

Chapter 2

Main Challenges of Price Volatility in Agricultural Commodity Markets

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Abstract Prices of agricultural commodities undergoing rapid adjustments were in the spotlight following the “food crises” in late 2007 and early 2008, and again more recently in summer and fall of 2010, raising concerns about increased price volatility, whether temporal or structural. Although price volatility is a normal feature of markets given the seasonal production cycle and discontinuity of supply in the face of a continuing demand, a greater uncertainty of a rapidly changing economic and natural environment contributes to and magnifies its occurrence. This chapter focuses on the main challenges of price volatility in agricultural commodity markets. We start by briefly touching upon the theoretical aspects of volatility, followed by a comparison of international and European markets to identify whether one was more affected than the other by increases in price volatility. Factors, implications and preliminary policy considerations of increased volatility follow before initial conclusions on future prospects are drawn.

2.1 A Primer on Theoretical Aspects of Volatility

Volatility provides a measure of the possible variation or movement in a particular economic variable. Prices change as rapid adjustments to market circumstances. Wide price movements over a short period of time typify the term “high volatility”. What constitutes a volatile market or an “excess volatility” can be subjective, sector and commodity-specific.

Two measures of volatility are used:

Historical (realised) volatility, indicating a volatility of an asset in the past, is based on observed (realised) movements of price over an historical period. It represents past price movements and reflects the resolution of supply and demand factors.

Disclaimer: The views expressed in this chapter are those of the author and should not be attributed to her affiliated institution.

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Implicit volatility,¹ is the markets' view on how volatile an asset will be in the future. It represents the market's expectation of how much the price of a commodity is likely to move and tends to be more responsive to current market conditions.

This chapter discusses historical volatility and does not refer to implicit volatility. However, historical volatility can also serve as an indicator of the possible price changes of the assets in the future. Assets – including commodities – that have high volatility are likely to undergo larger and more frequent price changes in the future, possibly attracting market participants benefiting from frequent price changes. A casual link between volatility and uncertainty is not clearly defined: volatility thrives in the environment of uncertainty, and volatile prices themselves contribute to uncertainty for producers, processors and consumers.

A variety of measures is used to detect historical volatility, some of which are referred to in the next section.

First Challenge of Volatility: Choice of Data for Analysis: Which Type, Frequency?

Choice of representative prices to analyse price volatility and their frequency is of crucial importance. Data with higher frequency exhibit higher volatility. Volatility decreases with decreasing frequency. Cash (spot) prices, such as CIF (cost, insurance, freight), can bring additional uncertainties to the analysis since transport prices alone are very variable, influencing the result. FOB (free on board) prices are better candidates.

Commodity exchanges provide a steady stream of daily settlement prices making them ideal for analysis. However, futures markets do not exist or are not used for all commodities. In addition, some contracts, such as the wheat contract on the Chicago Board of Trade, suffer from lack of convergence between cash and future prices.

2.2 Analysis: Is There More Volatility Now?

This section looks at spot and future prices using two different approaches to determine whether the amount of volatility on agricultural commodity markets has increased.² Differences in price volatility on EU and world markets are also discussed.

¹This is calculated from the Black–Scholes formula for the price of a European call option on a stock.

²*Volatility* and *variation* are used interchangeably in this chapter.

2.2.1 Spot Prices: An Intuitive Approach

For the “intuitive approach”-based deviations from a trend in prices, monthly price series from January 1997 to October 2010 on the EU and world agricultural commodity markets are analysed to determine whether:

1. World markets experienced higher price variation than EU markets, or
2. Price variation on international and EU commodity markets increased over time.

EU data were taken from Agriview’s EU market prices³ for representative products, and international commodity prices from international benchmarks from the World Bank or FAO (Food and Agriculture Organization). Some commodities might not be directly comparable in terms of quality and in some cases price data were not available on both world and the EU markets. Data and sources are described in Appendix 1. As discussed in the first challenge, monthly frequency can hide more serious volatility issues by averaging daily data. In addition, international reference prices for soybeans and soybean meal are CIF and thus include freight cost.

