commodity prices are still poorly understood.

Many studies identify low stocks as one of the main factors in driving prices to peak values in 2007/08 and 2010/11 pointing out that global stocks-to-use ratios were at their lowest levels in decades (European Commission, 2008; OECD, 2008; Wiggins and Keats, 2010). Thirtle and Piesse (2009, p. 1) state that “if a single factor is to be identified as the cause of the recent price spikes, it has to be low stocks.”

Others suggest that the role of stocks in the 2007/08 price pike is generally overestimated. They argue that the low stock-to-use ratios were mainly due to a large decrease in stock levels in China from 2000 onwards, which was driven by a Chinese government policy decision to reduce the excessively high stock levels of the 1990s (e.g. Fuglie, 2008). Even though the reduction in grain stock levels in China was very substantial, the impact on the world markets can be expected to have been small because the policy decisions in China were not driven by world market developments and because China was largely self-sufficient in grains and, thus, was not a major player on any of the world grains markets (e.g. Dawe, 2009).

In the 1990s, China accumulated substantial stock levels and stocks-to-use ratios for the main cereals were much higher there than elsewhere. At the end of the 1990s, China started to reduce its cereal stocks. Figure 3.1 shows that global wheat ending stocks were lower in 2006/07 and 2007/08 than in any year since 1990. However, the picture differs if Chinese stocks are excluded. Stocks in the rest of the world were relatively low in 2006/07 and 2007/08 but higher than in 1995/96 and 1996/97. And in recent years stocks have been at relatively high levels.

Figure 3.1 Global and Chinese wheat ending stocks from 1990/91 to 2012/13



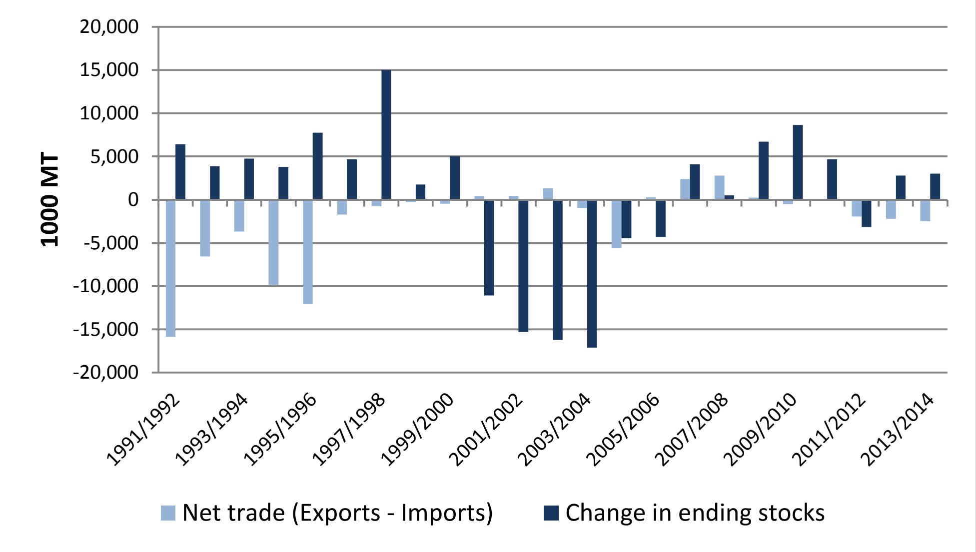
Source: USDA http://www.fas.usda.gov/psdonline/psdhome.aspx

The picture does not change much when looking at the stocks-to-consumption ratio. For the world as a whole, the stocks-to-consumption ratio was 21 percent in 2007/08, the lowest over the period 1990/91 to 2012/13, slightly lower than 2006/07 when it was 22 percent and 2003/04 when it was 23 percent. When China is excluded, the stocks-to-consumption ratio in 2007/08 was 18 percent, a level also reached in 2006/07, 1996/97 and 1995/96 and only slightly lower than in 2003/04 when the stocks-to-consumption ratio in the world without China was 19 per cent.

These figures show that stock levels in 2007/08 were unquestionably relatively low in 2007/08. However, most of the decline in global cereal stocks in the 2000s was due to the decrease in stocks in China and when China is excluded the situation in 2007/08 does not look very different to some other years when stocks were relatively low without leading to price increases of a similar extent.

China has been a relatively small player on world markets, since the mid-1990 at least, because most of the adjustment to supply and demand shocks within China has been made by stock changes rather than by trade (see Figure 3.2). Therefore, some argue, world stock levels excluding China should drive world prices (e.g. Dawe, 2009). This position is equivalent to saying that China and the rest of the world should be considered as two separate markets as China follows effectively an autarky policy. This shows that stockholding and trade policies should be seen as closely linked. Stockholding and trade policies can both buffer production shocks. While stockholding achieves this through intertemporal arbitrage, trade can do so through spatial arbitrage (as long as harvests are not perfectly correlated). Stockholding and trade policies can be used individually or together to exploit intertemporal and spatial arbitrage opportunities.

Figure 3.2 Changes in stocks and net trade for wheat in China from 1991/92 to 2013/14



Source: USDA http://www.fas.usda.gov/psdonline/psdhome.aspx

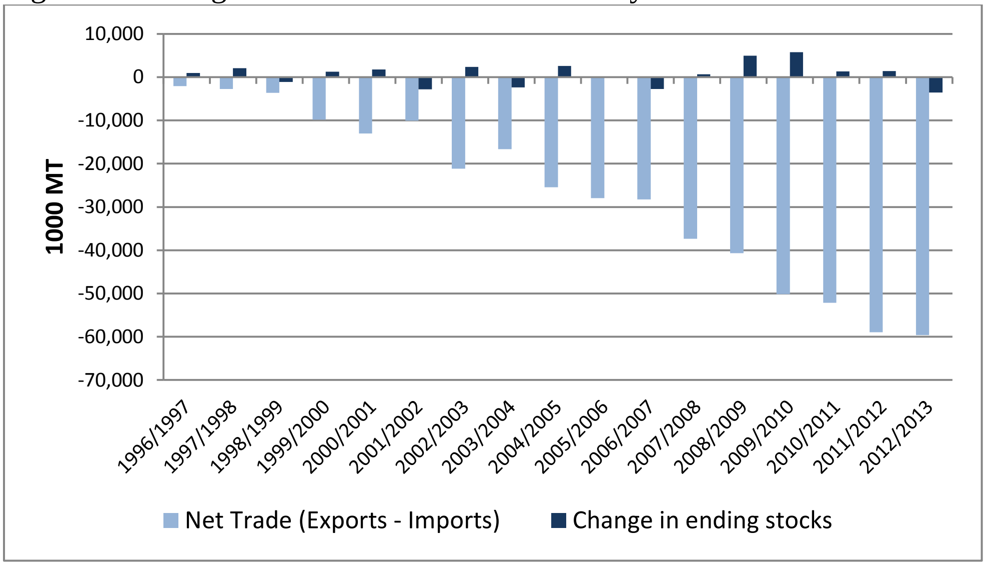
Any impact of Chinese grains policy on world markets must be transmitted through changing patterns of trade between China and the rest of the world.

Figure 3.2 shows that trade in wheat between China and the rest of the world was close to zero between 1996/1997 and 2003/2004. Since then, China has traded wheat in some years but still at relatively low levels.

Most of the studies suggesting that low stocks were an important factor in the 2007/08 price spike do not explicitly model the complexity of the stock-price relationship and its link to trade patterns. The focus of these studies is simply on the fact that in presence of low stocks, prices are more sensitive to negative supply and positive demand shocks. The causality is bi-directional, though. Stocks and prices are jointly determined. Stockholders decide the amount of a commodity to carry over to the next marketing year depending on the current price and the expected price in the next marketing year. At the same time, the current price and the expected price in the next period depend on the stocks carried over to the next period. The picture is further complicated by the fact that stock declines can either be the result of random variations in yield, policy changes, structural shifts in supply or demand or a combination of those. In the case of structural shifts in supply and/or demand these are seen as the fundamental causes of a price spike of which low stocks and high prices are the consequences (Headey and Fan, 2008).

Indeed, such structural changes were suggested as possible causes of the 2007/08 price spike. Rapid demand growth, especially in China and India, was frequently named as a possible cause (e.g. Headey and Fan, 2008; FAO, 2008). The impact of sustained demand growth in China on world prices depends on how the increased demand is met. If the increase in demand is met by domestic supply, as it was the case for wheat for most of the 2000s, the effect on the world price can be expected to be small. If the increase in demand is met through increased imports though, the impact on world prices can be expected to be more substantial.

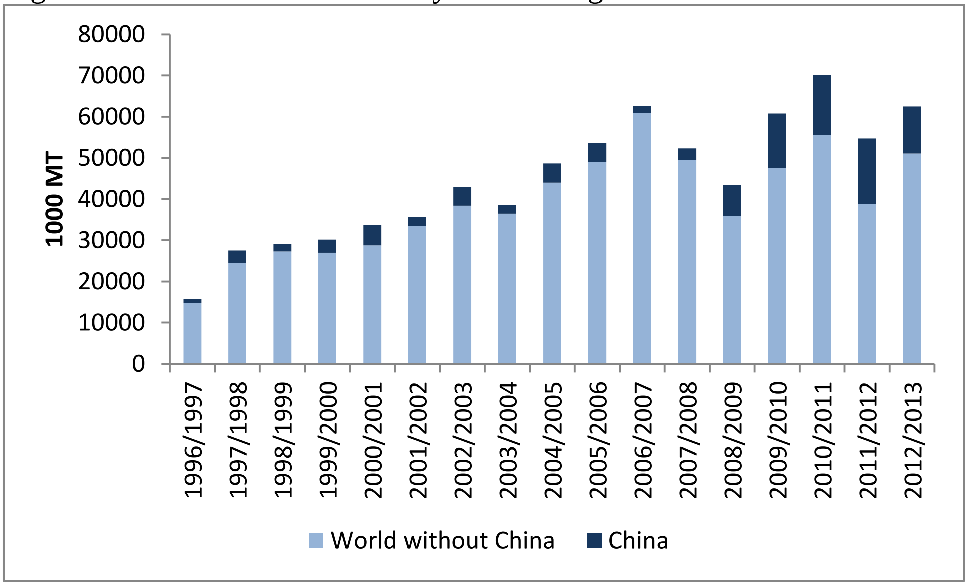
Figure 3.3 Changes in stocks and net trade for soybeans in China from 1996/97 to 2013/14



Source: USDA http://www.fas.usda.gov/psdonline/psdhome.aspx

As Figure 3.3 shows, in contrast to the wheat market, China has met its increasing demand for soybeans through steadily increasing imports (for a more detailed discussion see Abbott et al., 2011, pp. 13-16). However, as Figure 3.4 shows, in terms of stocks of soybeans, China has accounted for a rather small component of global stocks.

Figure 3.4 Global and Chinese soybean ending stocks from 1996/97 to 2012/13



Source: USDA http://www.fas.usda.gov/psdonline/psdhome.aspx

The public discussion about the impact of sustained demand growth in China on global grains markets has recently been revived (see for example Lucas, 2013). In February 2014, guidelines were issued by the Chinese government that effectively translate into the abolition, or at least loosening, of China's long-established self-sufficiency targets in grains (Hornby, 2014). The impact of the loosening of the self-sufficiency targets on global grains prices has since been subject to a controversial debate (e.g. Zhang, 2014).

Estimating the impact of stock policy changes on prices empirically is difficult due to the lack of accurate stocks data (e.g. Bobenrieth et al., 2012; Wiggins and Keats, 2010). The lack of accurate stocks data is particularly acute for China where no official estimates of grains stocks are published because these data are considered a state secret (e.g. Carter et al., 2012). The estimates available are produced by organisations outside China, such as the estimates made by the United States Department of Agriculture (USDA) and published monthly in the World Agricultural Supply and Demand Estimate report.

The substantial uncertainty surrounding these stock estimates was clearly illustrated by the revisions of Chinese grain stock estimates by the USDA in May 2001 when wheat, maize and rice stocks in China were increased by 158 percent, 93 percent and 272 per cent, respectively, leading to revisions of global stocks by 33 percent, 40 percent and 112 percent, respectively.

This study takes a closer look at the potential impact of changes in Chinese grains market policies on world wheat prices using the competitive storage model. Any impact of changes in grain policy in China will be transmitted to the world market through changing trade patterns. Hence, the question is asked what impact a large country has on global price dynamics in a competitive storage framework under different trade scenarios that are consistent with changing stockholding and self-sufficiency policies. The analysis in this chapter brings together two of the frequently identified possible causes of the price spike of 2007/08, namely low global stocks and shifts in the supply and demand balance in China. This study is also relevant for the current discussion of the impact of the change in self-sufficiency policy in China on global grains markets. In contrast to the literature cited above, a formal model is used to study the impact changes in the Chinese markets on global prices under different trade and market situations. The model used in this analysis is the competitive storage model.

The chapter proceeds as follows: section 3.2 reviews some of the seminal contributions to the competitive storage literature and a number of more recent additions. Section 3.3.1 outlines the competitive storage model in autarky; section 3.3.2 describes the model with one-directional trade and free trade; section 3.3.3 briefly states the solution method employed and section 3.3.4 describes the parameterisation of the model. Results are presented in section 3.4 followed by a discussion of the results and their limitations in section 3.5. Section 3.6 concludes.

3.2 Literature review

The important role of storage in commodity price formation has long been recognised. Models of intertemporal price relationship and storage go back to at least the 1930s and 1940s with the seminal work of Working on intertemporal price relationships, futures prices and the role of storage (e.g. Working, 1948, 1949).

Samuelson (1957) introduced a simple model of intertemporal price equilibrium. For markets with annual crops, assuming known constant and continuous demand and one single harvest a year of constant and known size, prices move in a regular pattern. Prices are lowest at harvest and then increase steadily throughout the year until the next harvest. The increase in price is due to storage and interest costs. If harvests are variable but of known size, price movements are more irregular but still follow a similar zigzag pattern.

Gustafson's (1958) monograph made ground-breaking advances to the literature of price formation and storage under uncertainty. He added supply shocks to the intertemporal model through probabilistic harvests. Gustafson's model is in effect a rational expectations model but was published three years before Muth's (1961) introduction of rational expectations into the economics literature. Storage in Gustafson's model is subject to a non-negativity constraint which makes the model analytically intractable. The model is solved for the profit-maximising stock level using dynamic programming techniques. To solve the model, Gustafson suggested three methods and carried out one of them, namely iteration of the value function. The non-negativity of stock levels introduces asymmetry in the price movements, a feature generally observed in agricultural commodity price series.

Over the following two decades, Gustafson's work received scant recognition and few advances were made in the literature. However, at the end of the 1970s, a number of authors revived the interest in the storage models for the analysis of the welfare impact of different policies for price stabilisation such as grain reserves. Johnson and Sumner (1976), for example, analysed the effects of grain reserves policies for developing countries and Gardner (1979) investigated the welfare effects of price stabilisation policies that can be taken by International Commodity Agreements. In the early 1980s, Newbery and Stiglitz (1981, 1982) examined the potential of public interventions to increase welfare of consumers and producers in the presence of incomplete markets. They conclude that when markets are incomplete, public policies may exist that improve welfare.

Williams and Wright (1991, ch. 9) and Miranda and Glauber (1995) added trade between two countries to the competitive storage model. Combining spatial arbitrage through trade and intertemporal arbitrage through storage in the same model substantially increases the complexity of the model. Williams and Wright (1991) find that storage is more effective in reducing price variation than is trade for two countries with uncorrelated shocks to production that would not trade without uncertainty. Miranda and Glauber (1995) studied the impact of introducing trade and storage for regions with chronic supply-demand imbalances and for regions where no such imbalance exists. Without chronic supply-demand imbalances, the impacts of trade and storage are similar. This is not the case when the countries are imbalanced. In this case, the introduction of trade leads to a substantial change in storage behaviour while the introduction of storage only has a small effect on trade.

The empirical relevance of the competitive storage model was questioned by Deaton and Laroque (1992, 1996). Deaton and Laroque (1992) compared the model predictions for commodity prices with actual prices for commodities. They find that the model performs well with regards to the asymmetry of price movements and large price spikes. The model suggests persistence in prices, but, according to its authors, it fails to replicate the extent of the autocorrelation in the actual price series (Deaton and Laroque, 1996).

A number of recent papers revisit the question of whether the competitive storage model can replicate price and stocks dynamics on commodity markets. Cafiero et al. (2011) take the Deaton and Laroque models as starting points. Using a different set of parameters, which they believe to be more realistic, high autocorrelations are generated using the Deaton and Laroque (1992) model when also adding a constant marginal cost to storage. Furthermore, they investigate the effect of using a finer grid for the approximation of the equilibrium price function. The model, econometric estimation and the data are the same as in Deaton and Laroque (1996). The use of the finer grid results in autocorrelations that are similar to observed autocorrelations for the commodities studied. In addition, as in observed data, stock-outs are less frequent than in the original work by Deaton and Laroque.

Miao et al. (2011) take a different approach. They extend the Deaton and Laroque model. They introduce trends in demand and supply and interest rates that vary over time to make the model more realistic. Unlike Deaton and Laroque’s model prediction, their model predictions are in line with the main characteristics of actual commodity price series, including higher autocorrelations of price series.

Arseneau and Leduc (2013) embed a competitive storage model into a general equilibrium model where the interest rate is endogenous. With endogenous interest rates, the serial correlation in prices increases and stock-outs are less frequent.

These recent results suggest that the competitive storage model can provide valuable insights into the stock-price relationship on commodity markets.

Two recent studies that have employed the competitive storage model are worth mentioning here. Liu et al. (2013) study the impact of a potential change in China’s rice trade policy to become more integrated into the world market. In their model four regions are included, China, major exporters, major importers and rest of the world. According to their model, greater integration of China into the rice market would lead to a reduction in the world rice price and stabilisation of world rice market. The rice market differs from the wheat market in that governments play a dominant role in the world rice market and that the commercial market in rice is much thinner than the world wheat market.

Gautam et al. (2014) analyse Indian wheat market policies on the basis of a two region competitive storage model. The focus of their study differs from Liu et al. (2013) and the current study in that the main interest is not the effect that the policies have on the rest of the world but the effect that different policies have on the welfare in India. They analyse four policies; current policy is compared to three alternatives: laissez-faire, optimal and simple rules policies. The current policy leads to very stable prices at a high cost. The tentative conclusions of their study is that, compared to the current policy, the optimal policy and the simple rules policies lead to welfare gains in India while also reducing price volatility for the rest of the world.

In this study the competitive storage model is employed to gain insights into the impact of China on global wheat prices. The main question addressed in the chapter is: What impact does a large country have on global price dynamics in a competitive storage framework under different trade regimes and different supply and demand balances? In the chapter, the main characteristics of the large country market are chosen to mirror the Chinese wheat market and that of the rest of the world market are chosen to mirror the world wheat market characteristics.

3.3 The competitive storage model

The competitive storage model is a rational expectation model. The expectations formed by the agents for variables in the next period, here the price in the next period, are required to be consistent with the distribution of these variables that results given the model and expectations. One of the main characteristics of the model is the fact that storage cannot be negative. Due to this non-negativity constraint on storage the model cannot be solved algebraically. However, a number of numerical methods are available to solve the competitive storage model. With modern computers even more complex models, such as models including storage and trade, can be solved in short periods of time. The following sections outline the equations of the model in autarky and with trade.

3.3.1 The competitive storage model in autarky

The situation in which China chooses to follow a policy of self-sufficiency in grains forms the starting point of the analysis. In this scenario, the rest of the world (ROW) is modelled separately from China. The two models are not linked and each model is solved independently. This scenario is a reasonable representation of the situation when China was holding very high levels of stocks of grains at the beginning of the 2000s. During this period, in years with positive shocks to production, China generally did not export its surpluses but increased stock levels. In years with negative shocks to production China generally did not import grains but reduced stock levels.

The models in autarky are similar to the model presented in Wright and Williams (1982). The set-up used in this analysis builds on demonstration files for a variety of competitive storage models made available by Christophe Gouel at http://www.recs-solver.org/index.html.

The general set-up is identical for the ROW and China. The models only differ in the parameterisation (demand and supply elasticities, size parameters and shock specification). The competitive storage model in autarky has one state variable, availability (A) and three control variables storage (S), planned production (H) and price (P). There are three arbitrage equations, one for each control variable. Where necessary, the equations are set up as mixed complementarity problems. In a mixed complementarity problem, a variable x is associated with a lower bound l, an upper bound u and a function F(x). The problem is solved for x so that F(x) = 0 if x is between the lower bound and the upper bound, F(x) is positive if x is at the lower bound and F(x) is negative if x is at the upper bound. Mixed complementarity problems can be written compactly, using the perpendicular symbol, as $F(x) \perp l \leq x \leq u$.

a) Storage arbitrage

$$P_t + k - E_t[P_{t+1}] * \frac{1-\delta}{1+r} \quad \perp \; 0 \leq S_t \leq \infty \tag{3.1}$$

where P_t is the price in period t, k is the unit storage cost, $E_t[P_{t+1}]$ the expected price in period t for period t+1, δ is the share by which the goods in storage depreciate or shrink, r is the interest rate and S_t is the amount of the commodity carried over from period t to period t+1.

When storage, S_t, is between the lower and the upper limit, the expression on the left-hand side equals zero. Thus, when storage is positive, the current price plus the unit storage cost must equal the discounted expected price in the following period, adjusted for shrinkage. If the current price plus unit storage cost were higher than the discounted expected price in the following period adjusted for shrinkage, then it would be profitable for stockholders to reduce storage by a unit and sell it in period t. By contrast, if the current price plus unit storage cost were lower than the discounted expected price in the following period adjusted for shrinkage, then it would be profitable for stockholders to increase storage by a unit and sell it in period t+1. Thus, with storage above zero, stockholders will take advantage of arbitrage opportunities until the current price plus storage cost equals the discounted expected price in the following period adjusted for shrinkage.

If storage is at the lower limit, that is if storage is zero, then the expression on the left-hand side of (3.1) will be positive. In this case arbitrage is limited by the fact that storage cannot be below zero as it is not possible to borrow physical units of the commodity from future harvests. In this case, the current price plus unit storage cost will be higher than the discounted expected price in the following period adjusted for shrinkage.

b) Producer production decision

$$h * (H_t/\gamma)^{\mu} = \mathrm{E_t}[\mathrm{P_{t+1}}\varepsilon_{t+1}]/(1+\mathrm{r}) \quad (3.2)$$

where h is the scale parameter for the production cost function, H_t is the planned production in period t which will be realised in period t+1, γ the size adjustment parameter, μ is the inverse of the supply elasticity β (i.e. $\mu = \frac{1}{\beta}$), $E_t[P_{t+1}\varepsilon_{t+1}]$ is the expected incentive price in period t for period t+1 and r is the interest rate.

Producers have to make their production decision one period in advance; that is they plan production in period t to be harvested in period t+1. This is a realistic assumption for many crops, including wheat. Actual production is subject to a multiplicative shock, representing a yield shock. The shocks are assumed to be normally distributed with mean of 1.

The expression on the left-hand side represents the marginal cost of planned production H_t. The cost function in this model is convex and isoelastic. The term on the right-hand side, $E_t[P_{t+1}\varepsilon_{t+1}]/(1+r)$, is the discounted expected incentive price in t for t+1. The incentive price generally differs from the market price because producers recognise that their multiplicative production shock is the same as the aggregate production shock. Hence, their own production and the price are correlated. Producers take the correlation into account when making the production decision and will increase production up until the point where marginal production costs equal their discounted expected marginal revenue, namely the discounted incentive price.

c) Market clearing condition

$$\mathrm{A_t} = \gamma * \mathrm{P_t^{\alpha}} + \mathrm{S_t} \quad (3.3)$$

where A_t is availability in period t which consists of actual production in period t (i.e. planned production in t-1 times the production shock in t) and stocks carried over into period t from period t-1, γ is a size adjustment parameter, P_t is the price in period t, α is the demand elasticity and S_t is storage in t, that is stocks carried from period t into period t+1.

The expression simply states that supply must equal demand. Supply here is availability, which is made of actual production in period t and stocks carried over from period t-1 and demand consists of demand for consumption P_t^{α} adjusted with a size parameter, and demand for storage S_t.

In addition to the arbitrage equations, it is necessary to define the transition equation which describes the transition of the state variable, here A, from one period to the next. Transition depends on the state and control variables in the previous period and the current shocks.

$$A_t = (1-\delta) * S_{t-1} + H_{t-1} * \epsilon_t \tag{3.4}$$

Availability in period t consists of stocks carried forward from period t-1 to period t, adjusted for shrinkage, plus the actual production in period t, which is the production planned in period t-1 times the yield shock which is realised in period t to production planned in period t-1.

For the model to be complete, it is necessary to specify how expectations are formed. In the model, rational expectations are assumed. The expectations formed by stockholders and producers for the price in the next period need to be consistent with the price distribution resulting given the model equations and the price expectations.

3.3.2 The competitive storage model with trade

As shown in Figures 3.1 and 3.2, China reduced stocks of wheat at the beginning of the millennium. With stocks at a much lower level, it becomes more likely that China would reach a point where stocks become insufficient to buffer negative production shocks and trade is used as an additional tool to buffer production shocks. Two different trade scenarios are considered. The one-directional trade set-up is based on the assumption that China will import grain while maintaining the policy of buffering positive production shocks by increasing stocks. In the competitive storage model framework such a policy can be represented by introducing exports from the ROW to China but still excluding the possibility that China exports to the ROW (this set-up is referred to as one-directional trade scenario). The one-directional trade scenario is modelled for both balanced (same price in the deterministic steady-state in autarky) and unbalanced (different prices in the deterministic steady-state in autarky) markets.

A free-trade set-up is also included for two reasons. Firstly, any analysis that focuses on global stocks, like many of the studies analysing the price spikes, implicitly assume that countries trade freely and all stocks, regardless of where they are held, have the same impact on ROW prices. Secondly, as can be seen from Figure 3.2, China has occasionally exported wheat. With the likely loosening of the self-sufficiency policy, China might move to a free trade policy; that is it might export when prices in the rest of the world are high compared to those in China.

The model now consists of two countries and has two state variables, availability in the ROW and availability in China. The models with trade are similar to the model in Miranda and Glauber (1995). The arbitrage equations then are:

a) Storage arbitrage

There is a storage arbitrage equation for each country but otherwise unchanged compared to Equation (3.1).

b) Producer production decision

Similarly, there is one arbitrage equation for each country but these are otherwise unchanged compared to Equation (3.2).

c) Market clearing condition

$$\mathrm{A}_{\mathrm{i,t}} + \mathrm{X}_{\mathrm{j,t}} = \gamma_i * \mathrm{P}_{\mathrm{i,t}}^{\alpha_i} + \mathrm{S}_{\mathrm{i,t}} + \mathrm{X}_{\mathrm{i,t}} \qquad \mathrm{i} = 1,2;\ \mathrm{j} = 1,2;\ \mathrm{i} \neq \mathrm{j} \qquad (3.5)$$

where $\mathrm{A}_{\mathrm{i,t}}$ is domestic availability, $\mathrm{X}_{\mathrm{j,t}}$ are exports from the other country to the domestic market, $\gamma_i * \mathrm{P}_{\mathrm{i,t}}^{\alpha_i}$ is domestic demand for consumption with γ_i the domestic demand size adjustment factors, P_i the domestic price and α_i the domestic demand elasticity, $\mathrm{S}_{\mathrm{i,t}}$ is the domestic demand for storage and $\mathrm{X}_{\mathrm{i,t}}$ are exports from the domestic market to the other country.

The market clearing condition takes into account the possibility of imports from the other country to increase supply and exports to the other country as an additional element of demand. In free trade, demand for wheat now consists of three components, namely domestic demand for consumption and storage and demand for exports. Supply consists of domestic availability and imports.

In the one-directional trade scenario, there are no exports from China to the ROW. As a consequence, demand in China only consists of domestic demand for consumption and domestic demand for storage and supply in the ROW only consists of domestic availability.

d) Spatial arbitrage

With the introduction of trade, spatial arbitrage is introduced into the model through the export equation. The domestic price and the price in other country become linked through the possibility of trade. If the difference between the prices is greater than the trade costs, it will be profitable to trade. Trade reduces supply and increases the price in the exporting country and increases supply and thus reduces the price in the importing country. Trade continues until the price difference is equal to the trade costs. For the free trade scenario, we have:

$$P_{i,t} + \theta - P_{j,t} \perp 0 \leq X_{i,t} \leq \infty \qquad i = 1,2;\ j = 1,2;\ i \neq j \tag{3.6}$$

where θ is the unit trade cost. When exports are between the lower and the upper bound the expression on the left-hand side equals zero. In other words, the price in the domestic market *i* plus trade costs equals the price in the other country *j*. When exports are zero, the expression on the left-hand side is positive, that is the sum of the domestic price and trade costs is higher than the price in the other country *j*.

For the one-directional trade scenario, there is only one spatial arbitrage equation, namely the one for the ROW.

3.3.3 Solution method

The competitive storage model can be solved using numerical methods. Gouel (2013) compared six approaches: value function iteration, parameterised expectations, price function approximation, decision rule approximation, perturbation, endogenous grid and decision rules approximation. He concludes that the parameterised expectation algorithm proposed by Wright and Williams (1982) is the most precise method for solving the competitive storage model.

The model was solved using MATLAB and the "Rational Expectations Complementarity Solver" (RECS) toolbox Version 0.6. RECS toolbox was developed by Christophe Gouel and is made available at http://www.recs-solver.org/index.html. For the interpolation of the one-country models with one state variable 40 grid points were used. For the interpolation of the two-country models with two state variables 17 grid points were used for each dimension. The model was simulated by first approximating the expectations in the next period and then solving the equilibrium equations.

3.3.4 Calibration

The model was calibrated using, wherever possible, parameters reflecting the Chinese and ROW wheat market characteristics. The size parameters for the ROW and China were set so that supply in the Chinese market is one fifth of supply in the ROW market in the deterministic steady state. Planned production is 2 in the ROW (using size parameter γ_1) in the deterministic steady state and 0.4 in China (using size parameter γ_2). An additional size parameter is introduced to scale demand in the Chinese market (γ_3) for the scenarios where two unbalanced markets trade (see section 3.4). The value of γ_3 is 0.4532 which leads to a price of 1.25 in China in the deterministic steady state compared to 1.00 for the balanced market analysis.

A wide range of estimates of supply and demand elasticities for grains are available from the literature. The US Department of Agriculture (USDA) Commodity and Food Elasticities database[21] contains demand elasticity estimates for many countries from a large number of studies. Another example is the Food and Agricultural Policy Research Institute (FAPRI) Elasticity Database[22] which contains the supply and demand elasticity values from the partial equilibrium model developed by the Food and Agricultural Policy Research Institute. The estimates vary widely. For China, most studies in the USDA Commodity and Food Elasticities database found an own price elasticity for wheat between -0.40 and -0.65 with one study even suggesting more elastic demand with the absolute value of the demand elasticity of above 1 (Zhang and Wang, 2003). The disadvantage of the USDA Commodity and Food Elasticities database is that most studies use data from the 1990s and earlier. A further disadvantage is that it does not contain supply elasticities.

The values from the FAPRI Elasticity Database have the advantage of being based on the latest version of the model and that it includes both supply and demand elasticities. Information on how these elasticities were estimated is not included in the database. In this type of model elasticities are often not estimated but are based on expert judgement. Furthermore, although the values are for the latest model version, it is not clear if the elasticity estimates are regularly revised. In the FAPRI database, the value for China's own-price demand elasticity for human consumption, the main use of wheat in China, is -0.07. This value seems unreasonably low compared to other sources.

The elasticities for China are therefore based on Zhuang and Abbott (2007). Their estimates have a number of advantages as a source for supply and demand elasticities for China. Firstly, they consistently estimate supply and demand elasticities for wheat in China and, secondly, theirs is a relatively recent study using data up to 2001, unlike many studies in the USDA database. Thirdly, and most importantly, unlike most other studies the methodology is based on a competitive storage framework and thus makes them most suitable for use in this exercise. Their supply elasticity for wheat in China is 0.32 and their demand elasticity is -0.24.

Elasticities for the ROW are taken from Gautam et al. (2014) who use the competitive storage model for an analysis of the Indian wheat market. The values they use for the ROW are 0.20 for the supply elasticity and -0.12 for the demand elasticity. There are few other sources that give estimates for the ROW, although, these could be derived, for example, as

[21] Available at: http://www.ers.usda.gov/data-products/commodity-and-food-elasticities.aspx#.U4Wu0HJ_uVO
[22] Available at: http://www.fapri.iastate.edu/tools/elasticity.aspx

weighted averages from the FAPRI database. Again, the main advantage of Gautam et al. (2014) is that the elasticities are from a study that uses the competitive storage model framework.

Yield shocks are assumed to be normally distributed with mean equal to one. The standard deviations are based on annual wheat yields for China and for the ROW from the USDA Production, Supply and Distribution Online (PSD online)[23] from 1990/91 to 2013/14. A linear trend was estimated over this period for both series. The standard deviation of the difference between the trend and the actual value was then calculated over the same period. The standard deviation for China is 0.15 and that for the ROW 0.08. The skewness of the difference between the trend and the actual values is close to zero for both China and the world which suggests that the distribution of the shocks is approximately symmetric. The skewness/kurtosis tests for normality cannot reject the hypothesis that the detrended yields are normally distributed (p-values for the test are 0.35 and 0.46 for the ROW and China, respectively). The correlation between the detrended yields in the ROW and China between 1990/91 and 2013/14 is not statistically significant (p-value 0.47). In the models, yield shocks in the ROW and China are, therefore, uncorrelated.

Finally, unit storage costs are set at 0.06, the interest rate at 0.03, shrinkage during storage is 0.02, the scale parameter for the production cost function is 0.97 and trade costs are 0.10.

Table 3.1 Parameter values used

	Parameter	Value
Supply elasticity for ROW	β_1	0.20
Supply elasticity for China	β_2	0.32
Demand elasticity for ROW	α_1	-0.12
Demand elasticity for China	α_2	-0.24
Size parameter for ROW	γ_1	2.00
Size parameter for China	γ_2	0.40
Size parameter for Chinese demand unbalanced	γ_3	0.4532
Yield shocks in ROW, normally distributed	ε_1	N(1, 0.08)
Yield shocks in China, normally distributed	ε_2	N(1, 0.15)
Unit cost of storage	k	0.06
Interest rate	r	0.03
Share of shrinkage during storage	δ	0.02
Scale parameter for the production cost function	h	0.97
Trade costs	θ	0.10

[23] Available at: http://www.fas.usda.gov/psdonline/psdQuery.aspx

3.4 Results

The results presented in this section are based on 10,000 simulated time series each containing 100 periods, of which the first 19 were not included. This results in data for 810,000 periods for each variable. Shocks were generated using a random number generator. Shock outcomes for the 10,000 series of 100 periods were generated for the ROW and for China. The same shock outcomes were then used for all scenarios so that the results are directly comparable without any impact from different outcomes of the random shocks.

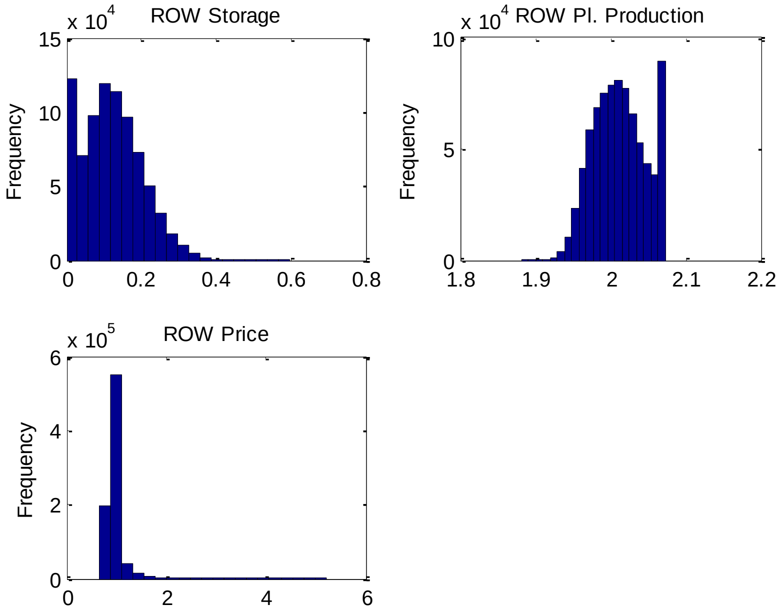
The results sections focus on the impacts of the different trade policies in China on stocks and on ROW prices. Results are presented separately for the case of balanced markets, where prices in the deterministic steady state are 1.00 in autarky in both the ROW and China, and for the case of unbalanced markets, where the price in the deterministic steady state in autarky is 25 per cent higher in China (i.e. 1.25) than in the ROW (i.e. 1.00).

For as long as China has a policy of maintaining a high level of self-sufficiency the balanced market scenarios seem a reasonable representation of the impacts of the Chinese wheat market policies on the ROW market. It is assumed that the Chinese government implements policies that would make sure that no structural imbalance in trade occurs. Whether this balance is achieved by subsidising domestic production, subsidising domestic consumption, by trade restrictions, structural reforms of the agricultural sector or investment in research and development is not the focus of this study. The main interest is on the impact of imports by China from the ROW in times of adverse production shocks. There are two trade scenarios, one where China only imports in case of adverse production shocks but does not export in case of surplus production. The free trade scenario for balanced countries models a world where China imports when supply is low but also exports when there are adverse production shocks in the ROW.

3.4.1 Impact of different trade policies for balanced markets

The figures below show the distribution of the control variables for the ROW market for balanced countries in autarky, the one-directional trade and the free trade scenarios (see appendix sections I to III for descriptive statistics and figures showing the distribution of ROW and Chinese state and control variables for all scenarios).

Figure 3.5 Distribution of ROW control variables for the autarky scenario for balanced markets

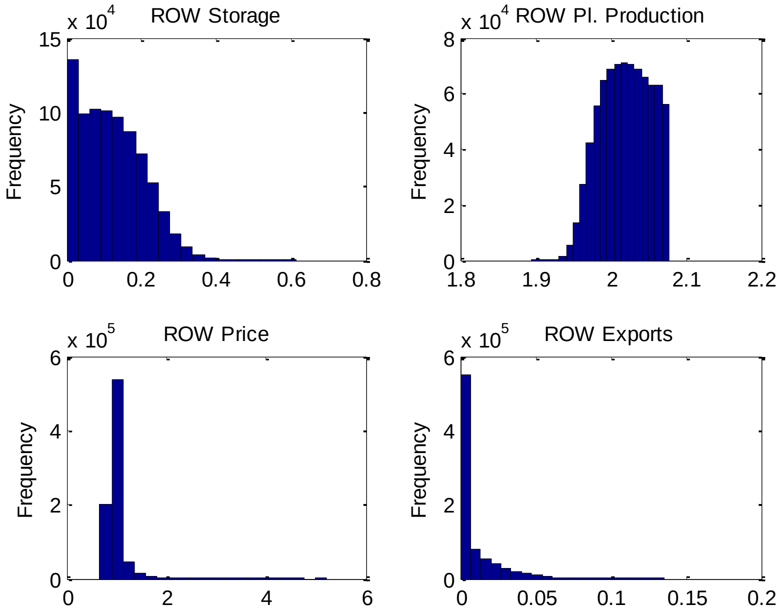


Source: Own results

Figure 3.5 shows that the storage distribution is bimodal in autarky. Storage is most frequently in the region of 0.15 and, due to the non-negativity constraint, in the region of zero. If negative storage were possible, the distribution would be much more symmetric. The distribution of planned production is almost a mirror image of that of storage. Planned production is frequently in a region just above two but the most frequent planned production is at the maximum planned production. When storage is zero, the expected price for the next period is at its maximum and so is production planned in the current period for the next period.

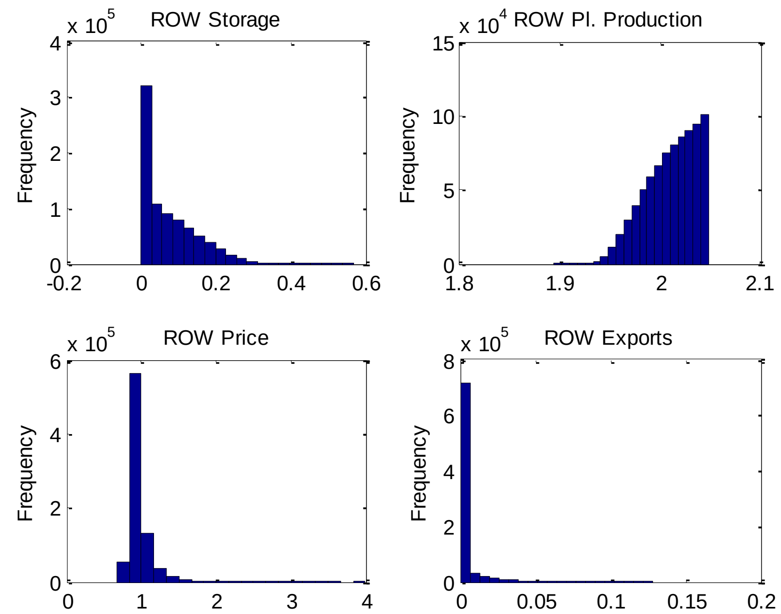
Figure 3.6 shows the control variables for the ROW in the one-directional trade scenario. With exports from the ROW to China added, compared to autarky the storage distribution shifts to the left and that of planned production to the right. Storage and planned production depend to some degree also on the situation in China. Planned production in the ROW is no longer most frequently at the maximum because planned production now depends on the situation in China leading to a more even distribution of production in the region between the 1.98 and 2.07.

Figure 3.6 Distribution of ROW control variables for the one-directional trade scenario for balanced markets



Source: Own results

Figure 3.7 Distribution of the ROW control variables for the free trade scenario for balanced markets



Source: Own results

With trade in both directions, trade and storage are both contributing to buffering production shortfalls. Storage in the ROW is lower on average and is much more frequently zero because of the possibility of importing from China when a large negative yield shock hits the ROW. Planned production is most frequently at its maximum and is more smoothly distributed than storage. Whilst storage in the ROW and China are weakly negatively correlated, planned production in the ROW and China are strongly positively correlated.

The analysis in the remainder of this section focuses on the impact of the different trade scenarios on stock levels in the ROW and China and on the ROW price, with particular focus on extreme price movements. The base scenario is the autarky scenario which represents the situation until the early 2000s. Table 3.2 compares stock levels in the different scenarios.

Starting with ROW stocks, mean ROW stocks are highest in autarky but only marginally so compared to the one-directional trade scenario (-1 per cent compared to autarky). In the free trade scenario mean ROW stocks are more than 40 per cent lower than in the other two scenarios. In the ROW mean stocks are 6 per cent of mean production in the autarky and one-direction trade scenarios and 4 per cent in the free trade scenario. In China, mean stock levels are highest in autarky and lowest in the one-directional trade scenario (84 per cent below autarky).

Table 3.2 ROW, Chinese and global stocks for balanced markets

	ROW stocks			Chinese stocks		
	Autarky	One-directional trade	Free trade	Autarky	One-directional trade	Free trade
Mean % change compared to Autarky	0.1223	0.1208 -1%	0.0714 -42%	0.0439	0.0070 -84%	0.0318 -28%
Standard deviation % change compared to Autarky	0.0799	0.0833 4%	0.0736 -8%	0.0224	0.0113 -50%	0.0297 33%
Proportion at lower bound % change compared to Autarky	6.0133	4.2630 -29%	22.2798 271%	1.8350	40.3394 2098%	13.8461 655%
	Global stocks					
	Autarky	One-directional trade	Free trade			
Mean % change compared to Autarky	0.1662	0.1278 -23%	0.1031 -38%			
Standard deviation % change compared to Autarky	0.0830	0.0836 1%	0.0745 -10%			
Proportion at lower bound % change compared to Autarky	0.0011	0.0204 1755%	0.0160 1355%			

Source: Own results

Mean stock levels in China in the free trade scenario are 28 per cent below the levels in autarky. The stocks to production ratios in China are 11 per cent in autarky, 2 per cent in the one-directional trade scenario and 8 per cent in the free trade scenario. Mean global stocks are highest in autarky. Compared to autarky, global stocks are 23 per cent lower under one-directional trade and 38 per cent lower under free trade. Thus, with the introduction of trade, global stocks are reduced and stockholding is reduced both in China and the ROW – more so in China under one-directional trade and more so in the ROW under free trade.

Another interesting aspect of stockholding is the incidence of stock-outs, that is, situations in which stocks reach their lower bound of zero[24]. When stocks are zero, price rises cannot be moderated by further reductions in stocks. Extreme prices are seen in situations of stock-outs but stock-outs do not necessarily lead to extreme price. In the presence of trade, imports can fill the gap and sometimes stock-outs have a small effect resulting in only small price differences between current and expected prices in the following period.

In the ROW, stock-outs are by far the most frequent under free trade when stock-outs happen in 22 per cent of the periods. In the autarky and one-directional trade scenarios stock-outs happen in 6 and 4 per cent of the periods, respectively. By contrast, in China stock-outs are much more common under the trade scenarios. In autarky, stock-outs only happen in 2 per cent of the periods. In the trade scenarios stock-outs happen much more regularly, in 40 per cent of the periods in the one-directional trade scenario and in 14 per cent of the periods in the free trade scenarios, which equates to increases of over 2,000 per cent and over 600 per cent, respectively. These results should not surprise because under the trade scenarios China can import when stocks are not sufficient to buffer an adverse production shock while this possibility does not exist in autarky.

Global stocks are zero in 0.1 per cent of the periods in autarky but in 2.0 per cent under one-directional trade and in 1.6 per cent under free trade, which equates to increases by more than 1,000 per cent. However, the comparison is not very meaningful because, without trade, the markets are not integrated. Stock levels in China have no impact on ROW prices and ROW stocks have no impact on Chinese prices. The increase in global stock-outs with trade is the result of the markets being integrated with trade. When trade is possible negative yield shocks can lead to destocking in both countries making a simultaneous stock-out in both countries more likely. By reducing stocks in both countries price movements are less extreme than they would otherwise be. This intuition is confirmed when comparing ROW price statistics across the scenarios. Table 3.3 compares statistics for the ROW price under the three different trade scenarios, autarky, one-directional trade and free trade.

The mean ROW price is similar across all scenarios. Prices in the free trade scenario are less variable than in autarky and one-directional trade scenario. In the free-trade scenario, the standard deviation is 8 per cent below that in autarky. There is also a small reduction in the standard deviation of the ROW price in the one-directional trade scenario compared to autarky, although by only 1 per cent.

[24] In reality, ending stocks are never zero for a number of reasons. Firstly, harvest times vary across the globe. Secondly, it takes time to get grain from surplus producers to deficit countries. Thirdly, operational stocks are held by companies that use grains, such as millers or feed companies.

Table 3.3 ROW price statistics for balanced markets

	Autarky	One-directional trade	Free trade
Mean	0.9686	0.9665	0.9632
% change compared to Autarky		0%	-1%
Standard deviation	0.1644	0.1632	0.1505
% change compared to Autarky		-1%	-8%
99^{th} percentile	1.6806	1.6463	1.6718
% change compared to Autarky		-2%	-1%
Proportion ROW price 100% above its mean	0.0044	0.0044	0.0019
% change compared to Autarky		0%	-57%

Source: Own results

The standard deviation measures variation across the whole distribution but often the main interest is on extreme price movements. Table 3.3, therefore, also reports the 99^{th} price percentile and how often the price exceeds its mean by 100 per cent i.e. is more than double the mean price. The 99^{th} percentile is only slightly lower in the trade scenarios than in autarky. In both autarky and one-directional trade the price is double the mean price in 0.4 per cent of the periods. In free-trade the price is double its mean in only 0.2 per cent of the periods (a 57 per cent reduction compared to autarky).

Table 3.4 shows the correlations between the ROW price and ROW stocks, ROW price and global stocks and ROW prices and Chinese prices under the three scenarios.

Table 3.4 Correlation between the ROW price and stocks as well as ROW and Chinese prices for balanced markets

	Autarky	One-directional trade	Free trade
Correlation ROW price and ROW stocks	-0.7268	-0.6304	-0.6287
Correlation ROW price and global stocks	-0.7001	-0.6327	-0.6767
Correlation ROW and Chinese prices	0.0018	0.3807	0.9273

Source: Own results

The negative correlation between ROW prices and stocks is strongest under autarky (-0.72) and weakest under free trade (-0.63) with one-directional trade just marginally above that under free trade. The picture is slightly different for the correlation between the ROW price and global stocks which is at -0.70 in autarky, -0.67 under free trade and -0.63 under one-directional trade. The correlation between global stocks and the ROW price is stronger than that between the ROW price and ROW stocks under free-trade and roughly the same under one-directional trade and slightly weaker in autarky. Finally, the correlation between the ROW price and the Chinese price is effectively zero in autarky as the markets are driven by independent yield shocks and are not linked through trade. Under one-directional trade the correlation between the ROW and Chinese prices is 0.38 which increases to 0.93 under free trade.

To summarise, ROW stocks decrease with trade for balanced markets but only marginally so in the one-directional trade scenario. The opposite is true for Chinese stocks which reduce with trade but much more so with free trade than with one-directional trade. These movements result in mean global stocks being lowest under free trade and highest in autarky.

The mean and minimum price hardly change across the scenarios, the standard deviation and maximum price are similar in the autarky and one-directional trade scenarios but lower in the free trade scenario. Prices are substantially less likely to exceed the mean by more than 100 per cent in the free trade scenario. With respect to the ROW price, the one-directional trade scenario is generally closer to the autarky scenario than to the free trade scenario.

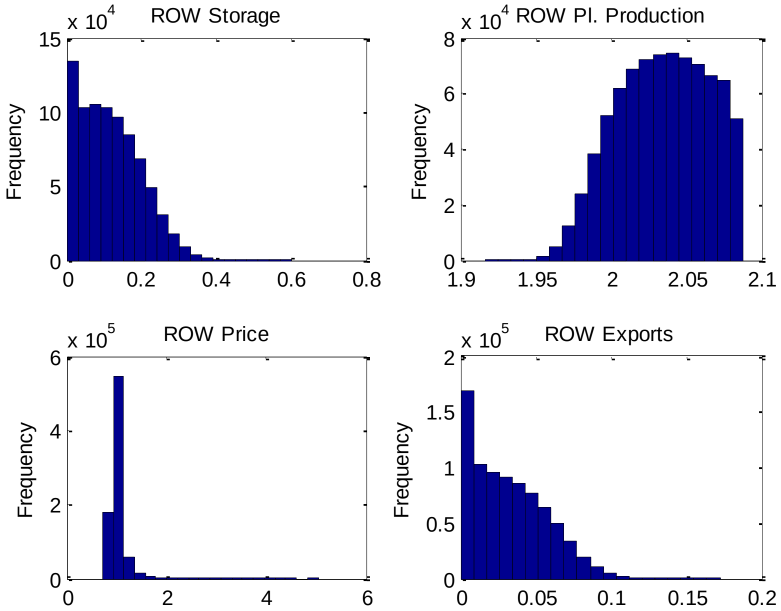
3.4.2 Impact of different trade policies for unbalanced markets

This section outlines results for unbalanced markets where the price in the deterministic steady state in autarky is 25 per cent higher in China than in the ROW making China a structural importer when trade is introduced. At the present time, Chinese production without support policies would likely be more expensive than production in the ROW, meaning that if China allowed imports, it would be a structural importer. The announced loosening of the self-sufficiency policy most likely means that China will move towards becoming a structural importer in the wheat market. This situation is modelled in the unbalanced market scenarios. The unbalanced market scenarios assess the impacts of China as a structural importer on the global wheat market.