Two indicators are calculated:

1. A percentage of price observations lying outside the 20% tunnel around the price trend line. Using this method, observations just slightly over the trend line are counted the same way as peaks.
2. A coefficient of variation as a ratio of standard deviation over mean as a measure of dispersion of data points. The higher the coefficient of variation, the larger the dispersion of series and the higher the price volatility.

Tables 2.1 and 2.2 summarise the results for relatively comparable products. Table 2.1 shows percentage of observations lying outside the 20% tunnel around the trend line. Table 2.2 shows coefficient of variations.

Table 2.1 shows that over the studied period from January 1997 to October 2010, the percentage of observations outside the 20% tunnel was higher on the world markets than on the EU markets (with the exception of chicken). However, differences are noticeable in the cases of butter and Skim Milk Powder (SMP) where the percentage of observations outside the 20% tunnel was significantly higher on the world markets than in the EU (70+% compared to 20–30%). Dividing the data into two equally sized intervals (January 1997–November 2003 and December 2003–October 2010), we note that the percentage of observations outside the 20% tunnel on the world market exceeded the percentage of observations outside the 20% tunnel on the EU market for barley, wheat, maize, butter, SMP and beef during the first time period. During the second time period, from December 2003 to October 2010 which also included the periods of price hikes, we note that the absolute percentage

³<http://www.agriview.com/>

Table 2.1 Twenty percent tunnel, comparable products

20% tunnel	World prices			EU prices		
Commodity	01/97–10/10 (%)	01/97–11/03 (%)	12/03–10/10 (%)	01/97–10/10 (%)	01/97–11/03 (%)	12/03–10/10 (%)
Barley	66.87	55.42	78.31	57.93	28.40	86.75
Wheat (Int. SRW, EU bread)	72.89	75.90	69.88	54.88	28.40	80.72
Maize	62.05	67.47	56.63	48.78	19.75	77.11
Butter	80.00	85.54	74.39	25.30	0	50.60
SMP	72.29	79.52	65.06	28.92	16.87	40.96
Chicken	10.84	13.25	8.43	15.66	9.64	21.69
Beef	22.89	22.89	22.89	6.02	6.02	6.02

The *bold figures* indicate that “volatility” (measured either as CV or number of observations outside the 20% tunnel) increased in the second period

of observations outside the 20% tunnel on the world market decreased for all products except for barley. On the EU market, the percentage of observations outside the 20% tunnel increased for all commodities except beef.

Table 2.2 summarises coefficients of variations for the products discussed in Table 2.1. Comparing coefficients of variation on the world and EU markets covering period from January 1997 to October 2010, we observe that prices on the world markets were more dispersed than prices on the EU markets, with meats being less dispersed than crops and dairy. On both the world and EU markets, the coefficient of variation increased between 1997–11/2003 and 12/2003–2010, indicating increased dispersion of prices. However, with the exception of chicken, world markets experienced more dispersed prices in the first period between 1997 and 2003 than EU markets did.

Table 2.2 Coefficient of variation, comparable products

Coefficient of variation	World prices			EU prices		
Commodity	01/97–10/10 (%)	01/97–11/03 (%)	12/03–10/10 (%)	01/97–10/10 (%)	01/97–11/03 (%)	12/03–10/10 (%)
Barley	34.04	15.42	31.05	20.80	6.39	26.26
Wheat (Int. SRW, EU bread)	38.92	17.32	33.23	21.44	5.82	27.54
Maize	33.68	11.96	30.17	18.52	5.64	23.23
Butter	46.56	16.93	35.72	10.55	3.47	12.84
SMP	39.63	17.66	33.03	14.39	8.35	18.31
Chicken	13.90	5.57	8.42	10.71	6.15	9.28
Beef	21.26	9.77	13.00	6.84	4.07	5.40

Even in the second time period, with the exception of chicken, the coefficient of variation in the world price series exceeded the coefficient of variation in the EU. Price charts for comparable products are presented in Fig. 2.1.

Tables 2.3 and 2.4 show both number of observations outside the 20% tunnel and coefficient of variation for world (Table 2.3) and EU (Table 2.4) prices for which respective equivalents were not identified. On the international markets, the percentage of observations outside the 20% tunnel increased for sorghum, soybean meal and Whole Milk Powder (WMP). Coefficient of variation increased for all products between both sub-time periods, indicating higher dispersion of prices after 2003. On the EU market, the percentage of price observations outside the 20% tunnel more than doubled between both sub-time periods for crops and dairy, increased somewhat for eggs and decreased for most of the meats. The coefficient of variation increased significantly for crops and cheeses while it decreased for meats and remained relatively stable for eggs.

Although the intuitive method suffers from a number of shortcomings (e.g. it fails to properly account for seasonality), it allows one to draw preliminary conclusions:

1. Using both the number of observations outside the 20% tunnel and the coefficient of variation, from January 1997 to October 2010 world commodity markets experienced more volatility than EU markets. Coefficient of variation increased both on the world and EU markets between 01/1997–11/2003 and 12/2003–10/2010, with the EU recording more dramatic increases. However, in absolute terms the coefficient of variation remains higher on the world markets than on the EU markets during 12/2003–10/2010 for all products except for chicken where the levels are comparable.
2. Compared to 01/1997–11/2003, dispersion of prices in 12/2003–10/2010 measured by coefficient of variation increased for all commodities studied both in the EU and the world, with the exception of some meat products in the EU. However, compared to crops and dairy, volatility of meat prices is relatively low. Note that the latter time period includes price peaks, significantly shifting the mean of the time series.

2.2.2 Volatility on the Futures Markets

Commodity exchanges produce a stream of daily settlement data. The use of nearby futures is also justified by frequently using those futures as international reference prices. The Chicago Mercantile Exchange (CME) group offers already calculated measures of volatility.⁴ For consistency for European exchanges we used settlement prices and the formula applied in the CME calculations for the milling wheat (from

⁴<http://www.cmegroup.com/market-data/reports/historical-volatility.html>. To annualize their volatility figures, the CME group uses an average of 252 trading days each year. Due to holidays