Figures 3.8 and 3.9 show the distribution of the control variables for the ROW market for balanced countries in the one-directional trade and the free trade scenarios. For the autarky scenario see Figure 3.5 because the ROW market parameters are the same for balanced and unbalanced markets (see sections I, IV and V in the appendix for descriptive statistics and figures showing the distribution of ROW and Chinese state and control variables for all scenarios).

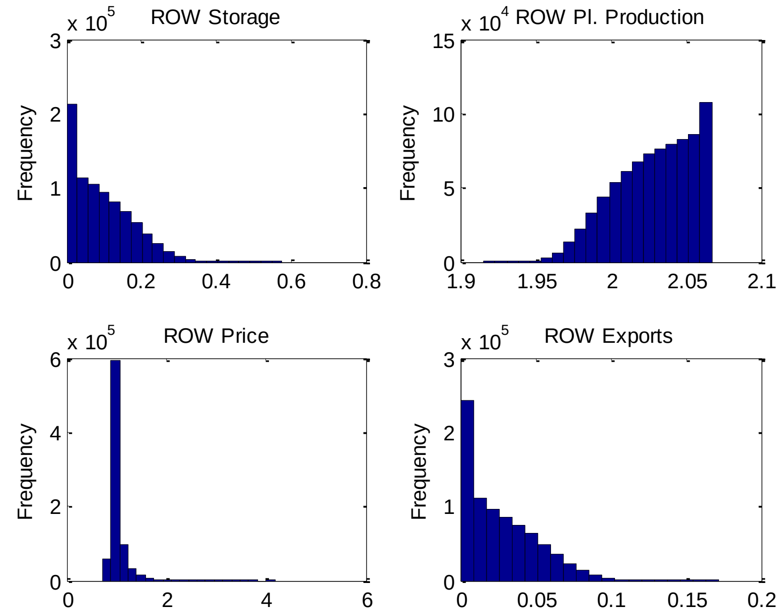
A Comparison of Figures 3.6 and 3.8 shows that under one-directional trade the shapes of the distributions of ROW storage and ROW planned production for unbalanced markets are similar to those for balanced markets but with slightly lower average storage and higher average planned production. The most noticeable difference between balanced and unbalanced markets is in the distribution of exports. The frequency of non-zero exports for unbalanced markets is much higher than for balanced markets.

Figure 3.8 Distribution of ROW control variables for the one-directional trade scenario for unbalanced markets



Source: Own results

Figure 3.9 Distribution of the ROW control variables for the free trade scenario for unbalanced markets



Source: Own results

Figure 3.9 shows the distribution of the control variables for the free trade scenario for unbalanced markets. In the free trade scenario, similar observations to those for one-directional trade can be made. The biggest difference between balanced and unbalanced markets is in the distribution of ROW exports which are non-zero with a much higher frequency for unbalanced markets than for balanced markets.

Table 3.5 ROW, Chinese and global stocks for unbalanced markets

	ROW stocks			Chinese stocks		
	Autarky	One-directional trade	Free trade	Autarky	One-directional trade	Free trade
Mean	0.1223	0.1165	0.0938	0.0512	0.0012	0.0037
% change compared to Autarky		-5%	-23%		-98%	-93%
Standard deviation	0.0799	0.0812	0.0780	0.0251	0.0042	0.0088
% change compared to Autarky		2%	-2%		-83%	-65%
Proportion at lower bound	6.0133	3.7199	9.3531	1.5153	41.4583	37.0692
% change compared to Autarky		-38%	56%		2636%	2346%
	Global stocks					
	Autarky	One-directional trade	Free trade			
Mean	0.1735	0.1177	0.0975			
% change compared to Autarky		-32%	-44%			
Standard deviation	0.0838	0.0811	0.0776			
% change compared to Autarky		-3%	-7%			
Proportion at lower bound	0.0009	0.0250	0.0449			
% change compared to Autarky		2709%	4944%			

Source: Own results

Table 3.5 compares stock levels in the different scenarios. Mean ROW stocks are slightly higher in autarky than under one-directional trade. In the free trade scenario, mean ROW stocks are 23 per cent lower than in autarky. As noted earlier, in the ROW mean stocks are 6 per cent of mean production in the autarky. For unbalanced markets ROW mean stocks are 6 per cent of mean ROW production in the one-directional-trade scenario and 5 per cent in the free trade scenario. In China, mean stock levels are much higher in autarky than in the trade scenarios. Stocks in China are reduced by 98 per cent in the one-directional trade scenario compared to autarky and by 93 per cent in free trade compared to autarky. The stocks to production ratios in China are 12 per cent in autarky, 0.1 per cent in the one-directional trade scenario and 1 per cent in the free trade scenario

In all scenarios, stock levels are higher in China when the countries are balanced than when they are unbalanced. A structural importer is better off to rely on imports for buffering adverse production shocks than holding considerable stock levels itself. As implied by Equation 3.6, in the presence of trade the price in the importing country is higher than in the exporting country because of the trade costs. In this case, even with the same physical costs of storage, storage is more expensive in the importing country because of the interest on the value of the stored product. The value of the same amount stored is higher in the importing country due to the higher price and, thus, so is the required interest on the value of the stored product. Therefore, the bulk of storage takes place in the exporting country (Williams and Wright, 1991).

Mean global stocks are highest in autarky. Compared to autarky, global stocks are 32 per cent lower under one-directional trade and 44 per cent lower under free trade. Compared to balanced markets, in unbalanced markets stock levels are higher in autarky but lower in the trade scenarios.

In the ROW, stock-outs are by far the most frequent under free trade when stock-outs happen in 9 per cent of the periods. In the autarky and one-directional trade scenarios stock-outs happen in 6 and 4 per cent of the periods, respectively. By contrast, in China stock-outs are much more common under the trade scenarios. In autarky, stock-outs only happen in 2 per cent of the periods. In the trade scenarios stock-outs happen in 41 per cent of the periods in the one-directional trade scenario and in 37 per cent of the periods in the free trade scenarios, which equate to increases of more than 2000 per cent. In the one-directional trade scenarios, stock-outs occur at similar frequencies for balanced and balanced markets for both the ROW and China. However, the picture is very different for balanced and unbalanced countries under free trade. ROW stock-outs happen in 22 per cent of the periods for balanced markets and only 9 per cent for unbalanced markets. Chinese stock-outs, by contrast, happen less frequently for balanced markets (14 per cent of the periods) than unbalanced markets (37 per cent of the periods).

Global stocks are virtually never zero in autarky but in 2 per cent of the periods under one-directional trade, which equates to an increase of about 2700 per cent and in 4 per cent of the cases under free trade, which equates to an increase of almost 5000 per cent. Compared to balanced markets, global stocks experience stock-outs slightly more often in unbalanced markets in autarky and under one-directional trade. Under free trade, by contrast, stock-outs are more frequent for unbalanced than for balanced markets.

Table 3.6 ROW price statistics for unbalanced markets

	Autarky	One-directional trade	Free trade
Mean	0.9686	1.0082	1.0025
% change compared to Autarky		4%	3%
Standard deviation	0.1644	0.1532	0.1607
% change compared to Autarky		-7%	-2%
99th percentile	1.6806	1.6751	1.5627
% change compared to Autarky		0%	-7%
Proportion ROW price 100% above its mean	0.0044	0.0027	0.0025
% change compared to Autarky		-39%	-43%

Source: Own results

Table 3.6 compares statistics for the ROW price under the three different scenarios. The mean ROW price is slightly higher for the trade scenarios than in autarky, by 4 per cent under one-directional trade and by 3 per cent under free trade. For unbalanced markets the changes are somewhat more pronounced and the mean ROW price increases compared to autarky in both trade scenarios.

Trade reduces the standard deviation of the ROW price compared to autarky by 7 per cent and 2 per cent under one-directional trade and free trade, respectively. The 99th percentile is 7 per cent below that in autarky under free trade and similar to autarky under one-directional trade.

In autarky the price is double the mean price in 0.4 per cent of the periods. Under the trade scenarios, this threshold is exceeded less often, a reduction compared to autarky by 39 per cent under one-directional trade and by 43 per cent under free trade. These figures are higher in balanced markets for one-directional trade and lower for free trade.

Table 3.7 shows the correlations between ROW prices and ROW stocks, ROW prices and global stocks and ROW and Chinese prices under the three scenarios for unbalanced markets.

Table 3.7 Correlation between ROW price and stocks as well as ROW and Chinese price for unbalanced markets

	Autarky	One-directional trade	Free trade
Correlation ROW price and ROW stocks	-0.7268	-0.6171	-0.6999
Correlation ROW price and global stocks	-0.6937	-0.6757	-0.6476
Correlation ROW price and Chinese price	0.0018	0.7797	0.9840

Source: Own results

The negative correlation between the ROW price and stocks is slightly weaker for unbalanced countries than balanced countries in the one-directional trade scenario. For free trade, the negative correlation is stronger for unbalanced than for balanced markets. The correlation between global stocks and the ROW price is stronger than that between the ROW price and ROW stocks under the trade scenarios but weaker in autarky.

The main difference between the balanced and unbalanced markets with regards to the correlations is the correlation between the ROW price and the Chinese price under one-directional trade. The correlation is much higher for unbalanced countries under the one-directional scenarios (0.78) than for balanced countries (0.38).

To summarise, the results are very similar for stock levels in autarky and under one-directional trade regardless of whether or not the markets are balanced or unbalanced. However, under free trade ROW stock levels are higher for unbalanced than for balanced markets leading to fewer ROW stock-outs. Global stocks are lower in both unbalanced and balanced markets when free trade occurs. Nevertheless, stock-outs are less frequent under free trade for unbalanced than balanced markets. Trade always leads to substantial reductions in global stocks; this is true for one-directional and free trade and for balanced and unbalanced markets.

The ROW mean price is slightly higher for unbalanced than balanced markets and slightly higher under one-directional trade than free trade. Despite substantially lower stock levels with trade, price variation is reduced with trade compared to autarky. The biggest difference between the balanced an unbalanced market results with respect to the correlations is for the correlation between the ROW and Chinese price under one-directional trade. For balanced market the correlation is 0.38 and for unbalanced markets 0.78.

3.5 Discussion

The role of grain market policies in China, more specifically stockholding policy in the 1990s and 2000s and more recently the self-sufficiency policy, in global price movements has been discussed in a number of papers. The treatment of possible impacts of developments on Chinese grain markets often has not gone beyond informal discussions. Some commentators suggested that China remained largely self-sufficient in grains and that the stocks reductions in China, therefore, have no impact on world prices. Others simply look at global stock levels implicitly assuming that stock changes in China have the same effect on world prices as stocks elsewhere. Both these positions appear overly simplistic. As for self-sufficiency policies, they will impact trade patterns as well as optimal stock levels. In both cases, for the impact on global markets it is not so much the internal Chinese policies that matter but the resulting trade patterns.

In this chapter, the competitive storage model is used to model stocks, trade and price relationships. In the early 2000s, a substantial decrease in Chinese stocks of grains took place over a relatively short period of time. To mirror the period before the stocks reductions, modelling China as autarkic seems a reasonable approach when China held about half of global stocks. The high stocks at the end of the 1990s made China self-sufficient in grains as adverse production shocks could always be buffered by reducing stocks.

In the 1990s and early 2000s, prediction on future imports of grain by China differed widely. Many forecast that China would become a regular importer. The Chinese Government’s forecast at the time predicted that China would continue to be largely self-sufficient (Zhuang and Abbott, 2007). The Chinese government continues to consider food security a top priority and until recently this translated into an objective of a self-sufficiency rate for grains of 95 per cent (Ito and Ni, 2013). With the aim of remaining 95 per cent self-sufficient but a decrease in stocks in the early 2000s, imports into China in times of adverse production shocks became a possibility. However, with these targets in place, China could not become a structural importer.

For as long as China had a policy of maintaining a high level of self-sufficiency the balanced market scenario seems a reasonable representation of the impacts of developments in the Chinese grains markets on the ROW markets. To achieve the target, it is necessary that the Chinese government implements policies that make sure that no structural imbalances in trade occur. The ratio of mean imports to mean production in China under the balanced market scenarios are 98 per cent for the one-directional trade scenario and 96 per cent for the free trade scenario. These values are close to the 95 per cent self-sufficiency target.

The competitive storage model provides interesting insights into the impacts of a policy change from autarky to a policy where imports are occasionally used to buffer adverse production shocks. Such a policy change can be modelled as a move from autarky to trade between two markets that have the same price in the deterministic state. The main function of trade is to provide an additional option to buffer adverse production shocks resulting from uncertain harvests.

In the one-directional trade scenario, ROW stocks remain virtually unchanged but Chinese stocks are reduced substantially, by more than 80 per cent, resulting in a reduction in global stocks of more than 20 per cent. This reduction of stocks has very little impact on ROW prices. The mean and standard deviation of the ROW price remain virtually unchanged compared to autarky. The same is true for the measures of extreme price movements, the 99th percentile of the ROW price and the proportion of periods in which the price exceeds double its mean.

In the free trade scenario, ROW stocks are more than 40 per cent below their level in autarky and Chinese stocks are reduced by almost 30 per cent, resulting in a reduction in global stocks of almost 40 per cent. Again, this reduction of stocks has very little impact on ROW prices. The mean and standard deviation of the ROW price remain virtually unchanged compared to autarky. For free trade the measures of extreme price movements suggest that if anything, extreme price movements are reduced despite the much lower global stock levels. Thus, also taking into account that reduced stock levels in China are accompanied by an opening to trade, lower stocks do not lead to increased price levels and volatilities. This suggests that low stocks in China are not likely to have had a large impact on global prices in the 2000s.

If, as suggested by recent policy announcements, China is to loosen its self-sufficiency policy and become a structural importer of wheat, the balanced market scenarios will not be appropriate anymore. Therefore, the different trade scenarios are also run for unbalanced markets with higher prices in China in an autarkic deterministic steady state than in the ROW. With unbalanced markets, the ratio of mean imports to mean production is 8 per cent under one-directional trade and 14 per cent under free trade.

For unbalanced markets, China reduces stock levels substantially, by more than 90 per cent under both trade scenarios. The reduction in Chinese stocks compared to autarky are accompanied by a small reduction in ROW stocks under the one-directional trade scenario and by a more substantial reduction in ROW stocks in the free trade scenario of more than 20 per cent compared to autarky.

The changes in trade pattern and stock levels have some impact on ROW prices. For unbalanced market, there is a small increase in the mean ROW price of 4 per cent in the trade scenarios compared to autarky. This higher mean price is accompanied by reductions in the standard deviation of the ROW price. It should be further noted that for unbalanced markets the reduction in stocks which results from the introduction of trade does not lead to an increase in extreme price movements. For one-directional trade the measures of extreme price movements are similar to those in autarky. For free trade, the measures of extreme prices suggest a reduction in the occurrence of extreme prices.

Thus similar as for the change in stockholding policy, the model suggests that lower stocks in China as a result of the loosening of the self-sufficiency policy do not lead to more variable prices, in general, and more extreme price movements, more specifically. The mean price in the ROW is slightly higher though than in autarky.

While a move from autarky to the trade scenarios has similar effect on balanced and unbalanced markets with regards to the stock-price correlations, the impact differs substantially with respect to the correlation between the ROW price and the Chinese price under one-directional trade. In autarky the correlation is effectively zero while under free trade the correlation is above 90 per cent for both balanced and unbalanced markets. However, under one-directional trade between balanced markets the correlation is much weaker (0.38) than under one-directional trade between unbalanced markets (0.78).

Following the 2007/08 price spike, a link was suggested between lower stocks in China and more variable world prices, with particular focus on extreme price movements. While for a country in autarky lower stocks can be expected to increase price variation and especially price spikes, the results of this modelling exercise show a more complex pattern when stock changes are linked to changing trading patterns.

For both balanced and unbalanced markets, ROW prices are most variable in autarky and extreme price movements are much more frequent despite the higher stock levels in autarky. Therefore, in any analysis of stocks and extreme prices, both trade and stockholding are important. The grain stock reductions in China are in line with those predicted as the results of a policy change from autarky to trade. This fact cannot be ignored when analysing the price impact of Chinese stock reductions. Similarly, the change in the self-sufficiency policy will impact on stock levels and the interpretation of any accompanying stock changes need to be put into this context.

The model predicts a reduction of Chinese stocks under one-directional and free trade compared to autarky for both balanced and unbalanced markets. The reality is likely to be more complex than the results of this study suggest as can be seen from the recent developments in the Chinese soybean markets. The model suggests very low stock levels for a structural importer. Stock levels for soybeans in China were very low up to the late 2000s as can be seen in Figure 3.4. However, in 2008, the Chinese government introduced the Temporary Stockpiling Policy for soybeans which is meant to keep prices at a set minimum level (Carter et al., 2012; Ito and Ni, 2013). Given the focus on food security in China, the increased stock levels might also serve the purpose of increasing food security. In reality, China might want to keep stock levels above those suggested by the competitive storage model as part of a food security policy. A buffer stock policy in a country with structural imports might be a better representation.

3.6 Conclusions

Many studies of the 2007/08 price spike pointed to low stocks as one possible cause of the price spike. When stocks are low prices tend to be more volatile and prone to price spikes. However, few studies have modelled price-stocks relationships formally. More recently, the discussion of the impact of Chinese grain market policies on global prices has focused on the changes in the self-sufficiency policy in China that were outlined in guidelines by the Chinese government. In this study, the competitive storage model is used to gain insights into the impact of grain market policies in China on global markets. The policies themselves are not modelled in detail. However, if Chinese policy changes are to have impacts on global markets these have to be transmitted to the world market through changing trade patterns. In this analysis, the modelling of the changing trade patterns provide valuable insights into the impact of Chinese policy changes on world stock levels and prices.

Rather than viewing reduced stock levels in China as the effect of a series of negative yield shocks, the reduced stock levels in China in the early 2000's are better interpreted as a move from an autarky policy to a situation where China would import grains in the case of an adverse production shock instead of holding extremely high levels of stock in the country.

The model shows that such a move away from autarky reduces the stock levels in China, in the rest of the world and thus also global stock levels. This reduction in stock levels does not lead to an increase in price variation in general and, more importantly for policy-makers, does not lead to an increase in extreme price movements. If China is importing as well as exporting in such a scenario, a reduction in extreme price movements is achieved with much lower stocks.

Ignoring the change in policy would lead to misleading conclusions. Without a policy change, it is true that low stocks make extreme price movements more likely. However, if the reduction in stocks is the result of a policy change towards more trade, lower stocks do not necessary result in more frequent extreme price movements. This is true for the one-directional trade scenario but even more so under free trade.

Similarly, a move away from a self-sufficiency policy in China is not predicted to lead to increased variation in world prices. A move away from self-sufficiency necessarily involves a higher integration with the world market because it would mean that China is to become a structural importer over time. In such a scenario, stocks are projected to be much lower in China and the rest of the world than in autarky. The model predicts a small increase in mean world prices of 4 per cent but no change or even a decrease in the price variation.

Further work is needed to draw any conclusions about the magnitude of the price and stock effects and the robustness of the results. The parameterisation of the model is based on empirical data for China and the rest of the world with respect to supply and demand elasticities, yield variation and the relative size of the two wheat markets. Better information of storage costs and interest rates would be a next step. In addition, sensitivity analysis with regards to the parameters included in the model would provide robustness checks. Nevertheless, this simple modelling exercise constitutes a significant improvement on the previous discussions of the impact of Chinese stocks and self-sufficiency policies on world grains prices.

Appendix

Summary statistics and distribution of ROW and China state and control variables for all scenarios (all own results).

I Autarky

Table 3.Ia Descriptive statistics autarky

	Mean	Std. Dev.	Skew-ness	Kurto-sis	Min	Max	%at lower bound
Availability - ROW	2.1327	0.1096	0.0245	3.0107	1.6404	2.7033	
Stocks - ROW	0.1223	0.0799	0.4192	2.8559	0	0.5960	6.0133
Planned production - ROW	2.0128	0.0346	0.0420	2.1909	1.8817	2.0732	0
Price - ROW	0.9686	0.1644	4.3089	38.1630	0.6469	5.2169	0
Availability - B China	0.4468	0.0312	-0.0045	3.0118	0.2823	0.5918	
Stocks - B China	0.0439	0.0224	0.2437	2.8890	0	0.1584	1.8350
Planned production - China B	0.4038	0.0089	0.2288	2.5209	0.3726	0.4239	0
Price- China B	0.9757	0.1005	2.5338	24.2452	0.7159	4.2715	0
Availability - UB China	0.4835	0.0340	0.0068	3.014	0.3060	0.6422	
Stocks - UB China	0.0512	0.0251	0.2399	2.9239	0	0.1792	1.5153
Planned production - China UB	0.4333	0.0094	0.3367	2.6572	0.4010	0.4561	0
Price- China UB	1.2244	0.1181	2.4434	24.3124	0.9148	5.1399	0

Table 3.Ib Correlations autarky

	Availability	Stocks	Planned production	Price
ROW				
Availability	1	0.9872	-0.9870	-0.8252
Stocks	0.9872	1	-0.9911	-0.7268
Planned production	-0.9870	-0.9911	1	0.7526
Price	-0.8252	-0.7268	0.7526	1
China Balanced				
Availability	1	0.9959	-0.9939	-0.9303
Stocks	0.9959	1	-0.9919	-0.8938
Planned production	-0.9939	-0.9919	1	0.9150
Price	-0.9303	-0.8938	0.9150	1
China Unbalanced				
Availability	1	0.9967	-0.9925	-0.9345
Stocks	0.9967	1	-0.9885	-0.9031
Planned production	-0.9925	-0.9885	1	0.9283
Price	-0.9345	-0.9031	0.9283	1

Table 3.Ic Autocorrelations autarky

	1	2	3	4
ROW				
Availability	0.3627	0.1245	0.0324	-0.0037
Stocks	0.3700	0.1280	0.0342	-0.0034
Planned production	0.3596	0.1228	0.0323	-0.0036
Price	0.2381	0.0739	0.0137	-0.0077
China Balanced				
Availability	0.3886	0.1409	0.0391	-0.0022
Stocks	0.3919	0.1424	0.0397	-0.0021
Planned production	0.3835	0.1380	0.0382	-0.0025
Price	0.3381	0.1179	0.0307	-0.0043
China Unbalanced				
Availability	0.4165	0.1641	0.0533	0.0049
Stocks	0.4201	0.1661	0.0540	0.0051
Planned production	0.4070	0.1585	0.0511	0.0041
Price	0.3659	0.1387	0.0430	0.0017

Figure 3.Ia Distribution of state and control variables ROW in autarky

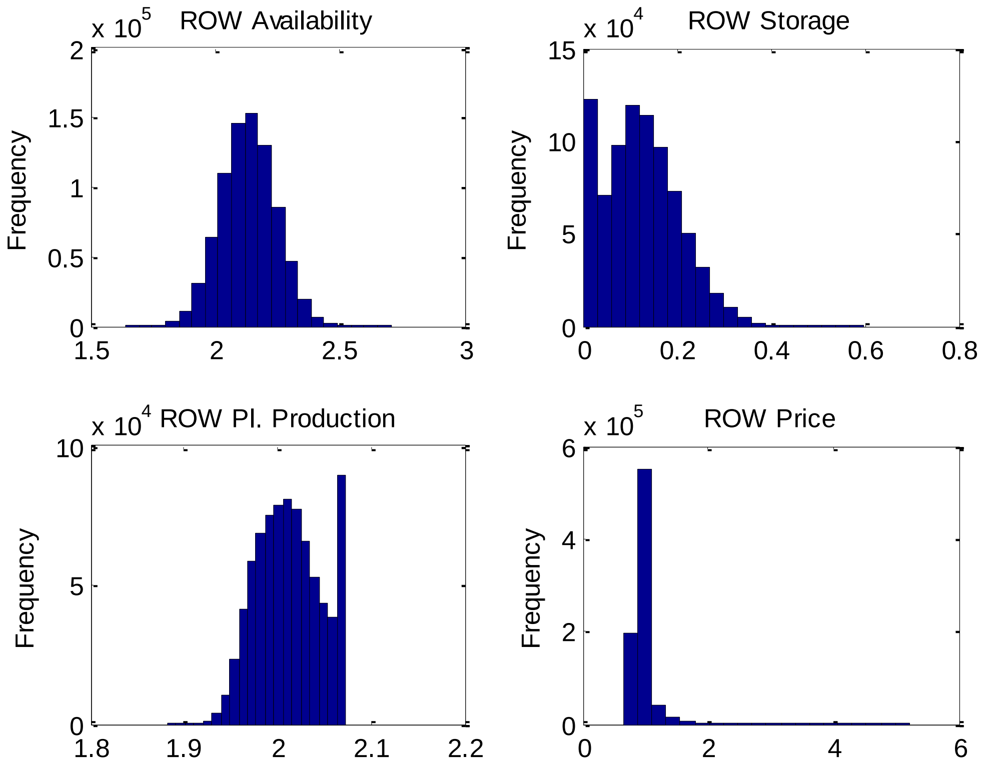


Figure 3.Ib Distribution of state and control variables China balanced markets in autarky