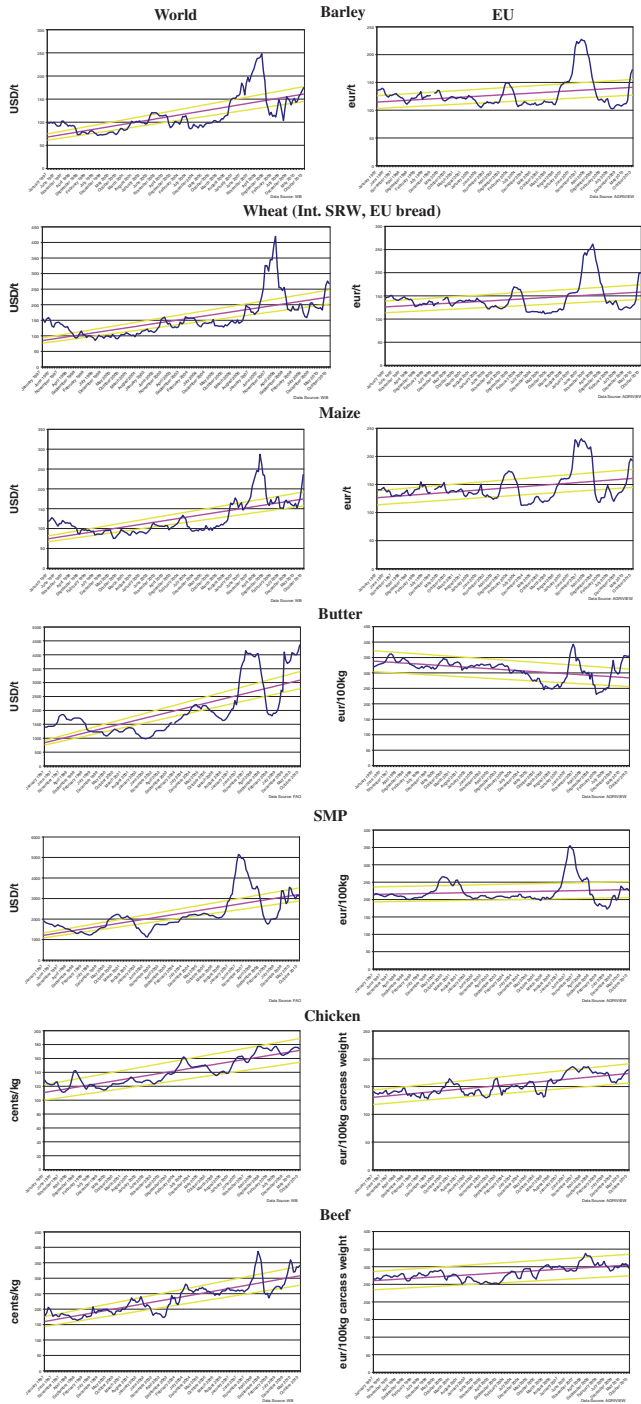


Fig. 2.1 Price charts with trend lines for comparable products

Table 2.3 World prices: 20% tunnel, coefficient of variation

20% tunnel	20% tunnel			Coefficient of variation		
	01/97–10/10	01/97–11/03	12/03–10/10	01/97–10/10	01/97–11/03	12/03–10/10
Commodity	(%)	(%)	(%)	(%)	(%)	(%)
HRW wheat	65.66	71.08	60.24	37.75	16.06	31.91
Rice Thai 5%	89.16	90.36	87.95	46.30	23.39	39.97
Sorghum	59.04	54.22	63.86	31.19	11.60	28.33
Soybeans	72.89	79.52	66.27	34.89	16.70	27.58
Soybean oil	74.70	87.95	61.45	41.40	23.81	33.08
Soybean meal	75.30	72.29	78.31	37.25	21.60	30.80
Cheese	57.83	62.65	53.01	37.42	10.53	27.59
WMP	73.49	69.88	77.11	40.15	13.12	33.91

Table 2.4 EU prices: 20% tunnel, coefficient of variation

20% tunnel	Coefficient of variation		
	01/97–10/10	01/97–11/03	12/03–10/10
Commodity	(%)	(%)	(%)
Feed wheat	56.10	28.40	83.13
Durum wheat	59.15	39.51	78.31
Malting barley	59.15	32.10	85.54
Cheddar	50.00	34.94	65.06
Eidam	27.11	10.84	43.37
Young bovines	9.64	18.07	1.20
Cows	24.70	39.76	9.64
Heifers	1.81	3.61	0
Piglets	59.64	77.11	42.17
Pork	31.93	50.60	13.25
Eggs	43.37	36.14	50.60

September 1998 to October 2010) contract on MATIF. The formula is outlined in Appendix 2.

Different products (wheat, maize, oats, soybeans and derived products) show different price and volatility patterns. However, there are commonalities across them. Although increased volatility can occur in any given period, actual peaks differ on the basis of the commodity and developments of their fundamentals. Due to space limitation we would focus on wheat in this chapter. Figure 2.2 shows historical volatility of wheat on the Chicago Board of Trade (CBOT – part of the CME group)

and weekends, the number of actual trading days each year can differ, and as such volatility results can differ.