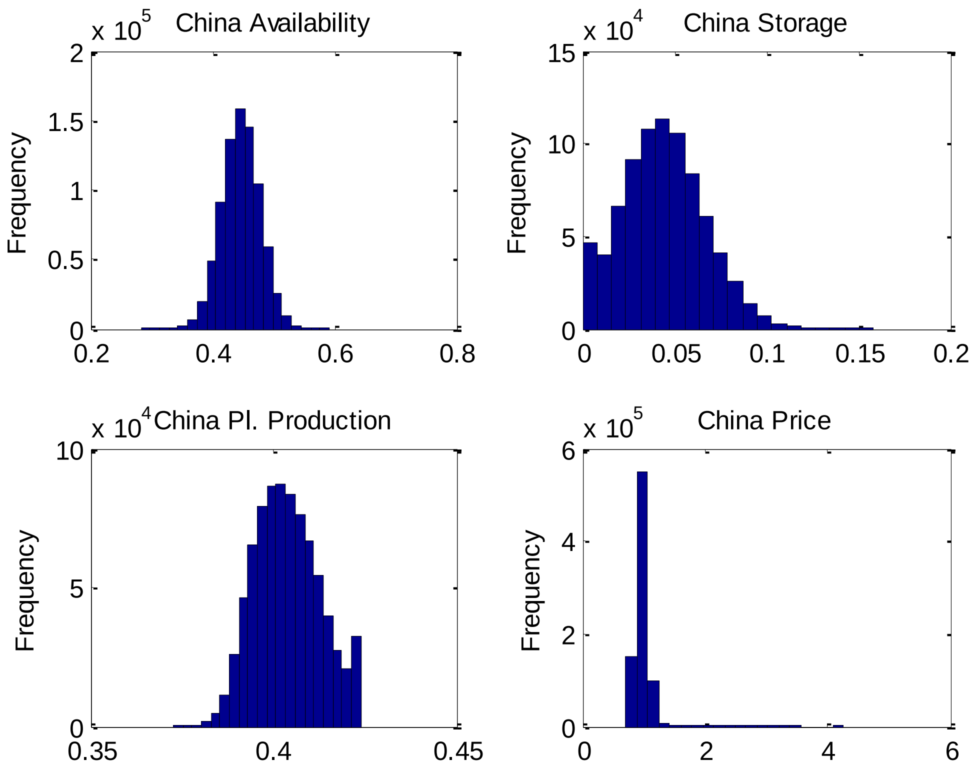
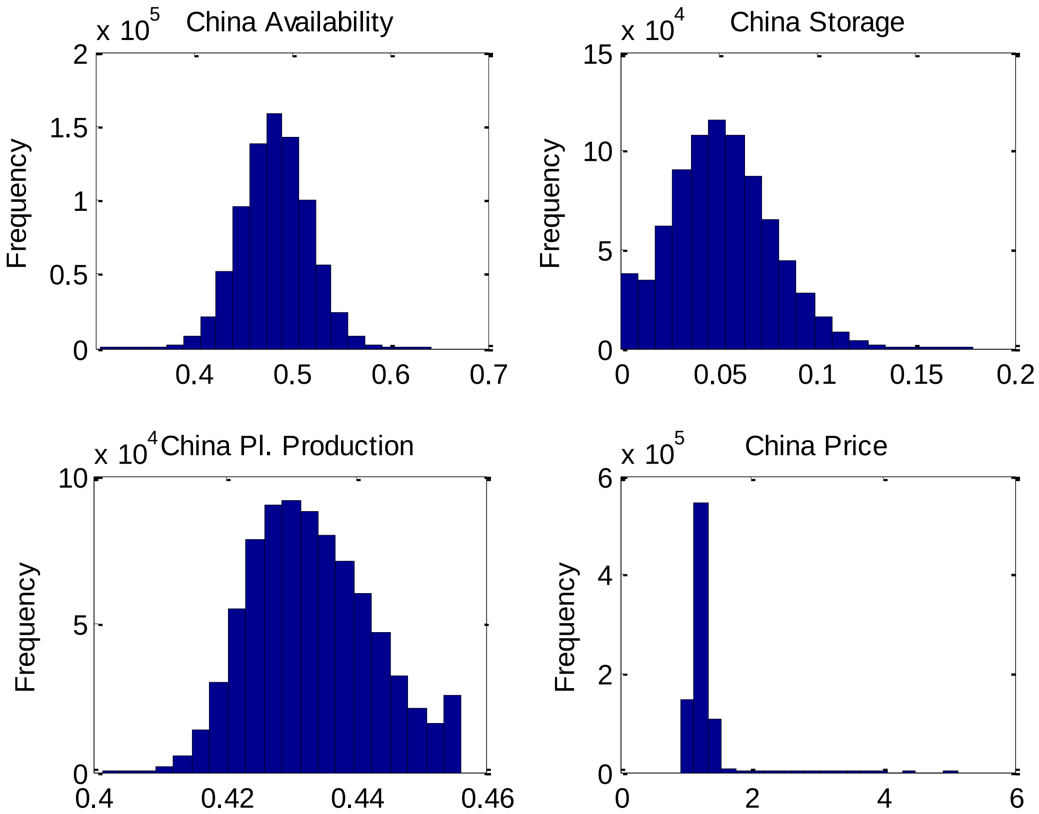


Figure 3.Ic Distribution of state and control variables China unbalanced markets in autarky



II Balanced markets, one-directional trade

Table 3.IIa Descriptive statistics balanced markets, one-directional trade

	Mean	Std. Dev.	Skew-ness	Kurto-sis	Min	Max	%at lower bound
Availability - ROW	2.1382	0.1120	0.0296	2.9940	1.6409	2.7362	
Availability - China	0.4021	0.0290	0.0327	3.0222	0.2552	0.5364	
Stocks - ROW	0.1208	0.0833	0.4743	2.6177	0	0.6140	4.2630
Stocks - China	0.0070	0.0113	2.1194	7.9309	0	0.1038	40.3394
Planned production - ROW	2.0198	0.0328	-0.1509	2.0938	1.8952	2.0773	0
Planned production - China	0.3953	0.0038	-0.8219	3.7654	0.3715	0.4012	0
Price - ROW	0.9665	0.1632	4.5903	38.8346	0.6729	5.2046	0
Price- China	0.9741	0.0980	1.1306	10.3928	0.7079	2.5891	0
Exports - ROW	0.0082	0.0138	2.1454	7.7377	0	0.1357	41.1374

Table 3.IIb Correlations balanced markets, one-directional trade

	Av Row	Av China	St ROW	St China	PP ROW	PP China	Pr ROW	Pr China	Ex ROW
Av ROW	1	-0.04	0.98	-0.08	-0.98	-0.55	-0.76	-0.31	0.23
Av China	-0.04	1	0.05	0.83	-0.08	-0.69	-0.04	-0.83	-0.78
St ROW	0.98	0.05	1	-0.04	-0.99	-0.60	-0.64	-0.36	0.10
St China	-0.08	0.83	-0.04	1	0.01	-0.77	0.01	-0.73	-0.35
PP ROW	-0.98	-0.08	-0.99	0.01	1	0.62	0.67	0.39	-0.09
PP China	-0.55	-0.69	-0.60	-0.77	0.62	1	0.38	0.82	0.21
Pr ROW	-0.76	-0.04	-0.64	0.01	0.67	0.38	1	0.28	-0.08
Pr China	-0.31	-0.83	-0.36	-0.73	0.39	0.82	0.28	1	0.43
Ex ROW	0.23	-0.78	0.10	-0.35	-0.09	0.21	-0.08	0.43	1

Notes: Av = Availability, St = Stocks, PP = Planned production, Pr = Price, Ex = Exports

Table 3.IIc Autocorrelations balanced markets, one-directional trade

	1	2	3	4
Availability - ROW	0.3942	0.1467	0.0439	0.0013
Availability - China	0.2025	0.0349	-0.0070	-0.0173
Stocks - ROW	0.3971	0.1473	0.0446	0.0014
Stocks - China	0.2445	0.0478	-0.0045	-0.0165
Planned production - ROW	0.3895	0.1430	0.0427	0.0009
Planned production - China	0.2771	0.0679	0.0046	-0.0134
Price - ROW	0.2044	0.0621	0.0113	-0.0073
Price- China	0.1950	0.0346	-0.0068	-0.0171
Exports - ROW	0.0732	0.0079	-0.0077	-0.0132

Figure 3.IIa Distribution of state and control variables ROW balanced markets, one-directional trade

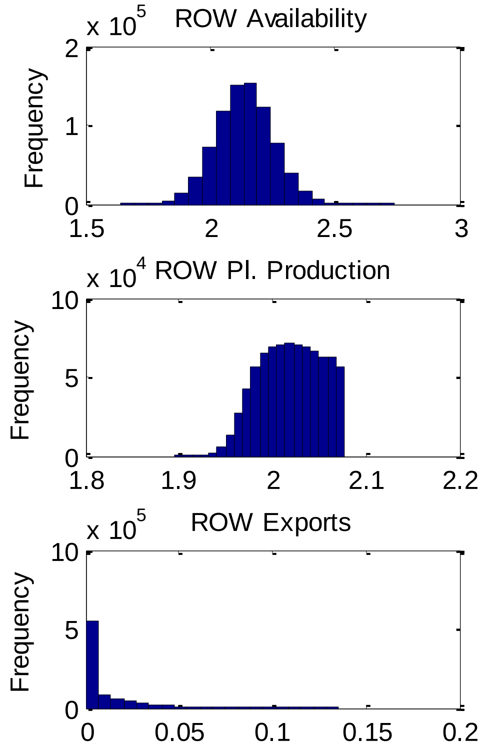
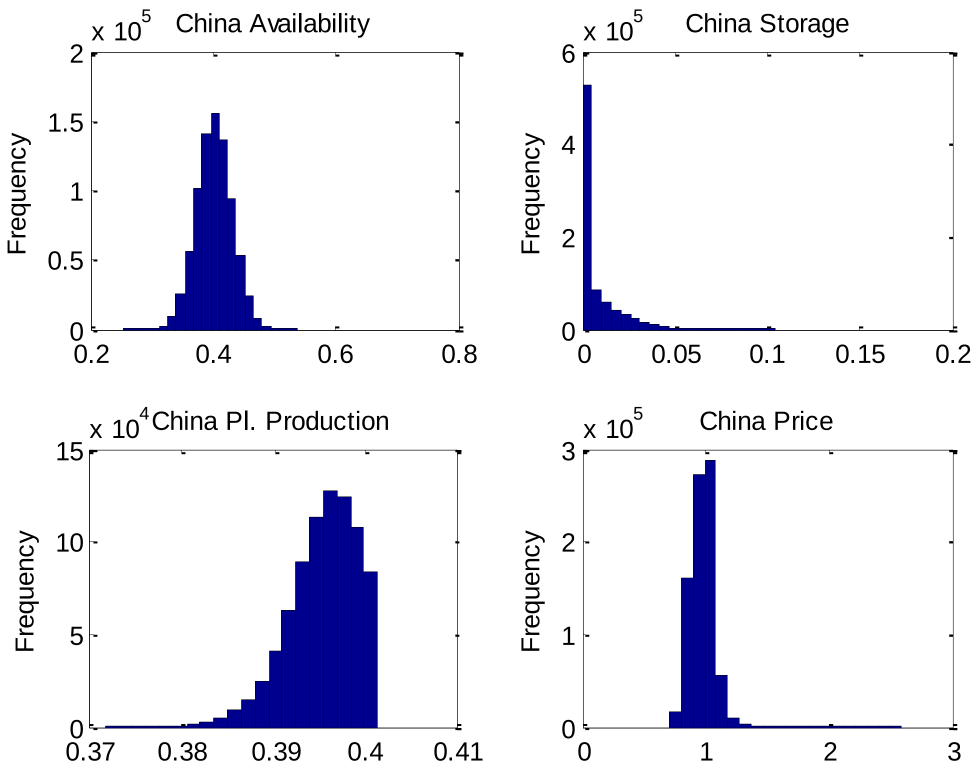


Figure 3.IIb Distribution of state and control variables China balanced markets, one-directional trade



III Balanced markets, free trade

Table 3.IIIa Descriptive statistics balanced markets, free trade

	Mean	Std. Dev.	Skew-ness	Kurto-sis	Min	Max	%at lower bound
Availability - ROW	2.0804	0.1113	0.0712	3.0093	1.5905	2.6735	
Availability - China	0.4355	0.0385	0.2196	2.9979	0.2648	0.6225	
Stocks - ROW	0.0714	0.0736	1.0223	3.4246	0	0.5659	22.2798
Stocks - China	0.0318	0.0297	0.9172	3.3153	0	0.1959	13.8461
Planned production - ROW	2.0104	0.0255	-0.5420	2.5032	1.8941	2.0479	0
Planned production - China	0.4044	0.0072	-0.2278	2.3007	0.3762	0.4179	0
Price - ROW	0.9632	0.1505	2.9776	18.0775	0.6709	3.9968	0
Price- China	0.9710	0.1278	3.2710	22.5106	0.7308	3.8917	0
Exports - ROW	0.0028	0.0081	4.3470	25.5012	0	0.1279	46.0619
Exports - China	0.0056	0.0155	4.1456	24.0535	0	0.2029	62.2224

Table 3.IIIb Correlations balanced markets, free trade

	Av Row	Av China	St ROW	St China	PP ROW	PP China	Pr ROW	Pr China	Ex ROW	Ex China
Av ROW	1	-0.16	0.94	-0.07	-0.94	-0.77	-0.83	-0.67	0.23	-0.60
Av China	-0.16	1	-0.15	0.91	-0.11	-0.48	-0.02	-0.37	-0.56	0.21
St ROW	0.94	-0.15	1	-0.17	-0.95	-0.74	-0.63	-0.46	0.18	-0.32
St China	-0.07	0.91	-0.17	1	-0.12	-0.53	-0.14	-0.46	-0.34	-0.08
PP ROW	-0.94	-0.11	-0.95	-0.12	1	0.91	0.71	0.62	-0.09	0.39
PP China	-0.77	-0.48	-0.74	-0.53	0.91	1	0.67	0.73	0.07	0.38
Pr ROW	-0.83	-0.02	-0.63	-0.14	0.71	0.67	1	0.93	-0.08	0.74
Pr China	-0.67	-0.37	-0.46	-0.46	0.62	0.73	0.93	1	0.14	0.64
Ex ROW	0.23	-0.56	0.18	-0.34	-0.09	0.07	-0.08	0.14	1	-0.11
Ex China	-0.60	0.21	-0.32	-0.08	0.39	0.38	0.74	0.64	-0.11	1

Notes: Av = Availability, St = Stocks, PP = Planned production, Pr = Price, Ex = Exports

Table 3.IIIc Autocorrelations balanced markets, free trade

	1	2	3	4
Availability - ROW	0.3601	0.1385	0.0487	0.0096
Availability - China	0.5635	0.3250	0.1822	0.0941
Stocks - ROW	0.3951	0.1564	0.0581	0.0133
Stocks - China	0.5873	0.3410	0.1910	0.0995
Planned production - ROW	0.3466	0.1122	0.0263	-0.0064
Planned production - China	0.3501	0.1184	0.0316	-0.0016
Price - ROW	0.1885	0.0542	0.0083	-0.0071
Price- China	0.1918	0.0581	0.0117	-0.0046
Exports - ROW	0.1572	0.0612	0.0245	0.0044
Exports - China	0.0460	0.0041	-0.0063	-0.0099

Figure 3.IIIa Distribution of state and control variables ROW balanced markets, free trade

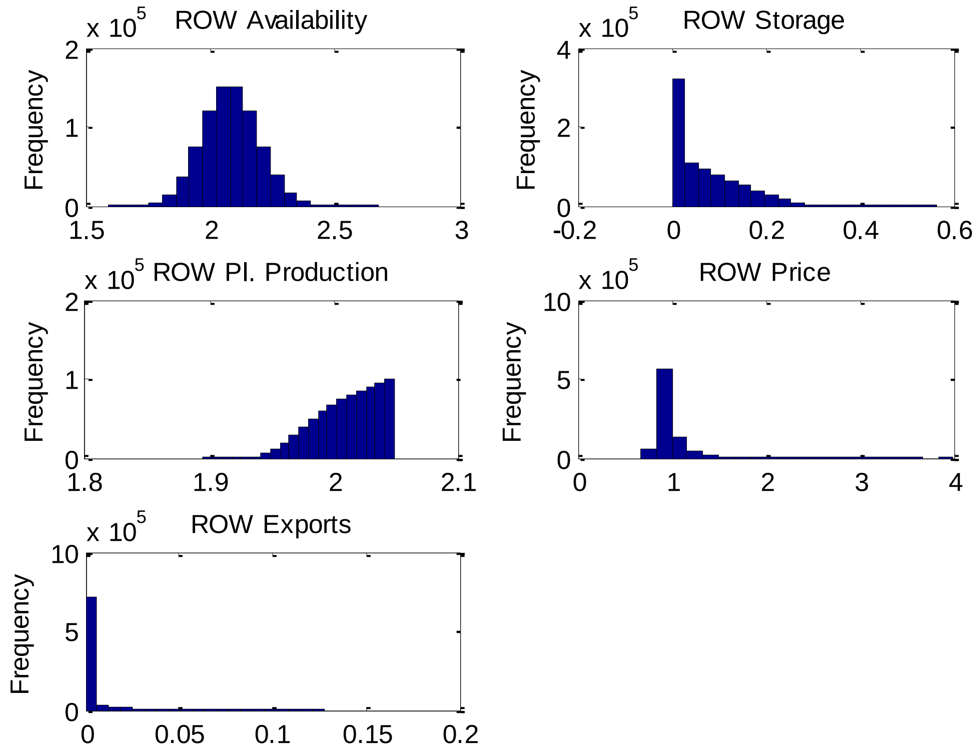
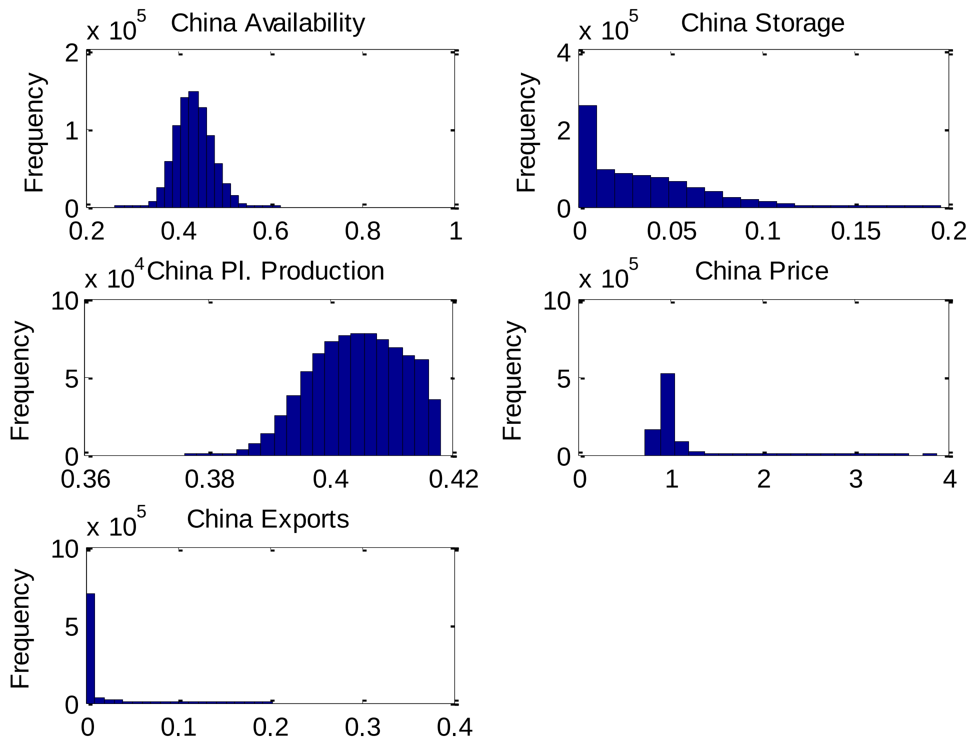


Figure 3.IIIb Distribution of state and control variables China balanced markets, free trade



IV Unbalanced markets, one-directional trade

Table 3.IVa Descriptive statistics unbalanced markets, one-directional trade

	Mean	Std. Dev.	Skew-ness	Kurto-sis	Min	Max	%at lower bound
Availability - ROW	2.1488	0.1129	0.0385	2.9998	1.6473	2.7535	
Availability - China	0.4132	0.0294	0.0097	3.0157	0.2661	0.5488	
Stocks - ROW	0.1165	0.0812	0.5479	2.7624	0	0.6011	3.7199
Stocks - China	0.0012	0.0042	6.2786	53.2171	0	0.0829	41.4583
Planned production - ROW	2.0346	0.0301	-0.2018	2.1739	1.9165	2.0876	0
Planned production - China	0.4121	0.0043	-0.5880	2.8768	0.3877	0.4188	0
Price - ROW	1.0082	0.1532	4.1845	35.1820	0.7147	5.0400	0
Price- China	1.0860	0.1166	2.9333	19.8050	0.8143	2.9994	0
Exports - ROW	0.0326	0.0249	0.6177	2.7580	0	0.1724	6.0985

Table 3.IVb Correlations unbalanced markets, one-directional trade

	Av Row	Av China	St ROW	St China	PP ROW	PP China	Pr ROW	Pr China	Ex ROW
Av ROW	1	-0.07	0.96	-0.12	-0.96	-0.92	-0.78	-0.73	0.37
Av China	-0.07	1	0.14	0.51	-0.15	-0.24	-0.11	-0.39	-0.92
St ROW	0.96	0.14	1	-0.05	-0.99	-0.98	-0.68	-0.72	0.14
St China	-0.12	0.51	-0.05	1	0.03	-0.16	0.04	-0.23	-0.31
PP ROW	-0.96	-0.15	-0.99	0.03	1	0.97	0.71	0.75	-0.14
PP China	-0.92	-0.24	-0.98	-0.16	0.97	1	0.65	0.76	-0.08
Pr ROW	-0.78	-0.11	-0.68	0.04	0.71	0.65	1	0.78	-0.16
Pr China	-0.73	-0.39	-0.72	-0.23	0.75	0.76	0.78	1	0.03
Ex ROW	0.37	-0.92	0.14	-0.31	-0.14	-0.08	-0.16	0.03	1

Notes: Av = Availability, St = Stocks, PP = Planned production, Pr = Price, Ex = Exports

Table 3.IVc Autocorrelations unbalanced markets, one-directional trade

	1	2	3	4
Availability - ROW	0.3889	0.1342	0.0350	-0.0033
Availability - China	0.0220	-0.0197	-0.0181	-0.0154
Stocks - ROW	0.3747	0.1287	0.0339	-0.0036
Stocks - China	0.0507	-0.0093	-0.0144	-0.0144
Planned production - ROW	0.3687	0.1259	0.0327	-0.0037
Planned production - China	0.3497	0.1171	0.0292	-0.0043
Price - ROW	0.2103	0.0604	0.0085	-0.0090
Price- China	0.1900	0.0537	0.0065	-0.0095
Exports - ROW	0.0535	0.0018	-0.0091	-0.0129

Figure 3.IVa Distribution of state and control variables ROW unbalanced markets, one-directional trade

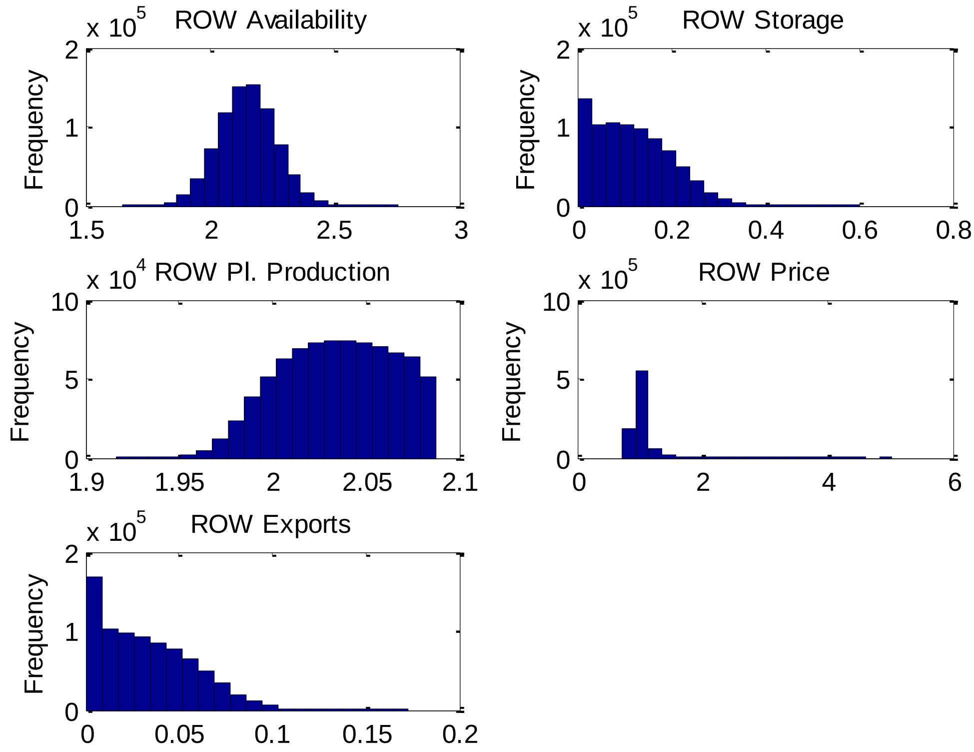
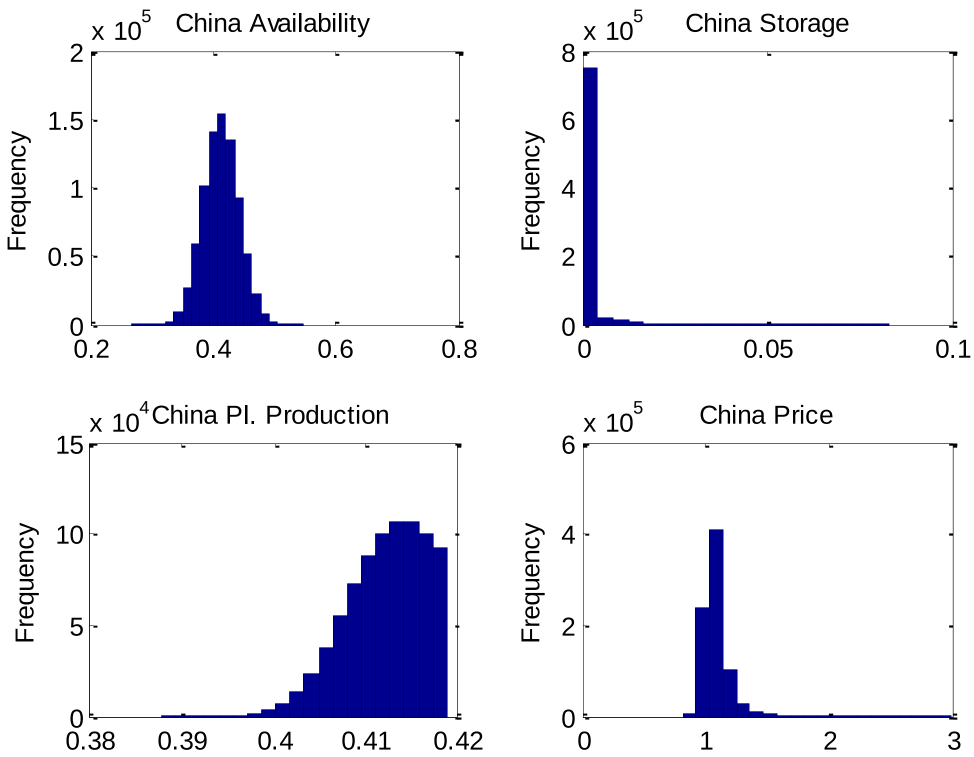