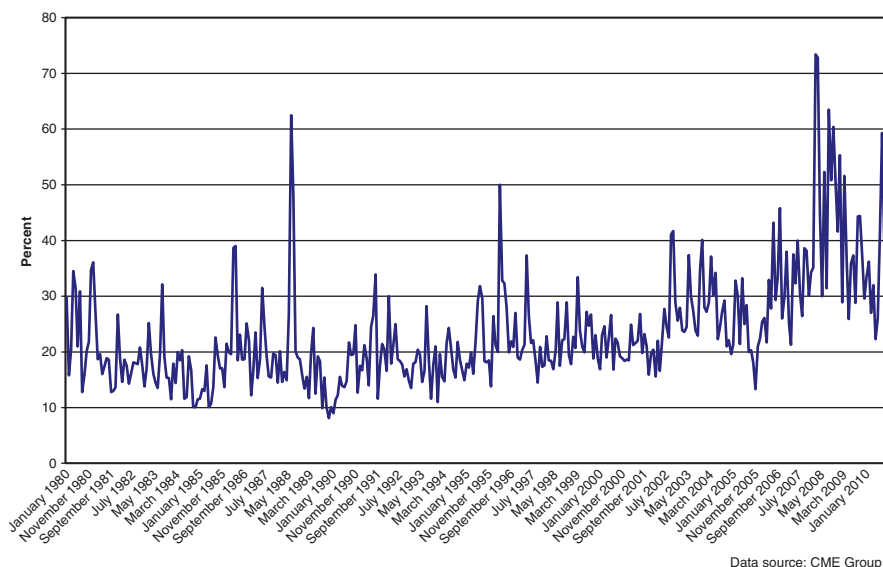


Fig. 2.2 US wheat, historical volatility, monthly annualised

on a monthly basis from January 1980 to October 2010. Wheat volatility has had an increasing trend over the observed period, ranging between 30 and 73%. In the last 4 years the average volatility has increased.

MATIF wheat experienced the highest volatility in September 2007, January 2009 and July–August 2010 when it reached around 44–48%. The summer 2010 high volatility episode accompanied poor harvest prospects in Russia and consequent export ban. However, in between those peaks, the volatility was as low as 8% (February 2010). Although experiencing peaks, wheat volatility on MATIF was relatively stable between 1998 and mid-2006 when it started increasing.

Second Challenge of Volatility: Choice of Method and Reference Period

A variety of approaches to detect volatility yielding different results are in use. Different results are also obtained using different reference periods for comparison. Crude methods applied in this chapter showed that price volatility is increasing. However, even though the presence of volatility was not increasing over a longer time frame, it is important to compare shorter time frames.

Although this chapter has not looked at the long-term data series, others (e.g. OECD/FAO, 2010) have done so and did not support a case for decreasing long-term volatility trend as the current boom of volatility does not match the heights reached in the 1970s. While correct on technical grounds, the findings are not of immediate relevance to producers who were faced with lower price variability in the preceding two decades.

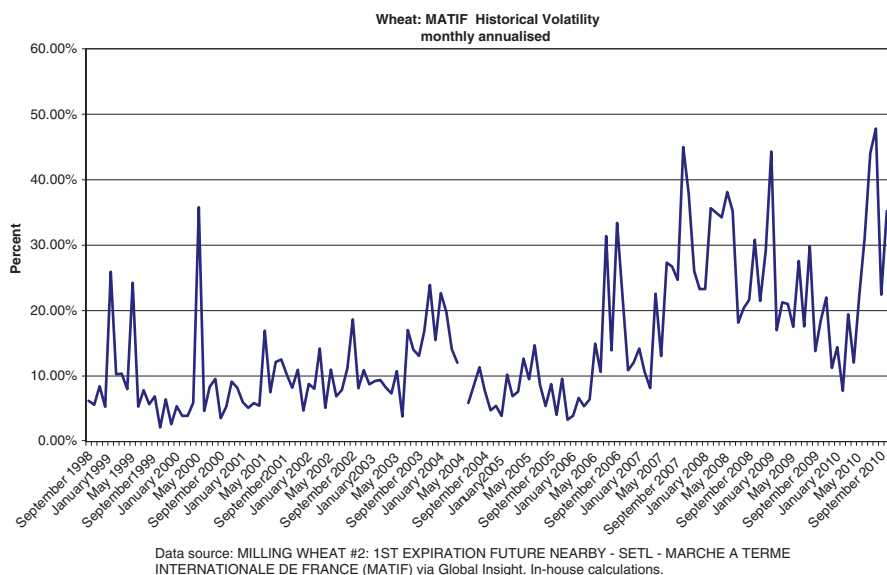


Fig. 2.3 MATIF milling wheat, historical volatility, monthly annualised

Agricultural commodities traded on European exchanges, although smaller in terms of volume, were not shielded from increased volatility. Figure 2.3 shows the development of historical volatility for milling wheat on MATIF.