Figure 3.IVb Distribution of state and control variables China unbalanced markets, one-directional trade



V Unbalanced markets, free trade

Table 3.Va Descriptive statistics unbalanced markets, free trade

	Mean	Std. Dev.	Skew-ness	Kurto-sis	Min	Max	%at lower bound
Availability - ROW	2.1208	0.1132	0.0570	2.9998	1.6229	2.7298	
Availability - China	0.4220	0.0312	0.0621	3.0584	0.2717	0.5806	
Stocks - ROW	0.0938	0.0780	0.7546	2.9784	0	0.5768	9.3531
Stocks - China	0.0037	0.0088	3.8597	21.9902	0	0.1349	37.0692
Planned production - ROW	2.0289	0.0260	-0.4609	2.3623	1.9158	2.0671	0
Planned production - China	0.4184	0.0069	-0.4415	2.3916	0.3877	0.4287	0
Price - ROW	1.0025	0.1607	3.3493	20.5219	0.7135	4.1765	0
Price- China	1.0906	0.1366	3.1852	21.3592	0.8130	4.0739	0
Exports - ROW	0.0268	0.0239	0.8507	3.1316	0	0.1719	11.6331
Exports - China	0.0015	0.0056	6.8332	65.4502	0	0.1311	57.6716

Table 3.Vb Correlations unbalanced markets, free trade

	Av Row	Av China	St ROW	St China	PP ROW	PP China	Pr ROW	Pr China	Ex ROW	Ex China
Av ROW	1	-0.11	0.95	-0.16	-0.95	-0.93	-0.79	-0.79	0.39	-0.45
Av China	-0.11	1	0.06	0.68	-0.13	-0.18	-0.12	-0.25	-0.90	0.20
St ROW	0.95	0.06	1	-0.11	-0.99	-0.98	-0.64	-0.68	0.18	-0.27
St China	-0.16	0.68	-0.11	1	0.01	-0.07	-0.04	-0.14	-0.44	0.08
PP ROW	-0.95	-0.13	-0.99	0.01	1	1.00	0.68	0.72	-0.15	0.28
PP China	-0.93	-0.18	-0.98	-0.07	1.00	1	0.68	0.73	-0.11	0.27
Pr ROW	-0.79	-0.12	-0.64	-0.04	0.68	0.68	1	0.98	-0.16	0.62
Pr China	-0.79	-0.25	-0.68	-0.14	0.72	0.73	0.98	1	-0.07	0.53
Ex ROW	0.39	-0.90	0.18	-0.44	-0.15	-0.11	-0.16	-0.07	1	-0.23
Ex China	-0.45	0.20	-0.27	0.08	0.28	0.27	0.62	0.53	-0.23	1

Notes: Av = Availability, St = Stocks, PP = Planned production, Pr = Price, Ex = Exports

Table 3.Vc Autocorrelations unbalanced markets, free trade

	1	2	3	4
Availability - ROW	0.3941	0.1380	0.0362	-0.0033
Availability - China	0.1232	0.0072	-0.0137	-0.0171
Stocks - ROW	0.3736	0.1270	0.0327	-0.0045
Stocks - China	0.2029	0.0332	-0.0069	-0.0141
Planned production - ROW	0.3572	0.1177	0.0285	-0.0055
Planned production - China	0.3439	0.1098	0.0249	-0.0065
Price - ROW	0.1839	0.0492	0.0041	-0.0099
Price- China	0.1869	0.0475	0.0024	-0.0108
Exports - ROW	0.1280	0.0256	-0.0024	-0.0123
Exports - China	0.0548	0.0045	-0.0073	-0.0130

Figure 3.Va Distribution of state and control variables ROW unbalanced markets, free trade

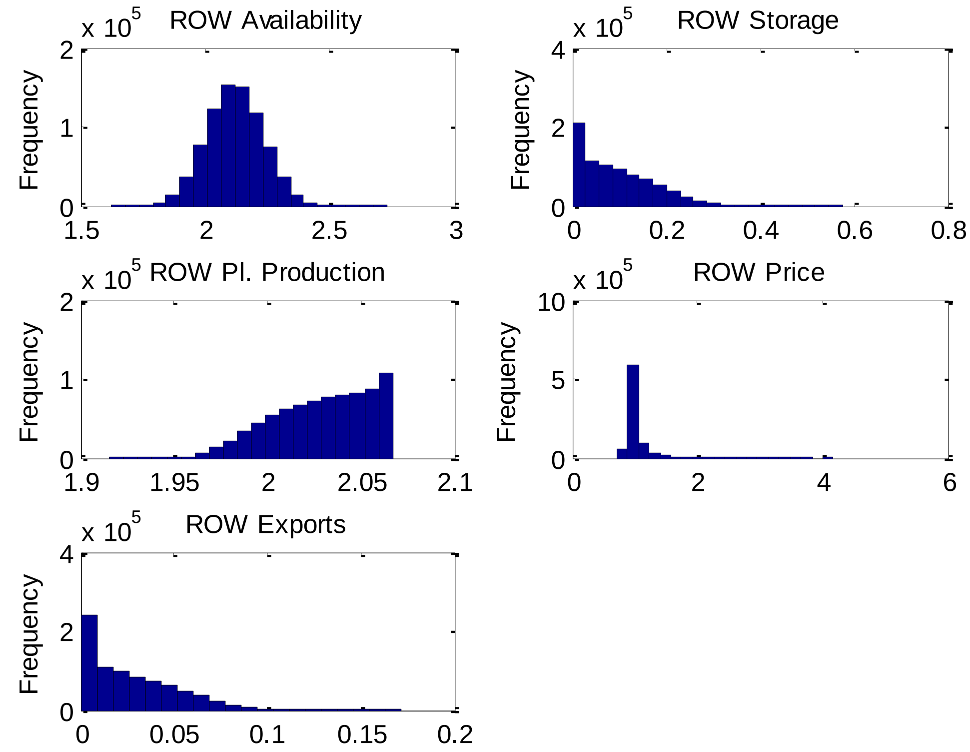
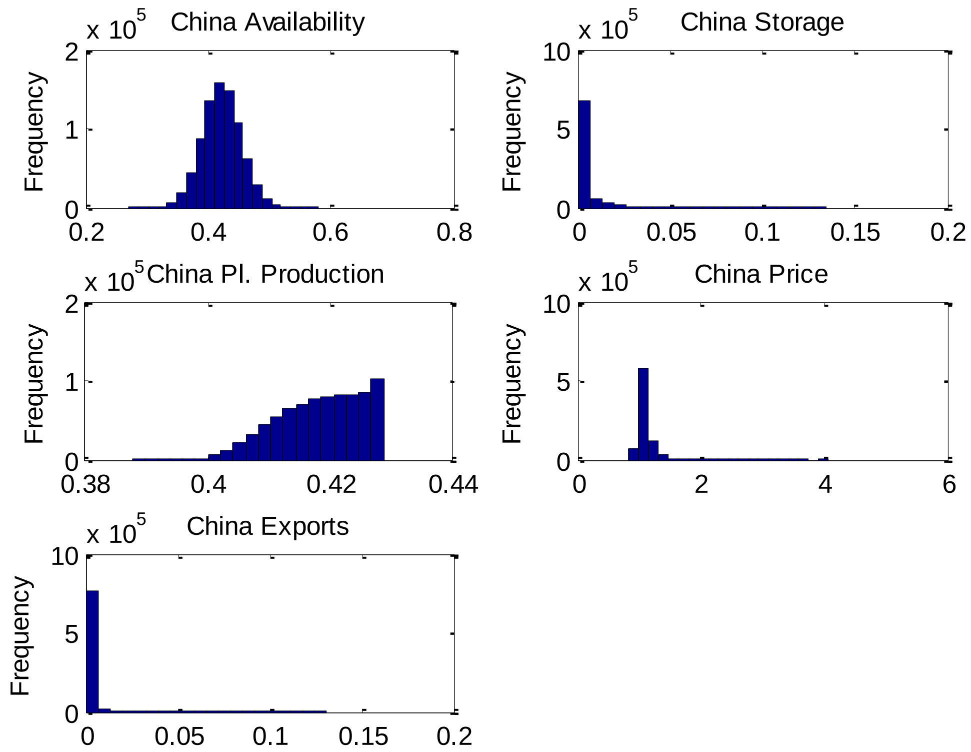


Figure 3.Vb Distribution of state and control variables China unbalanced markets, free trade



4 An Experimental Approach to Testing the Competitive Storage Model

4.1 Introduction

The exposition in this section partially follows the same lines as parts of sections 3.1 and 3.2 because both chapters make use of the competitive storage model but for different purposes.

It is undeniable that stockholding affects prices. The role of low stocks in recent price movements, especially the 2007/08 and 2010/11 grain price peaks, has been widely discussed. Global stocks-to-use ratios were relatively low in the mid-2000s for a number of grains and oilseeds. Several studies, therefore, suggest that low stocks contributed to price peak of 2007/08 (e.g. European Commission, 2008; OECD, 2008; Wiggins and Keats, 2010).

One of the difficulties in the analysis of the stock-price relationship is that causation is bi-directional. Stock levels depend on current prices and expected future prices. At the same time, the current price and the future expected prices depend on the level of stocks carried forward from the current period to future periods. The important role of storage in price formation is well known and a number of models have been developed over time. Modern models of intertemporal price formation and stockholding have a long tradition. In the 1930s and 1940s Working published a number of papers on futures markets and intertemporal price formation in which he highlights the important role that storage plays (e.g. Working, 1935, 1948, 1949).

Samuelson (1957) introduced a simple model of intertemporal price equilibrium. For markets with annual crops, assuming known constant and continuous demand and one single harvest a year of constant and known size, prices move in a regular pattern. Prices are lowest at harvest and then increase steadily throughout the year until the next harvest. The increase in price is due to storage and interest costs. If harvests are variable, but of known size, price movements are more irregular but still follow a similar zigzag pattern.

Gustafson (1958) introduced supply shocks in form of probabilistic harvests into a model of intertemporal price formation and storage. The storage decision is made taking into account the amount of the good available in the current period and the expected supply in the following period. The distribution of the harvest is known but the outcome of the stochastic harvest is only known for periods up to the current period. So when the storage decision is made, the outcome of the harvest in the current period is known but the harvest outcome in the following period is not known. Therefore, the storage decision maker has to form an expectation about the supply in the following period. The decision is further complicated by the fact that supply in this period and expected supply in the following period depend on the amount of stock carried forward into the next period. Furthermore, storage cannot be negative which means that the model cannot be solved analytically. The model is solved for the profit-maximising storage using numerical methods. Gustafson's model is basis of the modern stochastic competitive storage models which remain the main tool in theoretically analysing the stocks-price relationship.

One way of empirically testing these models is to look at their predictive power. The competitive storage model, like other models that try to explain agricultural commodity price movements, should be able to reproduce the characteristics of the price series seen on agricultural markets (Stigler, 2011). Agricultural commodity price series exhibit a number of general characteristics, such as high volatility, high persistence and asymmetry. The non-negativity of stock levels introduces the asymmetry into the price movements. A number of studies have shown that models based on optimal stockholding have been successful in mirroring several of the observed characteristics of agricultural commodity price movements.

Williams and Wright (1991) and Deaton and Laroque (1992, 1996) look at the characteristics of the price series predicted by the competitive storage model. Williams and Wright (1991) derive the implications of storage for price time series. Deaton and Laroque (1992) compare the model predictions for commodity prices with actual prices for commodities. They find that the model performs well with regards to the asymmetry of price movements and large price spikes. The model suggests persistence in prices but it does not replicate the extent of the autocorrelation in the actual price series (Deaton and Laroque, 1996). They conclude that the real world relevance of the model is therefore in question.

Following the recent price spike and renewed interest in commodity prices and commodity storage, the real world relevance of the competitive storage model has been explored in a number of recent papers. Cafiero et al. (2011) builds on the Deaton and Laroque papers of the 1990s. One change they make is that they use different parameters which they judge to be more realistic; another is the introduction of constant marginal costs to storage. In addition, a finer grid is used when approximating the equilibrium price function. The same model and econometric estimation techniques as Deaton and Laroque (1996) are then used. With these changes, the model version in Cafiero et al. (2011) predicts price series with autocorrelations that are of similar magnitude to those that are observed in a number of commodity markets. They find that for seven of the ten studied commodity price series, the observed first- and second-order correlations are covered by the symmetric 90% confidence interval.

Miao et al. (2011) take a different approach and extend the Deaton and Laroque model. They introduce trends in demand and supply and interest rates that vary over time to make the model more realistic. They find that their model predictions are generally in line with the main characteristics of actual commodity price series.

Arseneau and Leduc (2013) embed a competitive storage model into a general equilibrium model with endogenous interest rates. They also compare autocorrelation rates predicted by the model with actual commodity prices and conclude that their model can replicate autocorrelation levels of commodity price series.

This chapter introduces a new approach to testing the competitive storage model. A relatively simple version of the competitive storage model is taken to the experimental laboratory. The advantage of this approach is that the characteristics of the model are under the control of the experimenter and behaviour can be studied in this controlled environment. In the real world, information on storage decisions is difficult to collect. In an experimental setting, many parameters that have to be estimated in the real world and which might be only known with error can be controlled. In addition, data collection is straightforward in the laboratory. One of the main problems when analysing the stocks-price relationship in the real world is that available data on stockholding is subject to large errors (e.g. Bobenrieth et al., 2012; Wiggins and Keats, 2010). Stocks are often not measured but calculated as the residual once other elements of supply and demand have been estimated. In the laboratory, stocks and prices can be measured precisely within the controlled environmental.

There is little pre-existing experimental literature on storage. The only instance of which I am aware is Abbink et al. (2011) who present an experimental study of storage decisions of maize traders in Zambia. The study's focus is on the two sectors of the market that can exert market power in the Zambian maize market, large traders and government. The presence of players with market power complicates the analysis as it introduces strategic behaviour and requires a game-theoretic approach. The model on which their experimental design is based is, therefore, a game of strategic interaction between government and a small number of private stockholders.

To the best of my knowledge, this is the first experimental study of the competitive storage model. The absence of experimental work on the competitive storage model in the literature is somewhat surprising because experiments on optimal savings theory go back to at least the 1980s (Hey, 1988; Hey and Dardanoni 1988). As Gouel (2013) points out, the competitive storage model is formally very similar to the rational expectations model of optimal savings under income uncertainty. Experimental work on optimal saving have generally found that subjects save less than predicted by optimal savings models (Brown et al., 2009). An important difference in this experiment compared to the optimal savings experiments is that unlike in the saving experiments in which participants make individual choices participants in this experiment make intertemporal decisions in a market environment.

With respect to the multi-period market set-up, the storage experiment is similar to multi-period asset market experiments which started in the 1960s (Smith, 1962). In their seminal contribution to the experimental multi-period asset markets, Smith et al. (1988)

introduced a model of laboratory asset market that has been used extensively since then. Smith et al. (1988) found that these laboratory asset prices deviate from the efficient market paradigm and are prone to bubble behaviour. Subsequent research has studied the impact of different design features on market efficiency. For a review of the literature on asset markets see Noussair and Tucker (2013) and Palan (2013).

In this experiment participants were asked to make storage decisions within a competitive storage model framework. Their behaviour, the aggregate stock level and the resulting price series are compared to the model assumptions and predictions.

4.2 The competitive storage model

The competitive storage model is a rational expectations model of optimal storage for a commodity where production is uncertain and the commodity is storable from one period to another, such as an annual agricultural crop that is storable. The model can be formulated with a single state variable, a single control variable and one arbitrage equation. In line with the set-up of the experiment, the model is presented without discounting and storage costs which are included in the standard model.

In every period t, stockholders start with a pre-determined level of the commodity that was carried forward from the previous period, s_{t-1}. The quantity of the commodity available in period t, availability a_t, is the state variable. Availability is the quantity carried forward from the previous period, s_{t-1}, plus the harvest in period t. The quantity harvested is an exogenous random variable ϵ_t. Availability in period t, a_t, can be used for consumption and storage. The amount used for consumption, c_t, is sold to consumers at the price that clears the market, $p_t = P(c_t)$. The difference between availability, a_t, and consumption, c_t, is the amount of storage s_t, the control variable in the model. In the next period t+1, the pre-determined stock level carried forward from the previous period is s_t, which together with exogenous production, ϵ_{t+1}, gives the total amount available in period t+1, a_{t+1}. The transition equation of the dynamic model is therefore:

$$a_{t+1} = s_t + \epsilon_{t+1} \tag{4.1}$$

Availability in t+1, a_{t+1} depends on the exogenous variable ϵ_{t+1} and the endogenous variable s_t.

The stockholders' objective is to maximise their expected profit which leads to the storage arbitrage equation.

$$\mathrm{E_t}[\mathrm{p_{t+1}}] - p_\mathrm{t} = \pi_t \qquad (4.2)$$

where $E_t[p_{t+1}]$ is the expected price in period t for period t+1, p_t is the price in period t and π_t is expected marginal profit of a unit stocks. As noted before, s_t the amount of the commodity stored from period t to period t+1, is the control variable that the agents in the model, the stockholders, adjust to maximise their profits. In a competitive market and in the absence of storage capacity limitations, stockholders will adjust the storage level until the expected profits are zero. The arbitrage equation can be written as a function of the state variable a and the control variable s.

$$\mathrm{E_t}[P(a_{t+1} - s_{t+1})] - \mathrm{P}(a_t - s_t) = \pi_t \qquad (4.3)$$

As a whole, the economy cannot borrow production from future periods. Therefore, storage cannot be negative. The non-negativity constraint limits arbitrage when storage is zero and in these situations expected profits are negative.

$$\mathrm{E_t}[P(a_{t+1} - s_{t+1})] - \mathrm{P}(a_t - s_t) = \pi_t \qquad (4.4)$$

$$s_t \geq 0 \;\Rightarrow\; \pi_t \leq 0,\;\; s_t > 0 \;\Rightarrow\; \pi_t = 0$$

When expected profits are positive, that is when the expected price in period t for period t+1 exceeds the current price, stockholders will store another unit which will lower availability and increase the price in period t and increase availability and decrease the price in period t+1. Stockholders will continue to increase storage until the point is reached where expected profits are zero. When profits are negative, that is when the expected price in period t for period t+1 is lower than the current price, stockholders will reduce storage. Reducing storage increases availability and reduces the price in period t and, at the same time, lowers availability and increases the price in period t+1. When stocks are zero, arbitrage is limited and expected profit from storage is negative.

With a maximum storage capacity in the economy, the possibility of increasing storage when expected profits are positive is limited by the maximum storage level. When storage is at the maximum storage level, therefore, expected profits are positive.

$$\mathrm{E_t}[P(a_{t+1} - s_{t+1})] - \mathrm{P}(a_t - s_t) = \pi_t \qquad (4.5)$$

$$s_t > 0 \;\Rightarrow\; \pi_t \geq 0,\;\; s_t < s_{max} \;\Rightarrow\; \pi_t \leq 0, 0 < s_t < s_{max} \;\Rightarrow\; \pi_t = 0$$

In a rational expectations model, agents' expectations for variables in the next period have to be consistent with the resultant distribution of these variables given the structure of the model, the parameters in the model and the expectations. In the present model the expectations are with respect to the price in the next period. In this simple version of the model, stockholders are the only agents. They have to make a decision on how much of the commodity to store from one period to the next and this decision depends on their expectations of the price in the next period. The model does not have a closed-form solution because of the non-negativity constraint on storage and needs to be solved numerically.

4.3 The experiment

4.3.1 Participants and procedures

The experiment was run at the Cognitive and Experimental Economics Laboratory (CEEL) of the University of Trento in April 2014 (one session on the 8th of April and three sessions on the 15th of April 2014). An online system was used for participant recruitment and up to 30 potential participants could sign up for each session. No similar experiments had been run at CEEL before and thus no restriction was imposed on sign-up based on previous participation in any of the experiments run at CEEL. Sessions 1, 3 and 4 consisted of three groups of eight. Session 2 only comprised two groups of eight because of the 30 people who signed up less than 24 showed up for the experiment. Thus, overall 88 participants took part in the experiment which formed 11 groups of eight, leading to 11 independent market observations.

At the start of the experiment, participants were randomly assigned to groups of eight. The composition of the group did not change during the experiment ("partner matching"). Each session consisted of 25 periods which falls within the range of the number of rounds used in asset market experiments following Smith et al. (1988) that generally consists of 15 to 30 periods (Noussair and Tucker, 2013). Given possible learning and end game effects, a number of periods towards the higher end of this range was chosen. In a trial of the experiment, feedback from the volunteers suggested that 25 rounds was an adequate length for the experiment, some even suggesting that it could be longer. With 25 rounds 275 observations at the group level and 2200 at the individual level were collected.

Most of the participants were students at the University of Trento. Only three participants were not students. Just over half of the participants were students at the Department of Economics and Management while just under 20 per cent were from the Faculty of Law and just over ten per cent from the Department of Sociology and Social Research. The remaining students were students of engineering, mathematics and humanities. The average age of the participants was 22.5. Of the 88 participants 45 were female and 43 were male. The experiment was run as a computerised experiment, programmed and conducted using the z-Tree software (Fischbacher, 2007).

Before the start of the experiment participants were given written instructions (in Italian), which were also read out aloud after participants had a chance to read them privately (see appendix A for the English translation of the instructions). To check for possible framing effects through the example used to explain the market price mechanism, two different versions of the instructions were used. The three examples used to explain the market mechanism were the same in both versions. The only difference was in the order of the examples and which of the examples was described in detail.[25] Participants were reminded that the example is for illustrative purposes only.

The experiment only started after participants had a chance to ask questions and after all had correctly answered a number of control questions. The control questions related to the number of rounds, the group composition, the price function, the price mechanism and the initial endowment they received (see appendix A for the English translation of the control questions).

Participants were paid a show-up fee of 3.00 euros plus the amount that they had at their disposal at the end of the 25th round, which depended on the transactions they made during the 25 rounds. This was calculated as the initial endowment plus any profit made from buying and selling units of wheat on the market or minus any loss from buying and selling units of wheat. To lessen any potential end game effect, participants with a unit of wheat left in storage after round 25 received the average price over the 25 rounds for the unit of wheat in storage. The highest earning (including the show-up fee) was 14.85 euros, the lowest 11.25 euros and the average 13.15 euros. The payments were made in private at the end of the experiment.

At the end of the experiment participants were asked to fill in a short questionnaire including questions about their age, gender, field of study as well as their assessment of how interesting and how difficult the experiment had been (see appendix A for the English translation of the questionnaire). On a scale from 1 very boring to 10 very interesting, the average rating was 6.7. Participants were also asked to rate the difficulty of the experiment on a scale from 1 very easy to 10 very difficult. The average rating of the difficulty was 6.0.

[25] For sessions 1 and 3, the example with submitted prices of 3.00 Experimental Currency Units (ECU) and 1.50 ECU was used and for sessions 2 and 4, the example with 3.00 ECU and 1.70 ECU was used. A price of 3.00 ECU was chosen because it is clearly higher than any price that can be achieved within the experiment. Prices of 1.50 ECU and 1.70 ECU are possible and are 0.1 ECU higher and lower, respectively, than the optimal submitted price at the average harvest of 60.

4.3.2 Experimental design

In general, when there was a choice between simplicity and realism in the experimental design, the choice was in favour of simplicity for two reasons. Firstly, this is the first experiment testing the competitive storage model and as such the main aim is that of introducing a simple framework. At this initial stage it was important to find a simple design that was likely to work and that can be used as a baseline for future developments of more complicated and realistic settings. Secondly, the experiment in its simplest form was still relatively complex.

With respect to the level of complexity, the storage experiment is similar to asset market experiments with declining fundamental values, which participants often find confusing (Kirchler et al., 2012). In the case of asset markets with declining fundamental values, Kirchler at al. (2012) found that replacing the generic term “stock” with the more context-specific description “stock in a depletable gold mine” reduced confusion in participants and significantly reduced mispricing. Similarly, in the storage experiment, the main features of agricultural commodity markets, such as the stochastic harvest, are likely to be more easily grasped by participants if presented in a context-specific framework rather than a neutral framework. Therefore, a commodity specific framework was chosen for the experiment.

At the beginning of the experiment, each participant received an endowment of 10 Experimental Currency Units (ECU). All participants in the experiments had exactly the same role, namely that of wheat traders, who can buy, sell and store wheat. The eight participants in each group participated in the same market. At the start of the experiment stocks were zero for all participants. It would have been possible to randomly assign units of wheat to participants at the start. However, this would have introduced another random process to the experiment which would have had to be explained to participants creating an unnecessary additional level of complexity and possibly leading to confusion of the random processes with adding little to the experiment.

Each participant had a capacity of storage of one unit leading to a maximum storage capacity at the market level of eight. Wheat could only be bought, sold and stored in full units. In each period the participants were therefore either potential buyers (those participants that did not carry forward a unit of stock from the previous period) or potential sellers (those participants that carried forward one unit of stock from the previous period). As a consequence, each participant had to make a straightforward decision in each round, namely, for potential sellers, from which price on to sell and for buyers up to which price to buy. Participants did not have to decide whether to sell or to buy and how much to sell or buy.

These advantages of the design were thought to outweigh the disadvantages. The limitations of the design are taken into account in the analysis of the results as explained in section 4.3.3.

There was a single wheat harvest in each round which followed a simple three point distribution with a small harvest of 50 units, a medium of 60 units and good harvest of 65 units. In each round, the probability that the harvest was 50 units was 20 per cent, that it was 60 units was 40 per cent and that it was 65 units was 40 per cent. All units available in a round were used, either for consumption or for storage to the next round.

At the beginning of each round participants were informed about the size of the harvest (50, 60 or 65 units) and the total number of units of wheat carried[26] forward from the previous period by all group members (which could be between zero and eight). They were also reminded how many ECU they had available.

Those participants who had carried forward a unit of wheat from the previous round were potential sellers in that round and were asked to submit the minimum price for which they wanted to sell their unit of wheat (in steps of 0.05 ECU). If the market price in the round was above the minimum price submitted, their unit was sold at the market price and if the market price was below the minimum price submitted, their unit was not sold. If the market price was exactly the same as the price submitted the unit was either sold or not depending on the stock adjustments necessary to clear the market.

The participants who had not carried forward a unit of wheat from the previous round were potential buyers in that round and were asked to submit the maximum price for which they wanted to buy a unit of wheat (in steps of 0.05 ECU). Buyers could not submit a maximum price that was higher than the amount in ECU that they had available in that round. If the market price in the round was below the maximum price submitted, they bought a unit of wheat at the market price and if the market price was above the maximum price submitted, they did not buy a unit of wheat. If the market price was exactly the same as the price submitted, they either bought a unit or not, depending on the stock adjustments necessary to clear the market. In each round, wheat not stored was consumed according to a linear consumption function.

Consumption depended on the price and was specified in the deterministic consumption-price function, which was communicated to the participants. In this experiment a linear consumption-price function was chosen because it is easier to communicate the main aspects of a linear function to participants.

[26] In order to avoid confusion between the amount of storage at the start of the period and the amount of storage at the end of the period, storage at the start of the period will be referred to as *carry-in* or *stocks carried forward* (s_{t-1} are the stocks carried forward to period t). This level is pre-determined with respect to the storage decision in period t. The storage decision in period t relates to s_t, which will be referred to as *storage* in period t.

The consumption function in the experiment was:

$$C(p_t) = 90 - 20 * p_t \tag{4.6}$$

where C is consumption and p_t is the price in period t.

The equivalent price function, is:

$$P(c_t) = 4.5 - 0.05 * c_t \tag{4.7}$$

Thus, if the mean harvest of 60 units is consumed, the price is 1.5 and the elasticity is -0.5.

An algorithm included in the z-Tree program established the market price. The market price was the unique price at which

a) all participants with a unit in storage sold their unit if they submitted a minimum price lower than the price in the round but did not sell it if they submitted a price higher than the price in the round

b) all participants without a unit in storage bought if they submitted a maximum price higher than the market price in the round but did not buy if they submitted a price lower than the price in the round

c) the number of units of wheat not stored at the market price given a) and b) were consumed according to the consumption function (4.6).

If prices submitted by participants coincided with the market price, only those transactions that were necessary to clear the market were made. If the number of participants who submitted the same price as the market price exceeded the number of transactions required to clear the market, the participants to make the transactions were selected at random among all those participants that had submitted the same price as the market price.

Given the market price determined for the round, the units in storage were adjusted and payments were made. Sellers received the price for the unit they sold and buyers were required to pay the price for the unit they bought.

At the end of each round, participants were informed about the market price in the round, their new level of storage, the payment they made or received and how many ECU they had available after the transactions. The storage level at the end of one round was the storage level at the start of the next round.

4.3.3 Competitive storage model predictions

In this section, model predictions are derived using a discrete dynamic model with the same parameters as in the experiment: a three-point distribution for the harvest (50, 60 and 65 units with probabilities of 0.2, 0.4 and 0.4, respectively), a linear demand function as specified in (4.6) and a maximum storage capacity of eight.

Figure 4.1 shows the storage level at each possible level of availability according to the competitive storage model prediction. The storage function requires that up to a level of availability (harvest plus stocks carried forward) of 58 storage will be zero and that from a level of availability of 70 storage will be at its maximum level of eight units.

Figure 4.1 Equilibrium storage function

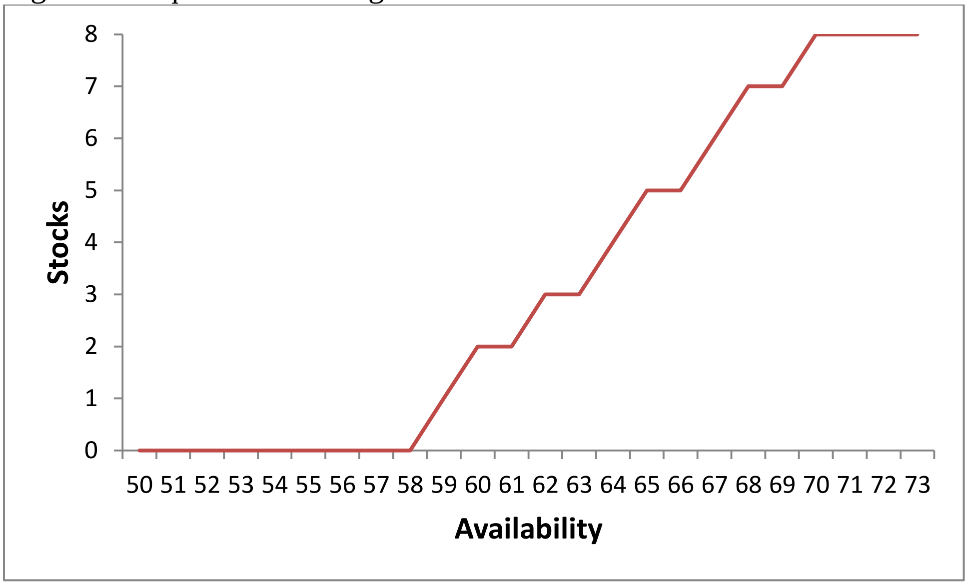
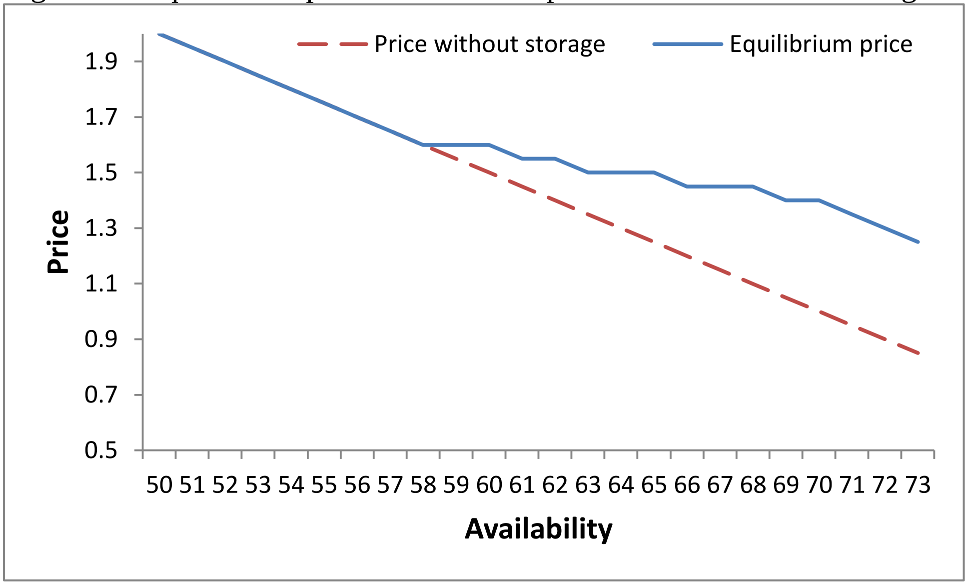


Figure 4.2 shows the equilibrium price function (solid line) and the price function without storage (dashed line). It shows that up to the level of availability of 58 when no storage takes place, the price is the same with and without storage. When availability exceeds 58 units, the optimal storage rule leads to storage, leaving less for consumption, and thus leads to an increase in the price compared to the no storage scenario. From 70 units of availability onwards the equilibrium price and price without storage lines are parallel. At 70 units of availability optimal storage reaches the maximum storage capacity level of eight units and storage cannot increase further at higher availability levels.

Figure 4.2 Equilibrium price function and price function without storage



The optimal storage[27] outcomes, to which the experimental results are compared, are based on simulations of the experiment assuming that participants behave as close to the competitive storage model outcomes as possible within the experimental design. The approach taken is explained in the following.

For each level of availability the model solution gives the optimal storage, consumption, price and expected price. Table 4.1 shows the availability levels possible in the experiment, the corresponding stock levels and expected prices at these levels of availability according to the competitive storage model solution.

Table 4.1 Competitive storage model: availability, storage and expected price

Availability	50	51	52	53	54	55	56	57	58	59	60	61
Storage	0	0	0	0	0	0	0	0	0	1	2	2
$E_t(P_{t+1})$	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.59	1.58	1.58
Availability	62	63	64	65	66	67	68	69	70	71	72	73
Storage	3	3	4	5	5	6	7	7	8	8	8	8
$E_t(P_{t+1})$	1.55	1.55	1.52	1.51	1.51	1.46	1.43	1.43	1.40	1.40	1.40	1.40

As a consequence of the price function and the limitation of storage to full units, the price can only take values in steps of 0.05 ECU whilst the expected price can take values in between those possible in the experiment. If all participants follow the optimal strategy, participants maximise their profit if they submit the expected price. However, participants had to submit limit prices that are possible in the experiment, i.e. prices in steps of 0.05 ECU. In the simulation of optimal storage in the experimental setting, therefore, for buyers not to make an expected loss they submit a rounded-down expected price and sellers a rounded-up

[27] In the following whenever reference is made to optimal strategy or behaviour, reference is made to these simulation results.

expected price. Table 4.2 shows the optimal decision rule for buyers and sellers in the experiment to which actual behaviour will be compared. This strategy maximises earnings within the experiment.

Table 4.2 Approximation of optimal limit prices for buyers and sellers

Availability	50	51	52	53	54	55	56	57	58	59	60	61
Submitted price buyer	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.55	1.55	1.55
Submitted price seller	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.60	1.60	1.60
Availability	62	63	64	65	66	67	68	69	70	71	72	73
Submitted price buyer	1.55	1.55	1.50	1.50	1.50	1.45	1.40	1.40	1.40	1.40	1.40	1.40
Submitted price seller	1.55	1.55	1.55	1.55	1.55	1.50	1.45	1.45	1.40	1.40	1.40	1.40

Table 4.3 confirms that average earnings for the optimal strategy are higher than average earnings in the experiment for all groups, and thus, that if all participants had followed the optimal strategy the earnings as a group would have been higher. However, the maximum earnings are often higher in the experiment than for simulation results of the optimal strategy. Some participants were able to take advantage of the suboptimal behaviour of fellow group members and thus make higher profits than they would have been able to make if all participants had behaved optimally. This result stresses the fact that the optimal individual strategy depends on the behaviour of other participants. The optimal strategy is only optimal if all participants follow the optimal strategy.

Table 4.3 Average, maximum and minimum earnings for each of the four sessions

	Optimal earnings	Group 1 earnings	Group 2 earnings	Group 3 earnings
Session 1				
Average earning	10.20	10.03	10.13	9.78
Maximum earning	10.40	10.40	11.00	11.17
Minimum earning	10.07	9.02	9.72	8.42
Session 2				
Average earning	10.55	10.40	10.52	
Maximum earning	10.71	11.75	11.85	
Minimum earning	10.11	8.25	9.70	
Session 3				
Average earning	10.30	10.07	10.05	10.07
Maximum earning	10.82	10.71	10.46	10.51
Minimum earning	10.02	9.25	9.51	9.35
Session 4				
Average earning	10.49	10.09	10.32	10.17
Maximum earning	10.93	10.80	11.62	10.95
Minimum earning	10.23	9.35	8.85	8.82

Table 4.3 also shows that the range of earning is rather narrow with a maximum of 11.75 ECU and a minimum of 8.25 ECU. The range would have been even smaller if all participants had followed the optimal strategy because in this case profits can only be made when storage is at its maximum.

4.4 Hypotheses tested

A number of hypotheses relative to the predictions and assumptions of the competitive storage model can be tested based on the results of the experiment.

The main predictions with respect to the level of storage in the market and the resulting price series can be tested through a comparison of the storage and price series in the experiment and the optimal storage and price series given the outcome of the random harvest during the experiment.

In addition, hypotheses can be tested with respect to two specific features of the competitive storage model. Firstly, the competitive storage model requires that storage decisions are solely dependent on variables in the current period. This entails that storage decisions are not dependent on the history of the price or any other variable. The assumptions can be tested both at the market level, i.e. the group level, as well as at the individual level.

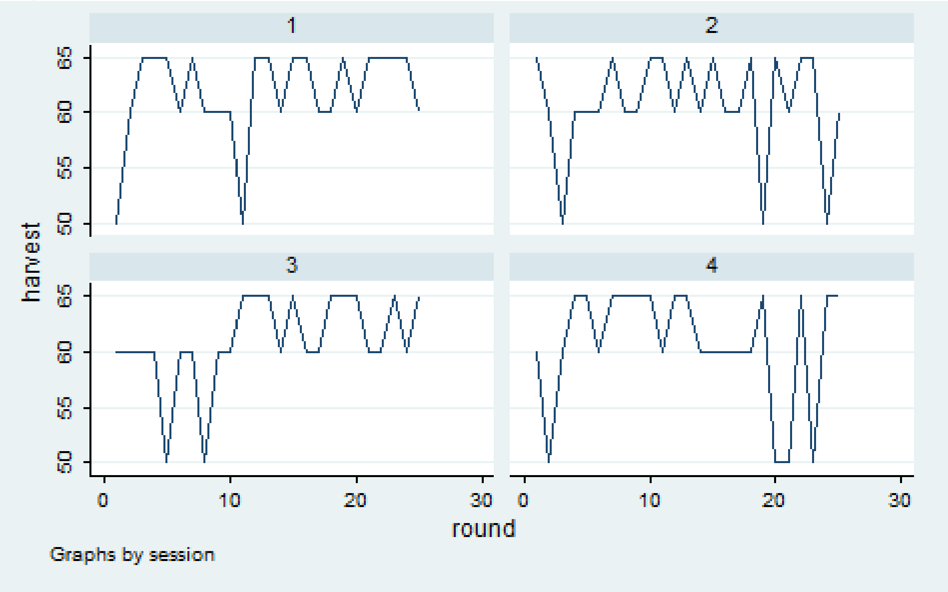
The main interest of the experiment is on how closely the experimental market matches the market outcome predicted by the competitive storage model. It would be possible for the assumptions to be well approximated at the group level by the competitive storage model without that being the case for the individual level. This would entail some agents compensating for under or over-storage behaviour by agents who depart from the optimal strategy. If the assumptions do not hold at the market level, the individual level analysis can explore how behaviour at the individual level differs from the competitive storage model. However, individual decisions are likely to be very noisy and for our purposes are mainly of interest insofar as they help to explain the market outcome.

Secondly, in the model stockholders base their storage decision on availability, the sum of the harvest outcome and the level of carry-in stocks. This means that one unit of wheat in storage has exactly the same effect on the storage decision as one unit of the harvest. However, for the optimal strategy within the experimental design set out above, the results are less clear cut than in the standard model because of the rounding up by sellers and down by buyers. Nevertheless, a comparison with the outcomes of the optimal strategy will shed light on whether any dependence on the history or any differential impact of harvest and stocks is due to the experimental design only or also due to behaviour that deviates from the optimal strategy within the experimental design.

4.5 Results

Figure 4.3 shows the random harvest outcome of the four sessions. In each session, the harvest outcome was the same for all groups. Before starting the analysis, checks were carried out for a possible framing effect of the two different versions of the instructions. In both versions the same examples were used but a different example was described in detail in the two versions. Sessions 1 and 3 described an example with a lower price submitted and sessions 2 and 4 with a higher price submitted. Sessions 3 and 4 started with the same level of the harvest – namely 60 – and thus the prices submitted can be directly compared. The average of the prices submitted in the first round of session 3 was 1.71 ECU and that of session 4 was 1.78 ECU, both higher than 1.50 ECU, the price used in the example that was a possible market price outcome with within the experiment (the other price in the example was not a possible market price but could be submitted as minimum or maximum price). The difference in the mean price of session 3 and session 4 in the first round is not statistically significant.

Figure 4.3 Harvest outcome series of the four sessions



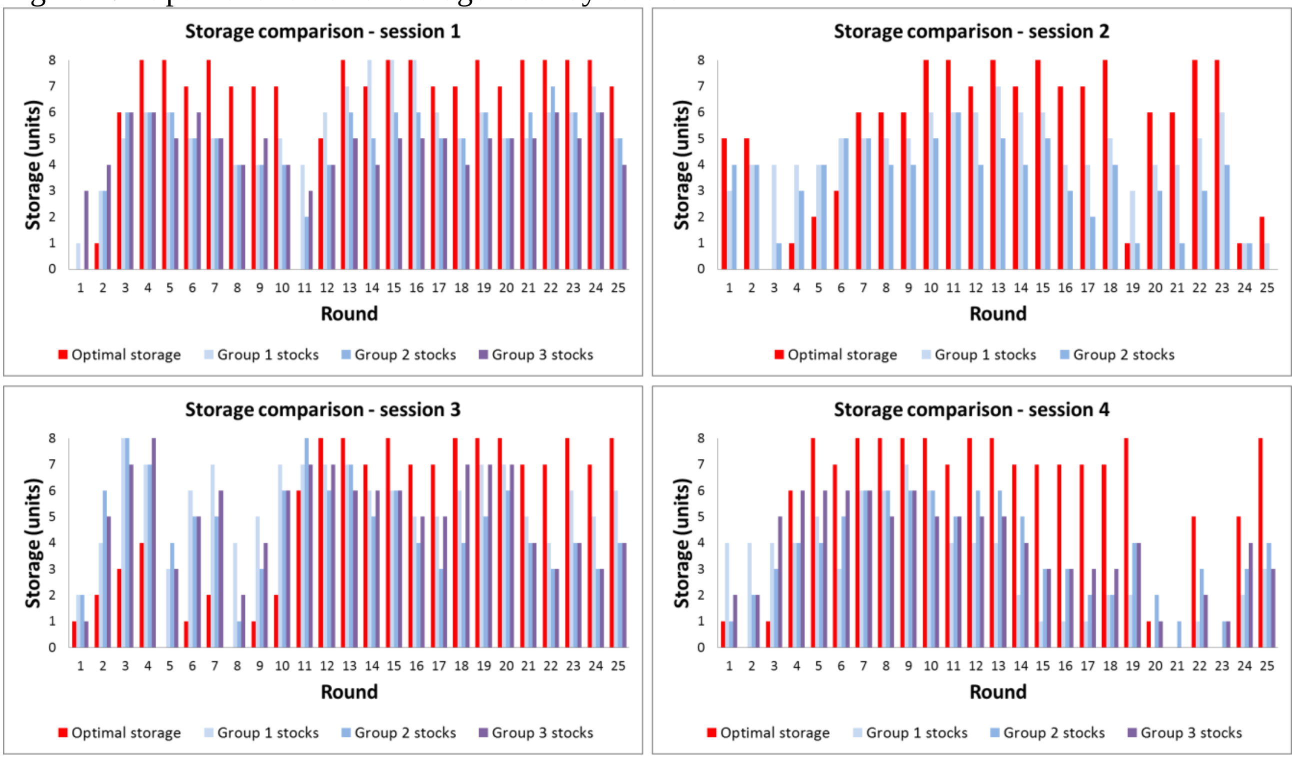
A comparison of the submitted price across all four sessions is not meaningful because the submitted prices will be influenced by the level of the harvest outcomes. A comparison of the deviation from the optimal price shows that in all sessions the average submitted prices were higher than the optimal prices. The deviation is greater for sessions 2 and 4 than for Sessions 1 and 3 but not statistically significantly so. Looking at the first two periods, the deviation is greater for Sessions 1 and 3 than for sessions 2 and 4 but not significantly so. These results suggest that there is no statistically significant effect from the examples used in the instructions.

In the experiment, participants with a unit of wheat in storage at the end of round 25 were paid the average price for this unit. Therefore, in round 25 the expected price for the next period is the average price over the last 24 rounds. This average price is close to, but not exactly the same as, the expected price assumed in the simulations. Therefore the results of the last round are not directly comparable to those of previous rounds but the effect should be small. There might also be learning effects especially at the start of the experiment. However, the main results are robust to the exclusion of the first three and last two periods. The results presented in the following are based on all 25 rounds but they do not substantially differ when the first three and last two periods are excluded.

4.5.1 Comparison of actual and optimal storage

Figure 4.4 shows the optimal storage level and the actual storage levels by the groups in each session.

Figure 4.4 Optimal and actual storage level by session



It is clear from Figure 4.4 that in general storage is below its optimal level when the optimal level is high but that it is above the optimal level when optimal storage is low. Table 4.4 compares the means and standard deviations of storage for the four sessions with the optimal mean and standard deviation. The optimal mean and standard deviations are based on the approach explained above.

In sessions 1 and 4 the mean stock levels for all groups are statistically significantly below the optimal level at the 5% significance level. In session 2 for group 2 the equality of mean is rejected at the 1% level but for group 1 the hypothesis that the mean is equal to the optimal mean cannot be rejected. In session 3, the hypothesis that the mean stock level is equal to the optimal mean stock level cannot be rejected for any of the groups. Excluding the first three (possible learning effects and effect of starting with zero storage) and the last two periods (possible end game effect) does not significantly change these results.

Table 4.4 Optimal and actual mean and standard deviation of storage (rounds 1 to 25)

	Optimal	Group 1	Group 2	Group 3
Session 1				
Mean	6.52	5.44	4.92	4.76
p-value		0.0357**	0.0042***	0.0010***
Std. Deviation	2.45	1.58	1.53	0.88
p-value		0.0184**	0.0119**	0.0000***
Session 2				
Mean	5.36	4.52	3.40	
p-value		0.0906*	0.0017***	
Std. Deviation	2.71	1.48	1.58	
p-value		0.0021***	0.0054***	
Session 3				
Mean	5.12	5.68	4.76	5.12
p-value		0.7918	0.3077	0.5000
Std. Deviation	3.07	1.46	1.79	1.81
p-value		0.0003***	0.0051***	0.0060***
Session 4				
Mean	5.60	3.04	3.72	3.80
p-value		0.0006***	0.0055***	0.0055***
Std. Deviation	3.06	2.05	1.74	1.78
p-value		0.0282**	0.0040***	0.0052***

Notes: The p-values are for the one-sided t-test that the actual mean is equal against the hypothesis that it is lower than the optimal mean and the one-sided F-test that the actual standard deviation is equal against the one-sided hypothesis that it is smaller than the optimal standard deviation. *** denote rejection at the 1% level, ** at the 5 % level.

The hypothesis that the actual standard deviation of storage is equal to the optimal standard deviation of storage is rejected at the 5 % level for all groups, including those in session 3 for which the hypothesis that the means are equal could not be rejected. Thus, the results suggest that in general stock levels are lower than would be optimal and that in all cases stock levels vary less than would be optimal. The next section looks at the impact of the storage behaviour on the price series.

4.5.2 Comparison of standard deviation of actual, optimal and no-storage price series

While for storage a comparison of actual stocks to a no storage scenario is not meaningful, for price series this comparison provides interesting insights into whether or not storage significantly reduces the variation of prices in the experiment. The expectation is that the actual price series in the experiment would lie somewhere between the price series that one would get without storage and the price series one would get with optimal storage. Because of the linear price function, the mean price will be very similar for optimal storage, no-storage and for the actual price series. The only difference in the mean price over the 25 rounds is due to the fact that storage at the end of the 25 rounds differs. If all units in storage were to be sold in the last round, the mean price would be exactly the same. The focus of the analysis is therefore on the standard deviation of the price series. Figure 4.5 shows the optimal, no-storage and actual price series of the four sessions.