2.3 Factors Influencing Price Volatility

Price volatility is driven by the same set of factors as prices – a topic studied in detail during and following the price hikes of 2007–2008 (e.g. EC, 2008; Meyers, 2009; Trostle, 2008). Among the wide variety of factors are underlying market fundamentals such as yields and stock levels; weather and changing weather patterns with their related impacts; cycles in key markets; policy driven developments including large purchases by the governments; developments outside the agricultural sector such as exchange rate and oil price movements; trade policies and their transmission; investment in agricultural production etc. Commodities for which the demand is inelastic (such as agricultural products) tend to be more volatile. Long-term structural changes are also responsible for the increase in price variability, although their effects are not immediate. Only some of the factors contributing to greater volatility are described below.

Low levels of stocks in their own right do not result in high price but provide a limited buffering capacity should increasing demand or short-term supply challenges occur. There is no single answer to the question “What normal stocks are?”.

In addition, stock management, such as stock creation and release, can affect market fundamentals and impact prices.

Climate change and *weather*-related events impact production variability and thus impact market fundamentals. So far on the EU level, no correlation has been established between the warming of the last decades and the level of crop yields, which have generally increased (EC, 2009). However, the impact of climate change might be visible already in other, more vulnerable countries.

A frequent culprit of increased price volatility is *speculation* based on investing in futures contracts on commodity markets to profit from price fluctuations. The wider and more unpredictable price changes are, the greater the possibility of realising large gains by speculating on future price movements of the commodity in question. Although the presence of “speculators” on the derivatives markets is a necessary condition for functioning markets and efficient hedging, volatility can attract significant speculative activity and destabilise markets, which are both the cause and effect of increased volatility. In thinly traded markets where only small quantities of physical goods are traded, the value of speculative trades may create false trends and drive up prices for consumers. Arguments both for (e.g. Irwin and Sanders, 2010) and against (e.g. Robles et al., 2009) “speculation” are ample, although evidence is inconclusive. While other factors and fundamentals are at play and have to be considered, there is a time overlap between increased volatility and increase in open interests on the commodity markets (Fig. 2.4). While increase in open interests and inflow of investment money increases the liquidity on the market, increased liquidity could come with increased volatility.

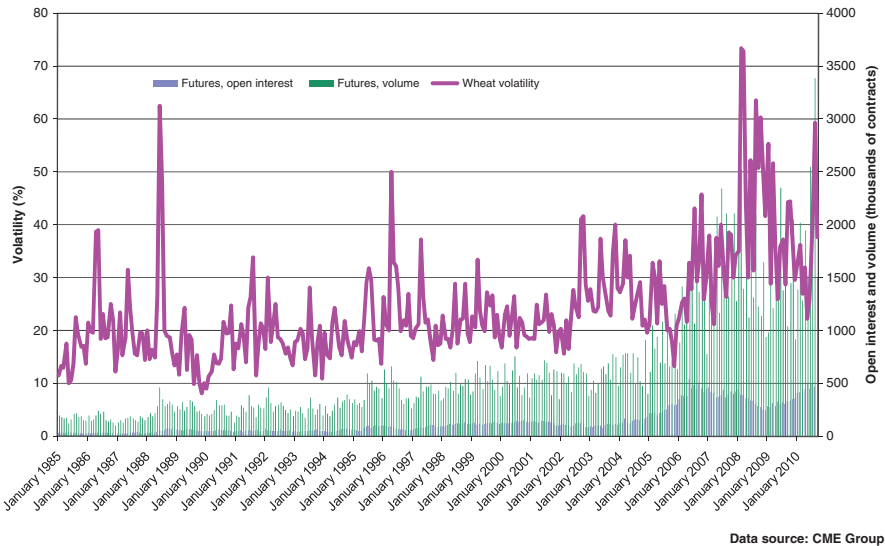


Fig. 2.4 US wheat historical volatility, futures open interest and volume monthly

Policies: Greater market orientation of agricultural policies (CAP included) relies on a greater transmission of market signals, and results in more variable prices. Policy instruments (described later) are in place to mitigate effects of price variability. Trade restrictive policies also play a role in limiting supplies, thus increasing uncertainty on the markets and price variability.