Figure 4.5 Optimal, no-storage and actual price series by session

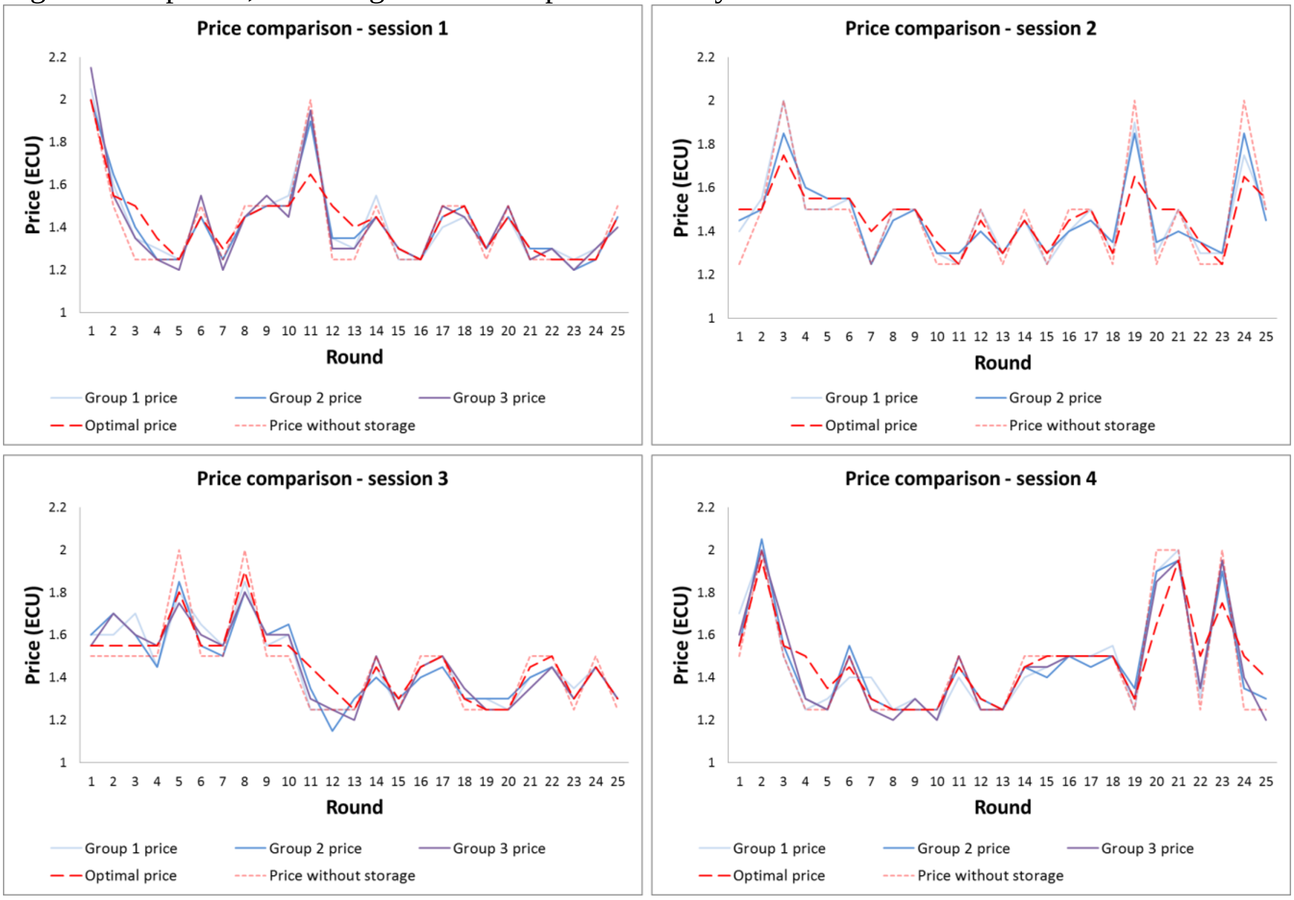


Figure 4.5 suggests that the optimal price series differs especially when prices are high. Table 4.5 reports the standard deviation of the price and the test results for the null hypothesis that the standard deviations of the actual price series are equal to those of the optimal price series against the one-sided hypothesis that the actual standard deviation is higher than the standard deviation of the optimal price series. The tests comparing the standard deviation of the actual price series with the no-storage price series test the hypothesis that the standard deviations are equal against the hypothesis that the actual standard deviation is lower than the standard deviation without storage.

As expected, the actual standard deviation of the price is above the standard deviation of the price for the optimal strategy for all groups. However, for one group (session 1, group 3), the standard deviation of the price is also higher than that of the no-storage price.

Thus, the storage behaviour of this group made the price more variable than would have been the case without any storage.

Table 4.5 shows that the only occurrence when the standard deviation of the actual series is statistically significantly below the series of no-storage (at the 10% level) is when it is also statistically significantly above the standard deviation of the optimal storage price series (at the 10% level). For three of the eleven groups the standard deviation is statistically significantly above the optimal price series. It is interesting that for session 3 the standard deviations of the price series without storage and that with optimal storage do not differ statistically significantly. It is therefore not surprising that no statistically significant results were found for the standard deviation of the actual price series as the latter is expected to lie between the optimal and no-storage benchmarks.

To conclude, in the experiment storage does not achieve the optimal reduction in the standard deviation that would be possible if participants behaved according to the competitive storage model. In ten out of the eleven groups, the standard deviation of the price series is not statistically significantly below the standard deviation of the price series that would occur without storage.

Table 4.5 Optimal, no storage and actual standard deviation of the price series (rounds 1 to 25)

	Optimal	No storage	Group 1	Group 2	Group 3
Session 1					
Standard deviation	0.1646	0.2151	0.2051	0.1942	0.2240
p-value optimal		0.0990*	0.1441	0.2124	0.0692*
p-value no storage			0.4095	0.3105	0.5784
Session 2					
Standard deviation	0.1279	0.2358	0.1927	0.1726	
p-value optimal		0.0020***	0.0249**	0.0746*	
p-value no storage			0.1646	0.0666*	
Session 3					
Standard deviation	0.1612	0.2041	0.1769	0.1742	0.1718
p-value optimal		0.1272	0.3258	0.3533	0.3787
p-value no storage			0.2446	0.2217	0.2022
Session 4					
Standard deviation	0.1926	0.2669	0.2503	0.2384	0.2465
p-value optimal		0.0585*	0.1034	0.1515	0.1170
p-value no storage			0.3776	0.2923	0.3500

Notes: The p-values are for the one-sided F-test that the actual standard deviation is equal against the hypothesis that it is higher than the optimal standard deviation and the one-sided F-test that the actual standard deviation is equal against the one-sided hypothesis that it is lower than the no storage standard deviation. *** denote rejection at the 1% level, ** at the 5 % level and * at the 10% level.

4.5.3 Decisions at the group level

The decisions by participants in each round and the random harvest outcome determine the stock level at the end of the round and the price in the round. In the competitive storage model, the stock level at the end of the round and the price in the round only depend on availability. Figure 4.6 plots the price against availability for the optimal strategy and for all sessions in the experiment. Whilst the relationship between availability and price in the experiment looks fairly linear, this is not the case for the optimal availability-price relationship which has two kinks, one at the level of availability where storing one unit becomes optimal and one at the level of availability where the maximum storage level becomes optimal. In between these two kinks the slope is much flatter.

Figure 4.6 Optimal and actual availability-price relationship

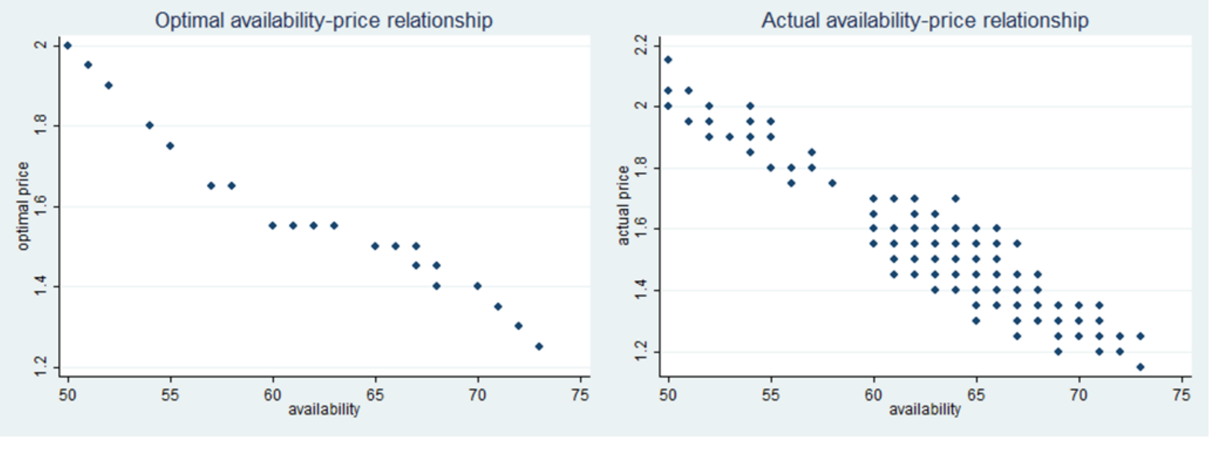
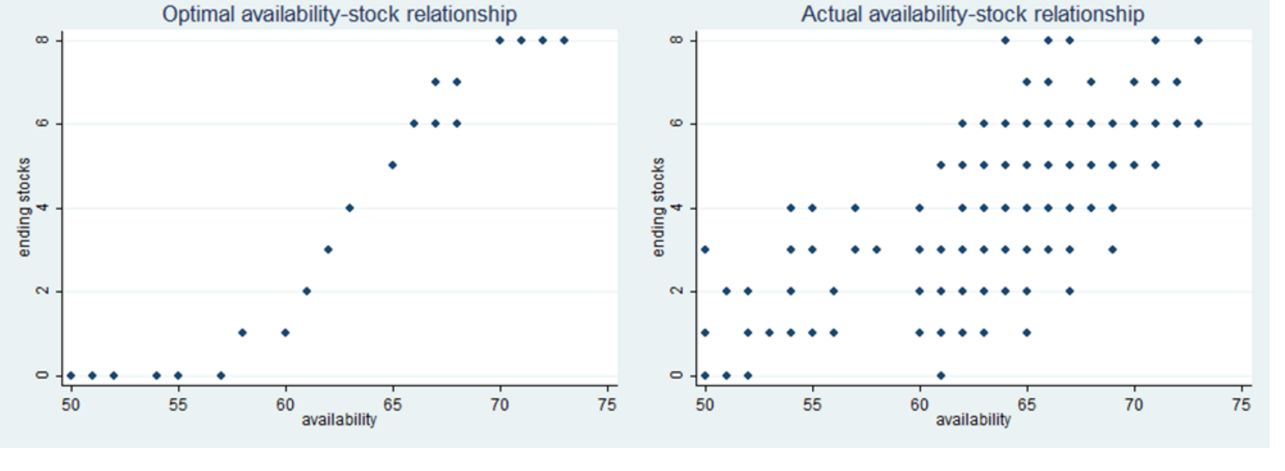


Figure 4.7 plots stocks at the end of the round against availability for the optimal behaviour and for the experiment. While optimal storage behaviour leads to left and right censoring of this relationship, this feature is not apparent in the case of the actual availability and storage relationship.

Figure 4.7 Optimal and actual availability-stock relationship



Similarly as for the availability-price relationship, while the optimal availability-storage relationship is clearly not linear, this is not obvious for the actual availability-storage relationship. Whether or not a linear model fits the availability-storage and the availability-price relationship can be tested using a Ramsey Regression Equation Specification Error Test (RESET) test (Ramsey, 1969).

Before analysing the availability-storage decision in more detail, the implications of the experimental design and the optimal strategy within the experimental design need to be investigated. Making the optimal strategy dependent on whether the participant is a buyer or a seller in that round has important implications for the availability-storage relationship. In the competitive storage model carry-in stocks and harvest have the same impact on storage. For the optimal strategy in the experiment, this is not the case, because the price submitted depends on the role of the participant.

If we have an availability of say 65, the expected price from the model solution is 1.51 ECU. The availability of 65 can either be the result of a harvest of 65 and no stocks carried forward or a harvest of 60 and 5 units of stocks carried forward. In the first case there are only buyers and in the second there are 5 sellers and 3 buyers. In the model these two scenarios are equivalent. However, for the optimal strategy within the experiment, the two scenarios are not equivalent because buyers submit a rounded-down optimal price and seller a rounded-up optimal price. In the first case all participants submit a price of 1.50 ECU but in the latter case five submit a price of 1.55 ECU and three a price of 1.50 ECU. So in the latter case stocks will tend to be higher for the same level of availability.

If sellers and buyers were both to round up or both to round down, the additional dependence on stocks would disappear and the impact of carry-in stocks and harvest would be identical. This would be in some ways preferable but it is not assumed in the analysis here because within the experimental design the suggested optimal strategy is superior in terms of expected profit. If sellers and buyers were both to round down, sellers would make a negative expected profit, which they could avoid by rounding up. If sellers and buyers were both to round up, buyers would make a negative expected profit, which they could avoid by rounding down. As a consequence of this assumption, for the optimal strategy proposed, the impact of one unit of wheat from the harvest and one unit of the carry-in stocks is not the same.

For this reason, the RESET test is based on a linear fixed effect regression[28] including both harvest and carry-in stocks and not just their sum, i.e. availability. The regression model of the test also includes squares and cubes of the fitted values to test if the linear model fits the data. The F-statistic testing that the coefficients of squares and cubes of the fitted values are jointly zero is reported together with the corresponding p-value. The test results are

[28] A fixed effects model was chosen based on the results of a Hausman test.

reported for the regression of price on carry-in stocks and harvest and that of storage on carry-in stocks and harvest. The test is carried out for all sessions together and for each session individually.

Table 4.6 shows the F-statistic and p-values for the RESET test. These results confirm that the relationships are clearly non-linear for the optimal strategy but linear in the experiment. For the actual relationships a linear model seems the appropriate specification. The only case where the RESET test does not reject the hypothesis that the squares and cubes of the fitted values are jointly zero is for the regression on price in session 3. Here the null hypothesis is rejected at the 10% level.

Table 4.6 RESET test results

	All sessions	Session 1	Session 2	Session 3	Session 4	Optimal
Dependent variable – price						
F statistic	$F_{(2,260)}$=0.98	$F_{(2,68)}$=0.91	$F_{(2,44)}$=2.40	$F_{(2,68)}$=2.90	$F_{(2,70)}$=1.31	$F_{(3,92)}$=320.25
p-value	0.3749	0.4058	0.1027	0.0616*	0.2764	0.0000***
Dependent variable – storage						
F statistic	$F_{(2,260)}$=2.26	$F_{(2,68)}$=1.99	$F_{(2,44)}$=0.02	$F_{(2,68)}$=1.18	$F_{(2,70)}$=0.98	$F_{(3,92)}$=340.59
p-value	0.1060	0.1453	0.9770	0.3135	0.3804	0.0000***

Notes: The p-values are for the F-test that testing that the coefficients of squares and cubes of the fitted values are jointly zero. *** denote rejection at the 1% level and * at the 10% level.

Thus, the market outcome, whether we look at price or storage, clearly differs from the optimal market outcome that would be possible within the experiment. In the following analysis the focus is on storage, partly because the results of the RESET test suggest that the linear model is appropriate overall and for all sessions but mainly because the experiment was framed as a storage experiment.

Regression analysis is used to explore how carry-in stocks and harvest levels influence storage and whether or not history matters. The comparison of the results with those that would occur if all participants used the optimal strategy is complicated by the fact that the model is clearly non-linear when the optimal strategy is used but that it is linear in the experiment. Thus the linear model for the optimal strategy is known to be mis-specified.

For the results of the experiment, Table 4.7, therefore, reports the coefficients of a linear fixed effects regression where storage is regressed on carry-in stocks, harvest and the lagged price. These coefficients are compared to those based on the simulated optimal strategy for two models, firstly, the same linear fixed effects regression and, secondly, a Tobit model, which is the more appropriate specification for the optimal strategy.

The coefficients for carry-in stocks are similar for the two linear models. Thus, carry-in stocks had a similar average effect on storage in the experiment as would be the case if the optimal strategy had been followed. However, while in the experiment the linear model with the constant marginal effect is the appropriate specification, this is not the case for the optimal strategy. The marginal effect in the optimal strategy is not constant. The marginal effect is zero for the censored observations and higher than the marginal effect in the linear model for the non-censored observations.

Table 4.7 Estimated coefficients in the experiment and for the optimal strategy

	Constant	Harvest	Carry-in stocks	Lagged price
Experiment				
coefficient	-11.8581***	0.1983***	0.5543***	1.2241***
t-statistic	-11.90	15.59	12.51	3.54
Optimal strategy - linear model				
coefficient	-22.9549***	0.4371***	0.5137***	-0.5961
t-statistic	-13.00	24.90	9.78	-0.66
Optimal strategy – Tobit model				
coefficient	-39.1036***	0.6644***	0. 7574***	0.3661
t-statistic	-28.30	40.14	24.69	0.75

Notes: The dependent variable is storage. The t-test statistics are reported testing that the null hypothesis that the coefficients is zero against a two-sided alternative. *** denote rejection at the 1% level and ** at the 5% level.

By contrast, the coefficient on harvest for the linear models is less than half in the experiment than that of the optimal strategy. An increase in the harvest of one unit on average only increased storage by 0.19 units; this compares with an average 0.44 unit increase if the optimal strategy is followed and an average 0.66 unit increase for the optimal strategy in the interval where storage is not censored. The coefficient on the lagged price is statistically different from zero in the linear model based on the results of the experiment but is not so in the models based on the results of the simulated optimal strategy.

In a market populated by stockholders behaving according to the competitive storage model, the decisions about storage depends exclusively on availability in the current period and the relationship between storage and availability would be non-linear due to censoring. The average sensitivity of storage to carry-in stocks is close to optimal but this average masks the underlying differences of these averages. The average sensitivity of storage to the harvest outcome is less than would be optimal and history in form of the lagged price only has a statistically significant impact in the experiment but not for the optimal strategy. The results from the experiment clearly show that actual behaviour differs markedly from the behaviour suggested by the competitive storage model.

4.5.4 Decisions at the individual level

As noted earlier, the main focus of the experiment is on the market outcome but the analysis of individual decisions might help to understand why the market outcome in the experiment deviates from the outcome of the optimal strategy based on the competitive storage model.

In the optimal strategy, the price submitted depends to some degree on the role of the participant in that round – buyer or seller. Figures 4.8 and 4.9 plot the relationship between availability and the submitted price for buyers and sellers and the optimal strategy. In the analysis of the submitted price by sellers, two outliers were removed – these were prices of 444 ECU and 777 ECU, submitted by the same subject. The market design is robust to these extreme prices. However, in the analysis of individual behaviour these extreme prices have an undue impact.

Figure 4.8 Optimal and actual availability-price relationship for buyers

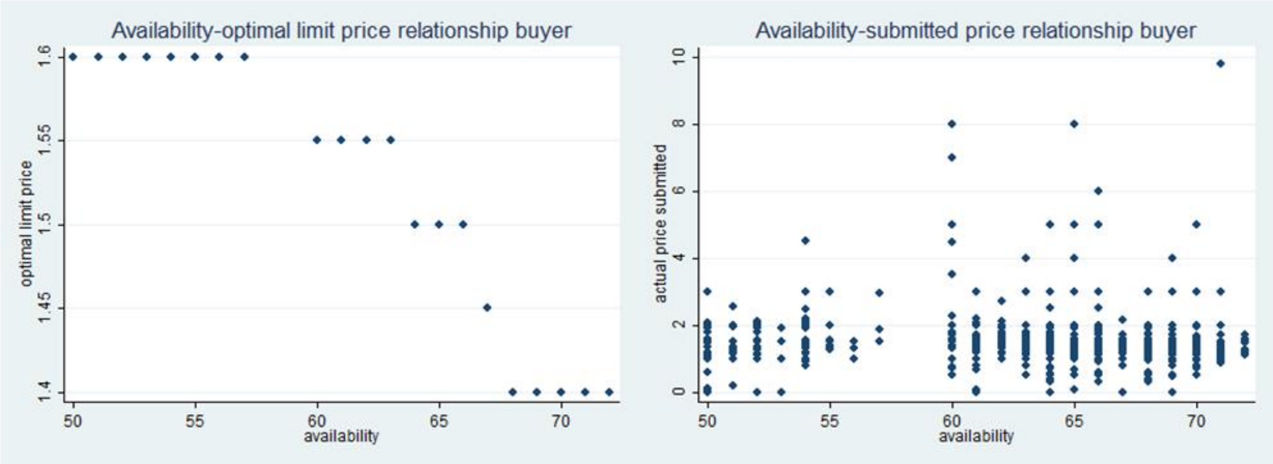
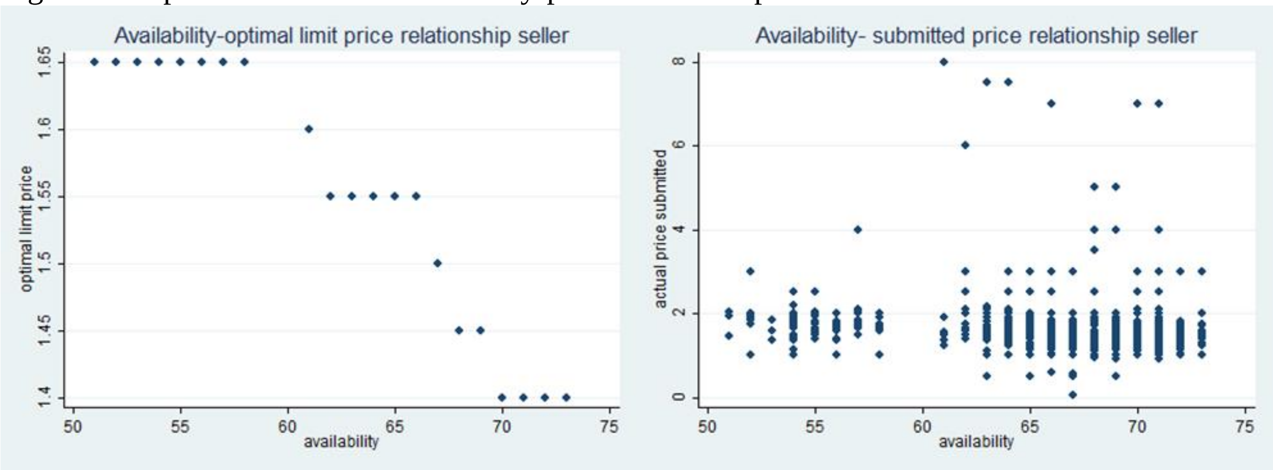


Figure 4.9 Optimal and actual availability-price relationship for sellers



It should be noted that the charts for the optimal strategy use a different scale on the y-axis than those for the experimental results. The charts show that the actual behaviour in the experiment differs greatly from the optimal strategy. It is difficult to draw any general conclusion at the level of individual behaviour, either from the charts or any further statistical analysis (see appendix B for further statistical analysis).

The fact that it is not easy to find a model to explain behaviour at the individual level is not very surprising. Firstly, individual behaviour is known to deviate from rational behaviour in many ways and different individuals diverge in different way. Secondly, the experimental design is such that any submitted price that is higher than the eventual market price in the round has exactly the same impact on the market price. So for example, since market prices of above 2.00 ECU are unlikely and above 2.40 ECU impossible, any price submitted above 2.00 ECU is likely lead to the same buy and sell outcome and thus has the same impact on the market equilibrium price as any higher price. Similarly, prices below 1.25 ECU are unlikely and below 0.85 ECU impossible, so any price submitted below 1.25 ECU leads to the same sell and buy outcome and thus has the same impact on the market price. If participants understood this, and some seem to have done, then there will be a lot of noise in the data at the individual level.

4.6 Discussion and conclusion

The main results of the experiment are that, at the market level, prices vary more than optimally because mean storage is lower than optimal and the storage level varies less than is optimal. The results are similar to those of savings experiments, which often find that participants in laboratory experiments under-save (see e.g. Brown et al., 2009 for of results from savings experiments). Savings and storage models are formally similar (Gouel, 2013). Unlike the storage experiment, though the savings experiments investigate individual decisions while the main interest of this storage experiment is at the market level. In this respect, the storage experiment is similar to multi-period asset market experiments where the main interest is also at the market level.

Participants in the storage experiment were mainly students as is the case in most experimental studies, including multi-period asset market experiments and the storage experiment on the Zambian maize market. This raises the question if such a convenience sample of student participants biases the results, especially because the set-up of the experiment, even in this simple form, is still relatively complex.

To make sure that participants had understood the main features of the experiment, the experiment was not started until all participants had answered the control questions correctly. Most participants answered the control questions correctly in a short period of time suggesting that the general features of the experiment were clear to the majority of participants. The rating of the difficulty of the experiment by the participants after the last round of the experiment was 6, on a scale from 1 (very easy) to 10 (very difficult). One participant rated the experiment 10 and five 9. Almost half rated it 7 or 8, suggesting that the experiment was somewhat difficult but not extremely so for most participants.

Without running the experiment using real world traders, the question of whether using a student population biases the results cannot be answered definitively. However, results for other experiments have shown that using student participants are similar results to those using a wider population (e.g. Andersen et al., 2010). In asset market experiments, bubbles were also found in experimental markets using participants who are experienced in real financial markets (Gerding, 2007).

The extent to which these results may generalise also depends, to some degree, on the impact of the design of the experiment on the storage level and variability. Since this is the first experiment of this kind and no comparison with other designs is possible, it is difficult to draw any firm conclusions. A number of possible impacts should be mentioned though. Participants can only buy, sell and store one unit. The optimal strategy, to which actual behaviour is compared, takes into account the fact that only changes in storage in integer steps are possible.

If some participants do not behave optimally though, the optimal strategy is no longer optimal for other participants. If some participants do not behave optimally and make lower profits, it is possible for other participants to deviate from the optimal strategy and make higher profits by doing so. As can be seen from Table 4.3 for five groups maximum earning was higher than the maximum earning of the optimal strategy.

If some participants do not behave optimally, as is clearly the case in the experiment, the design adopted in this experiment limits the response by other participants to this deviation from optimal behaviour. For example when the optimal strategy would lead to storage at the maximum level and some participants do not store anything, within the experiment the storage level will be too low. Other participants who might get to understand that generally the storage level is too low when availability is very high have no possibility to compensate by storing more. This will be the case in any design with a maximum storage capacity at the market level that is the sum of individual storage capacity limitations. It would not be the case if there was a maximum storage capacity at the market level but no individual maximum capacity limits e.g. when unused storage space could be transferred from one participant to another. In that case a participant who notices that generally storage is too low at very high availability could use his own storage capacity and that of other participants. In this way, the maximum at the market level could be reached even if some participants do not behave optimally. In the real world, storage capacity for grains is rarely (or never) exhausted. This means that in the real world storage might get closer to the optimal level when availability is large.

This is not true though for low storage levels. Storage in the experiment tends to be too high when optimal storage is very low. Without negative storage, the possibility of reacting to too much storage by some participants is limited. When optimal storage is zero and some stockholders hold positive stock levels, the other stockholders cannot compensate because of the non-negativity constraint on storage. This is true for the design adopted in this experiment, for more complex designs and for the real world. Therefore, it is possible that with more complex designs the variation in storage would increase but it is unlikely it would bring it to the optimal level as long as some participants overstore at zero or low levels of optimal storage.