Strong co-movements with energy and other agricultural prices: Linkages with energy markets before the emergence of biofuels were one-way: oil and energy as inputs to agricultural production. Increased connection between energy and agriculture raises questions about volatility transmission from more volatile energy and oil markets in addition to changing market fundamentals, or at times without a significant change in market fundamentals. The strength of the link is not yet determined, although Du et al. (2009) found evidence of volatility spillover among crude oil, maize and wheat markets after autumn 2006 and explained it by tightened interdependence between these markets induced by ethanol production. Figures 2.5 and 2.6 show scatter charts of daily settlement data for maize and crude oil for the 2000–2004 and 2005–2010 periods. An OLS line fitted to the data reveals a stronger correlation in the 2005–2010 time period with an R-squared of over 53% when not including a trend variable, and 56% when including a trend variable to avoid spurious regression, with all estimates significant at 5% level of significance. Scatter charts for data before 2000 (not included) resemble that of 2000–2004, with no significant correlation.

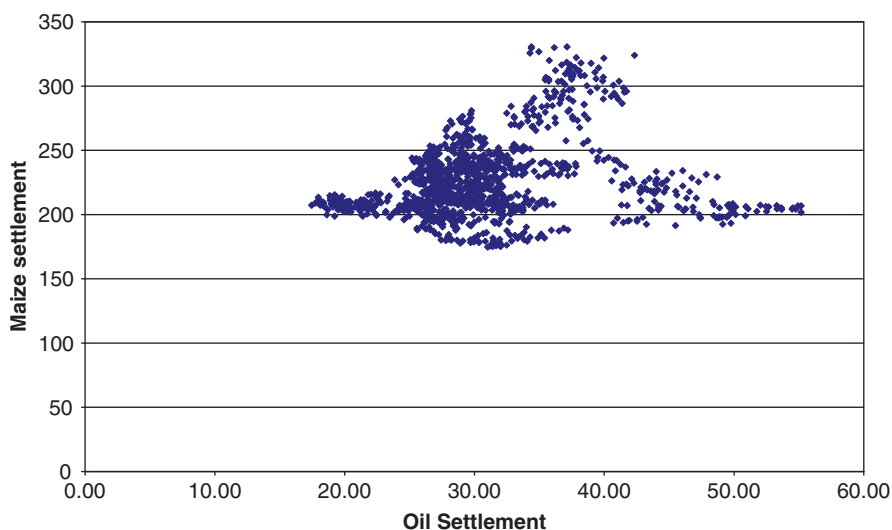


Fig. 2.5 Scatter chart of maize and crude oil settlement prices, 2000–2004

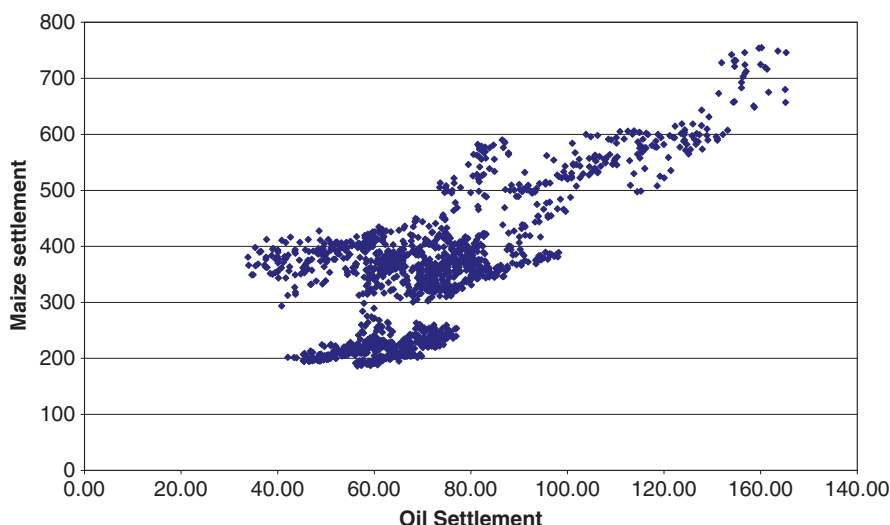


Fig. 2.6 Scatter chart of maize and crude oil settlement prices, 2005–2010

2.4 Implications of Increased Volatility

Although references are often made to “excess volatility”, it is generally accepted that a certain degree of volatility is desirable, and price volatility is a normal feature of the markets. Without price adjustments, markets would come to a stall. Volatility across the commodity markets is not consistent. Although active participants on agricultural commodity markets are finding prices to be volatile, compared to energy markets, volatility remains rather low. Energy returns have been significantly more volatile than other commodity sectors. Other markets, such as metals, have experienced higher volatility than energy markets; these episodes have been brief and transitory.

In macroeconomic terms, while price hikes are beneficial for net exporting countries that benefit from improved balance of payments, they increase the import bill of net importing countries. Food security considerations play an important role. Variable prices lead to an uncertain food import bill, and high prices impact the ability of poor consumers to purchase necessary food. On the other hand, producers and net sellers benefit from increased prices.

Concerns about increased price volatility are usually voiced by producers and processors who in the absence of risk management tools are exposed to unpredictability and uncertainty associated with changing prices. High fluctuations in prices may limit the ability of consumers (processors) to secure supplies and control input costs. Due to price transmission issues, contracting and relatively low percentage of raw commodity in the processed products, consumer prices do not necessarily follow commodity prices directly. While we focus on the volatility of output prices,

volatility of input prices (oil, fertiliser etc.) also affects agricultural production and decision-making.