The auction design in the experiment was very simple and this could also have influenced the results. Each participant was required to submit a price in each round which might actually have led to more transactions – and thus to more storage variability – than would be the case in a continuous auction design. In the real world, stockholders do not have to submit prices in each period but can just stay out of the market. In the experiment, a straightforward strategy for a seller who does not want to participate in the market was to submit a price that is impossible within the experiment. Prices that sellers could submit were not limited and any price above 2.40 ECU was impossible and thus meant that the seller would not make any transaction in that round – an outcome equivalent of not participating in a continuous double auction.

It would require a good understanding of the experiment and the design to calculate the lowest price that was impossible, however, only a vague understanding of the design was required to understand that a very high price, e.g. 10 ECU was impossible. One participant input values of 444 ECU and 777 ECU, for example. This seems to be clearly a non-sell strategy. Similarly, for buyers, any price below 0.85 ECU is impossible and though that threshold might not have been calculated or understood by participants, every buyer should have understood that submitting a price of 0 ECU will be equivalent to staying out of the market in this round. It is possible that the fact that participants had to submit a price led to more transactions, and thus more variability, than in a design, such as a continuous auction design, where participants have a more straightforward choice not to participate in the auction i.e. not to submit a price. A continuous auction design without limits to individual storage could be used in future experiments and then compared to the results of the simple design to assess the size of the impact of the design on storage variability.

The competitive storage model, used as benchmark in this study, assumes that stockholders are risk-neutral. However, experiments have shown that in general participants in laboratory experiments are not risk neutral (e.g. Harrison and Rutström, 2008; Holt and Laury, 2002). In other models isoelastic utility functions of the form $U(c) = \frac{c^{1-\rho}}{1-\rho}$ are often used which have the characteristic of constant relative risk aversion. Holt and Laury (2002) give ranges for the coefficient ρ for risk loving, risk neutral and risk averse agents. They suggest slightly risk averse agents have ρ between 0.15 and 0.41, risk average agents between 0.41 and 0.68 and very risk averse agents between 0.68 and 0.97. The derivation of the solution to the competitive storage model using constant relative risk aversion is complicated. Including constant absolute risk aversion is slightly less complex but still complicates the results significantly. Empirical and experimental studies tend to be more supportive of the constant relative risk aversion assumption than the constant absolute risk aversion assumption (e.g. Chiappori and Paiella, 2001; Levy, 1994; Szpiro, 1986). Hence, a benchmark with constant absolute risk attitude might not provide a much better benchmark than a benchmark with risk-neutral agents.

Risk averse stockholders will store less than the risk-neutral ones. Risk-aversion therefore is a possible explanation why mean storage is below the optimal. However, there are three factors that suggest that the impact of risk-aversion is probably small. Firstly, the stakes in this experiment were relatively small and risk aversion is generally smaller with small stakes (Holt and Laury, 2002). Secondly, the benchmark optimal strategy is already mildly risk averse because buyers round-down and sellers round-up the optimal price. Thirdly, risk averse participants had a simple strategy within the experiment – never buy and walk away with the initial endowment of 10 ECU. This simple strategy is to input a price of 0 in each round. This is an obvious simple strategy and requires only a minimal understanding of the experiment. None of the 88 participants followed this strategy. Only 2 participants out of the 88 never stored and they did not obviously follow a "no buy" strategy. The prices they submitted were not sufficiently low to guarantee that they would not buy and they varied the prices throughout the experiment. However, an improvement on the benchmark, or at least the elicitation of the level of risk aversion in future experiments, would be desirable.

Similarly, a more detailed analysis of the impact of the relatively small possible gains from storing would shed light on the robustness of the results. The small earning potential is in line with the model which assumes that profits should be eliminated if storage is below its maximum level. The fact that only two participants never traded suggests that the small differences in earnings might not have had a substantial detrimental effect on the trading incentives. Possibly participants understood that, though they do not make large profits by storing if others also store, they could make more substantial if others do not store at high availabilities. The experimental design could be adjusted to investigate if the size of the profit opportunities that exist within the optimal strategy changes storing behaviour.

Further research is needed to assess the robustness of these results with regard to a number of other characteristics of the experiment. The robustness to different harvest distributions is one obvious line of research. Different distributions might mean more or less diversion from optimal strategies. Different crops vary in the size of the yield variance and with more or less variance in the harvest shocks results might differ. Also, although, the three point distribution has the advantage of being simple and easily communicable to participants, it is not very realistic and results might or might not be robust to more complicated harvest distributions.

The inclusion of storage cost and discounting is another obvious future research area. With storage costs risk aversion of the participants might have a larger impact. It would be interesting to see if more participants opted for the obvious risk-averse strategy of never buying.

Eventually, the most interesting extension will be to assess the impact of market interventions on storage levels. The fact that average storage is below its optimal level and storage does not vary as much as would be optimal does not necessarily mean that market interventions would improve the outcome. Experiments including market interventions aimed at bringing storage closer to the optimal level would be required to check on their effectiveness.

To conclude, the results of the experiment show that within the experimental setting mean storage and the standard deviation of storage are below their optimal level leading to price series that vary more than is optimal. Whether or not any policy intervention could bring storage closer to the optimal level was not investigated in this study. Also, the robustness of the results in more realistic and complex settings will have to be investigated in future experiments before drawing any general conclusions from this experiment.

Appendix A Instructions, control questions and final questionnaire

Instructions

Dear participant,

We thank you for having decided to participate in this experiment. From now on, we kindly ask you not to speak to the other participants. Please read these instructions carefully. If you want to ask a question, please raise your hand. An experimenter will come to you and answer your question privately.

Rounds, groups and your role

The experiment extends over 25 rounds. Before the first round, you are randomly matched with 7 more participants and together you form a group of 8. The composition of the group will be the same in all 25 rounds, that is the other 7 members of the group are always the same. Their identity will not be disclosed to you and your identity will not be disclosed to the others in your group. The 8 participants of each group participate in one market. All participants have the role of traders who can buy wheat in order to store it and then sell it in subsequent rounds. The experiment will only start after all participants have correctly answered a number of control questions.

Harvest and price function

There is one wheat harvest in each round. The harvest is subject to weather shocks. If the weather is bad the harvest is 50 units, if the weather is average the harvest is 60 units and if the weather is good the harvest is 65 units. In each round, the probability that the harvest is 50 units is 20 per cent, that it is 60 units is 40 per cent and that it is 65 units is 40 per cent. The harvests are independent that is the harvest this round is not influenced by what happened in previous and by what will happen in future rounds.
All units of the harvest are used. The usage can be consumption or storage.
The following function characterises the relationship between price and consumption:

price = 4.5 – 0.05* units consumed

At your desk, you will find a table with different levels of consumption and the prices that results from that level of consumption on the basis of the price function.

Storage

You and all other members of your group can decide to store wheat. Wheat can only be bought, sold and stored in full units. Each of you has a storage capacity of one unit of wheat. Through storage you can move one unit of wheat from one round to another. At the start of the experiment each participants has 0 units of storage and is given an endowment of 10 Experimental Currency Units (ECU; 1 ECU = 1 euro) that can be used to buy units of wheat. Your aim is to make as high a profit as possible by buying and selling wheat. Profits can be made when a unit of wheat is bought at a low price and sold at a higher price. Losses occur when a unit of wheat is sold at a price lower than the purchase price.

Interactions in each round

At the beginning of each round you will be told how many units are harvested (50, 60 or 65), the total number of units of wheat that were stored from the previous period into this period by all group members (minimum 0, maximum 8) and how many ECU you have available. You will also be told about the role in the round, that is if you are a potential buyer or a potential seller. Because you only have a capacity of storage of one unit and units of wheat can only be bought, sold and stored in full units, in each round you will either be a potential buyer or a potential seller of wheat in that round.

If you have a unit of wheat in storage, you are automatically a seller in this round and will be asked to submit the minimum price for which you want to sell the unit of wheat you have in storage (in steps of 0.05 ECU).

a) If the market price in the round is above the minimum price you submitted, your unit will be sold at the market price.

b) If the market price is exactly the same as the price you have submitted your unit might be sold or not.

c) If the market price is below the minimum price you submitted, your unit will not be sold.

If you do not have a unit of wheat in storage at the beginning of the round, you are automatically a buyer in this round and will be asked to submit the maximum price up to which you want to buy a unit of wheat to store until the next round (in steps of 0.05 ECU). You cannot submit a maximum price higher than what is left of your endowment.

a) If the market price in the round is below the maximum price you submitted, you will buy a unit of wheat for the market price.

b) If the market price is exactly the same as the price you have submitted you might buy the unit or not.

c) If the market price is above the maximum price you submitted, you will not buy a unit of wheat.

In each round, wheat not stored will be consumed according to the price function:

market price = 4.5 – 0.05* units consumed

Following the determination of the market price in each round (the following section explains the price mechanism), the units in storage are adjusted and payments are made. Sellers receive the price for the unit they sold and buyers have to pay the price for the unit they bought.
At the end of each round, you will be informed about the market price in the round, your new level of storage, the payment you made/received and how many ECU you have available after the transactions. The storage level at the end of one round is the storage level at the start of the next round.

The market price mechanism

Given the harvest, storage at the beginning of the round and the prices submitted by participants, there is always exactly one market equilibrium price. The price mechanism is illustrated using three scenarios with only two participants. In all three scenarios, one participant starts with one unit in storage (the seller) and one starts with zero units in storage (the buyer). The declared prices in the example are chosen for illustrative purposes only and should not be taken in any way as reference for the experiment. One example scenario is described in detail. Because the mechanism is always the same, for the other two only the numbers are given.

Scenario 1:

Harvest: 60 units
Storage at start: 1 unit
Declared minimum price Seller: 3.00 ECU
Declared maximum price Buyer: 1.50 ECU

In equilibrium:
Market price: 1.50 ECU
Consumption: 60 units
Storage at end: 1 unit

At 1.50 ECU, the seller does not sell because the market price is below the seller's declared minimum price of 3.00 ECU. The buyer might buy or not because the market price is the same as the buyer's declared maximum price. Thus, either 1 or 2 of the 61 available units are used for storage to the next round. The seller definitely continues to hold his unit. If the buyer buys a unit, 2 units are used for storage (one stored by the seller and one stored by the buyer) and the remaining 59 units are used for consumption. Using the price function, with consumption at 59, the price would be 1.55 ECU (4.5 – 0.05*59 = 1.55). If the buyer does not buy a unit, 1 unit is used for storage (the one of the seller) and 60 units for

consumption. Using the price function, with consumption at 60, the price is 1.50 ECU (4.5 – 0.05*60 = 1.50). At 1.50 ECU therefore, the market is in equilibrium.
Any other price will not lead to an equilibrium. Take for example 1.55 ECU, the seller does not sell and the buyer does not buy, leading to 1 unit used for storage and 60 units for consumption. With consumption of 60 units, the price is 1.50 ECU and not 1.55 ECU. At 1.55 ECU, therefore, there is no equilibrium. Similarly, at a price of 1.45 ECU, the seller does not sell and the buyer buys, leading to 2 units used for storage and 59 units for consumption. With consumption of 59 units, the price is 1.55 ECU and not 1.45 ECU. At 1.55 ECU, therefore, there is no equilibrium.

Scenario 2:

Harvest: 60 units
Storage at start: 1 units
Declared minimum price seller: 3.00 ECU
Declared maximum price buyer: 3.00 ECU

In equilibrium:
Market price: 1.55 ECU
Consumption: 59 units
Storage at end: 2 units

Scenario 3:

Harvest: 50 units
Storage at start: 1 units
Declared minimum price seller: 3.00 ECU
Declared maximum price buyer: 3.00 ECU

In equilibrium:
Market price: 2.00 ECU
Consumption: 50 units
Storage at end: 1 unit

Payment

You will be paid 3.00 euro for having shown up on time and having participated.
In addition, you will be paid the amount that you have available at the last round in ECU. This amount will depend on the transactions you have made during the 25 rounds. To be more precise, you will be paid the initial endowment plus any profit you make from buying and selling units of wheat on the market or minus any loss you make. Those participants with a unit of wheat left in storage after round 25 will receive the average price over the 25 rounds for the unit of wheat in storage.

Control questions

1) How many participants form one group?
   a) 7
   b) 8
   c) 10
2) How many rounds are there in the experiment?
   a) 25
   b) 35
   c) 40
3) How much does the price change if one more unit of wheat is left for consumption by consumers?
   a) 0.01 ECU
   b) 0.05 ECU
   c) 0.10 ECU
4) The price in each round depends on
   a) Only the harvest
   b) Only the prices submitted by participants
   c) Both the harvest and the prices submitted by participants
5) One elements of your payment is the initial endowment plus
   a) the profit you made in the round randomly chosen at the end of the experiment
   b) profits and minus losses over the 25 round
   c) the profit you made in the last round
6) Your initial endowment is
   a) 0.05 ECU
   b) 2.00 ECU
   c) 10.00 ECU

Final questionnaire

1) Sex: □ female □ male

2) What year were you born in?

3) At which faculty are you studying?

□ Economics and Management
□ Law
□ Engineering
□ Humanities
□ Cognitive Sciences and Psychology
□ Sociology
□ Mathematics and Natural Sciences
□ Other
□ Not a student

4) How difficult did you find the experiment (1 very easy to 10 very difficult)?

5) How interesting did you find the experiment (1 very boring to 10 very interesting)?

Appendix B Statistical analysis of individual decisions

Table 4.I compares the mean of the optimal and actual prices submitted by session. From the session 1 dataset, the two outliers (444 and 777) were removed before calculating the mean price.

Table 4.I Mean price by session and role

Session 1				Session 2			
Optimal		Actual		Optimal		Actual	
Buyer	Seller	Buyer	Seller	Buyer	Seller	Buyer	Seller
1.473	1.472	1.572	1.639	1.494	1.516	1.513	1.477
Session 3				Session 4			
Optimal		Actual		Optimal		Actual	
Buyer	Seller	Buyer	Seller	Buyer	Seller	Buyer	Seller
1.489	1.496	1.505	1.689	1.507	1.488	1.360	1.595

The difference between the mean of the price submitted is larger than optimal in sessions 1, 3 and 4. In session 2, surprisingly, the mean of the prices submitted by buyers is higher than that by sellers.

It is difficult to find any pattern in the individual behaviour. RESET tests for any various specifications of a linear model suggest that the models are mis-specified, not just for the optimal strategy but also for the outcomes from the experiment. A better specification could not be found though. Therefore, Table 4.II shows the coefficients of regressions on the actual prices submitted and that for the optimal strategy similar to the analysis at the group level but with additionally controlling for carry-in stocks i.e. for whether the participant was a buyer or seller. As for the analysis the group level, a Hausman test suggests the use of a fixed effects model.

Table 4.II Estimated coefficients in the experiment and for the optimal strategy

	Constant	Group stocks	Harvest	Lagged price	Carry-in stocks
Experiment					
coefficient	1.589***	0.020*	-0.010***	0.315***	0.088***
t-statistic	6.82	1.78	-3.52	3.90	2.72
Optimal strategy - linear model					
coefficient	2.424***	-0.013***	-0.015***	0.004	0.033***
t-statistic	204.57	-23.02	-97.33	1.04	19.99
Optimal strategy – Tobit model					
coefficient	2.676***	-0.017***	-0.019***	0.012**	0.052***
t-statistic	135.51	-22.06	-68.51	2.09	21.28

Notes: The t-test statistics are reported testing that the null hypothesis that the coefficient is zero against a two-sided alternative. *** denote rejection at the 1% level and ** at the 5% level.

The coefficients on harvest are fairly similar but the coefficients for group stocks in the experiment and the optimal strategy differ markedly. While it would be optimal to decrease the price submitted with an increase in group stocks in the experiment an increase in group stocks leads to an increase in the price submitted, although the coefficient is only significant at the 10% level. The lagged price has a much larger impact in the experiment suggesting that history plays a role in the storage decision.

The use of fixed effects models precludes the analysis of the impact of participant characteristics because these do not vary over the experiment. If one, nevertheless, uses a random effects model, none of the characteristics from the final questionnaire (age, gender, faculty, how difficulty the participant found the experiment, how interesting the participant found the experiment), had any predictive power. Similarly, in a regression using average values over the 25 periods for each participant none of the coefficients for the participant characteristics is statistically significant at the 5% or 10% significance level.

5 Conclusions and Further Research

5.1 Summary of findings and conclusions

Discussions on recent agricultural price spikes have focused on financialisation, China, stockholding and biofuels. Three of these factors, namely financialisation, China and stockholding have been examined in this thesis. Different approaches were taken to analyse these factors. Econometric analysis is employed to analyse the potential price impact of index investment on agricultural commodity future prices in the period from 2006 to 2011. The role of changes in the Chinese stockholding and self-sufficiency policies on global prices was analysed with the help of the competitive storage model, a rational expectations model that is solved using numerical methods. Stockholding behaviour and its impacts on price formation was examined through a laboratory experiment.

Following the introduction, which sets out the context and motivation of this thesis, the second chapter used Granger-causality methods to assess whether index investors positions influence agricultural futures prices. The analysis builds on the results in Sanders and Irwin (2011a). The analysis in chapter 2 supports the conclusion that no Granger-causal impacts are detectable in the more liquid grains markets which were the focus in Sanders and Irwin (2011a). Extending the analysis to less liquid markets, Granger-causality was detected in the less liquid soybean oil and livestock markets. The clear evidence that index investment influenced the level of grains and livestock prices in illiquid markets over the five years from 2006 to 2011 led to the conjecture that index investment does also have price impact in liquid markets but that market efficiency prevents the detection of this impact using Granger-causality tests.

Chapter 3 explores the potential impacts of changes in Chinese stockholding and self-sufficiency policies on world wheat prices. Changes of grains policies in the Chinese market are transmitted to the world market through changing trade patterns. The results of the model employed in chapter 3 show that a move away from autarky reduces stock levels in China and in the rest of the world resulting in lower global stock levels. These results are in line with changes in stockholding observed over the last decade. In the two scenarios where China imports but does not export global stocks decline by 23 and 32 per cent, respectively, compared to autarky. In the two free trade scenarios, global stocks reduce by 38 and 44 per cent, respectively, compared to autarky. These reductions in stock levels when a country moves from autarky to trading with the rest of the world do not lead to an increase in price variation and, more importantly for policy-makers, do not lead to increases in extreme price movements. In the free trade scenarios, extreme price movements are even reduced despite much lower stock levels. These results indicate that changes in Chinese stockholding policy are unlikely to have played a substantial role in recent price movements.

In chapter 4, stockholding behaviour and its price impact were studied in a laboratory experiment. Although experiments on the formally similar optimal savings models have been carried out since the 1980s at least, the approach is novel with regards to the competitive storage model. For this reason, a relatively simple storage model was taken to the experimental laboratory. Participants' behaviour in the experiment deviated from the behaviour predicted by the competitive storage model in a number of ways. The predicted relationship between the amount of wheat available and storage is non-linear in the model but is linear in the experiment. In addition, storage is more sensitive to wheat carried forward from the previous period than wheat harvested while the model suggests that the effect of wheat in storage and wheat from harvest should be the same. Furthermore, average storage tends below the optimal level and storage does not vary as much as predicted by the competitive storage model. The resulting price series tend to be more variable than would be the case if stockholders behaved according to the competitive storage model. However, at this stage it is difficult to draw any general conclusions about the impact of stocks on prices other than that further research could improve our understanding of storage behaviour and its price impact.

5.2 Further research and policy implications

The results of the Granger-causality tests in less liquid markets indicate that the lack of evidence of Granger-causal effects might be mainly due to the limitations of the Granger-causality methodology in the context of relatively liquid futures markets rather than to the lack of such impacts (see also Grosche, 2014). To check this conclusion, an investigation of Granger-causal links in European markets could be instructive. Positions data on a number of European agricultural commodity futures contracts are now available and the analysis could be extended to those markets.

Building on the chapter 2 results, in the substantially revised analysis we test for Granger-causal impacts from CIT positions to price indices across the range of commodities and include contemporaneous tests based on an instrumental variable approach (Gilbert and Pfuderer, 2014a). Granger-non-causality is emphatically rejected for a number of non-agricultural indices leading to the conjecture that the relationship between index investment positions and commodity prices is informational and not causal. The contemporaneous tests provide strong evidence for causal impact of index investor positions on prices in the soybean complex and also on KCBT wheat. In contrast to Granger-causality-based literature, which does not find any impact of a price impact of index investment, our results show that index investment impacted prices in the period from 2006 to 2011. Our results, Tang and Xiong (2012) and Grosche (2014) indicate that academic consensus that there is no evidence of price impact from index investment is too simple. This conclusion is important in the context of the current policy discussion about futures market regulation.

Results obtained subsequently and reported in Gilbert and Pfuderer (2014a) are suggestive of a possible mechanism behind the price impact. If index investors are not solely seeking portfolio diversification but are also driven in their investment by information (or more generally beliefs) about or perceptions of future returns of commodities, it is this information that ultimately drives index investment and also commodity prices. One possible explanation for the price impact of index investment found in the non-agricultural markets and in the soybean complex would be that index investment is in part driven by growth expectations in China, a large player on the non-agricultural markets and on the soybean market but less so for maize and wheat. If, over the sample period, index investment was, at least in part, driven by expectations of strong growth in China and if these expectations were, at least in part correct, one would expect to find a Granger-causal impact in the tests. In this case, the link would be informational rather a direct causal link.

As mentioned above and discussed in detail by Grosche (2014), Granger-causality tests do not allow any inference about a direct causal impact of index investment on prices. Therefore, econometric approaches need to be supplemented by other approaches that explore the mechanisms behind the price impact. Possibly the most promising approach in this respect is agent-based modelling. Unlike Granger-causality tests, agent-based approaches simulating markets with heterogeneous agents, including index investors with different strategies, could shed light on the nature of the mechanism through which index investment impacts prices.

Furthermore, combining research on financial markets with approaches to model fundamental markets would be a challenging but possible fruitful avenue to explore. Vercammen and Doroudian (2014) incorporate index investors into a competitive storage model with rational grain stockholders and investors that follow a diversification strategy for their financial investments.

The results of chapter 3 indicate that if changes in China’s stock holding policies are accompanied by greater integration of China into the world market, these changes would be unlikely to increase price volatility on global wheat market and would be unlikely to exacerbate extreme price movements. For the main grains and oilseeds elasticities are similar and thus the results can be expected to be similar to those using wheat market elasticities and yield variations. The unbalanced market results, therefore, are indicative of the impact of China on the soybean market, where China has been a structural importer for over a decade. The model shows that a structural importer coming onto the world market leads to a small increase in the price level but does not increase the variation of the price. Nevertheless, further research is required in order to draw robust conclusions for other agricultural commodities. The effect depends to some degree on supply and demand elasticities, yield variation and the relative size of the Chinese market compared to the rest of the world.

The competitive storage model in this analysis makes strong assumptions about the behaviour of stockholders. One of the problems with testing the competitive storage model predictions for the grains markets is that information on grain stock levels is subject to large errors (e.g. Bobenrieth et al., 2012). With the exception of a few countries, such as the United States and European Union countries, stocks are often not measured but calculated as the residual once other elements of supply and demand have been estimated (AMIS, 2011). The lack of accurate stocks data is particularly acute for China as shown by the 2001 revisions of grain stock estimates (Wiggins and Keats, 2010). This lack of reliable data on stockholding currently hinders the analysis of the stocks-price relationship using real world data.

The importance of better information has been recognised by policy-makers. In 2011, the Agricultural Market Information System (AMIS) was set up at the request by G20 Agricultural Ministers to improve food market transparency. The aims of AMIS include capacity building for improved statistical information with respect to grain markets, including improved statistical information on stockholding, and improved dissemination of available information. However, it will take some years before reliable grain stock data will become available. In the meantime, information on price volatility in the wheat and soybean markets provide some support for the results presented in chapter 3.

Data on price volatility changes between 2000 and 2011 provide support for the conclusion that lower Chinese stocks and integration of China into the world market do not lead to increased price variation. Over the period between 2000 and 2011 China continuously increased imports of soybeans and has become a structural importer of soybeans (see Figure 3.3). Over the same period China occasionally imported and occasionally exported relatively small amounts of wheat (see Figure 3.2). A comparison of world price volatilities over the periods from 2000 to 2006 and from 2007 to 2011 shows that the volatility of the soybean world prices remained constant while volatility of the wheat world price was significantly higher over the period from 2007 to 2011 compared to the period between 2000 and 2006 (Gilbert and Pfuderer, 2014b).

The chapter 4 results of the experiment on stockholding show that the experimental approach can provide important new insights into stockholding behaviour in competitive markets. This first experiment on the competitive storage model shows that in the laboratory average storage was below the optimal level and that storage does not vary as much as predicted by the competitive storage model. Further research needs to explore the main reasons for the deviation between the model predictions and experimental results.

On the one hand, the difference between the experimental and the competitive storage model results may be due to the fact that the behaviour in the experiment does not characterise actual behaviour while the competitive storage model does. There are a number of reasons why this simple experiment might not replicate actual behaviour on agricultural markets. Firstly, the auction design was very simple which might have influenced the results. Secondly, limiting participants to one unit of storage capacity and trading only full units might also have impacted the results because it does not allow participants to compensate for non-optimal behaviour by other members of their group. Thirdly, the behaviour of students might deviate from the behaviour of actual stockholders in the grains markets. Further experimental research can explore if these limitations of the experiment can explain the deviation from the model predictions. Experiments using a continuous double auction design can explore the impact of the simple auction design. More complex design with regards to storage limits and quantities stored can provide insights of the effect of the simple design. Finally, storage experiments with grain traders as participants can check for any impact of having mainly student participants in the experiment.

On the other hand, the deviation between the experimental and the competitive storage model results might be due to the fact that the behavioural assumptions made by the competitive storage model do to characterise storage behaviour. Given that the competitive storage model has been the main workhorse of the stocks-price relationship, this would mean that different approaches to modelling and analysing the stocks-price relationship are required in order to improve our understanding of the impact of storage behaviour on price formation in grains markets. One direction for research would be to investigate how storage behaviour changes if participants do not have full knowledge of the harvest distribution and/or the storage level. Ultimately, for policy-makers the most interesting results would be those that assess the effectiveness of policy intervention on storage and price formation.

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