The biggest drawback of volatility is the associated uncertainty of marketing production, investment in technology, innovation etc. The persistence in volatility reflects the continued uncertainty with regards to how market fundamentals have unfolded and how they are likely to unfold. Higher price volatility means higher costs of managing risks (such as higher margins on futures contracts and higher premiums for crop revenue insurance). It is likely that higher costs of risk mitigation would eventually translate into higher consumer prices. Commodity shocks in the form of increased prices and increased volatility can also have an impact on inflation, although this chapter abstains from analyzing the link.

A distinction has to be made between the effects of volatility itself (such as unstable prices and their impact on food security) and effects of policy reactions. Short-term policy reaction can contribute to market instability and consequently volatility, as we observed in the case of rice in spring 2008 when in the wake of increasing price levels some major exporting countries introduced export restrictions, and again in summer 2010 following an export ban in Russia.

2.5 Policy Considerations

Increased volatility can be addressed in two different ways:

1. Dealing with price volatility itself by trying to stabilise markets using price controls and supply controls (stock management).
2. Dealing with the effects of increased price volatility by employing risk management tools (crop insurance, *[functioning]* futures markets), income stabilisation mechanisms, safety nets etc.

2.5.1 *Dealing with Price Volatility Itself*

Price controls and supply controls go hand in hand. Past attempts to stabilise commodity prices – and thus reduce volatility – using international commodity agreements, marketing boards, supply controls, planned economies, or more explicit price setting nationally were not a great success. Since successful manipulation of market fundamentals is unlikely, a safe – but rather slippery – way to reduce or even eliminate volatility is to fix prices. However, such experiments in the past led to various forms of market failures, leading to inefficiencies, and are unlikely to gain broad support. Dawe (2009) discusses both costs and benefits of stabilising prices of staple foods. The main cost of price stabilisation is the deadweight loss by not allowing market prices to follow world prices. Among the beneficiaries of price stabilisation are consumers and producers benefitting from stable prices. In this case price stabilisation serves as a safety net program, although not the most efficient one.

The *international commodity agreements* regulating supply through production quotas for its members and maintaining buffer stocks, so that world prices remain stable, within a specified range were used from the 1950s to the 1990s. These agreements managed to sustain world prices for a number of products (notably coffee), but the eventual collapse brought about by competitive pressure from producer countries and a withdrawal of support from consumer countries has made them largely ineffective at keeping prices level. For a detail on international commodity agreements, refer to Gilbert (1996).

Stock management played an important role in international commodity agreements. Following the price hikes of 2007–2008, many advocate the role of building stocks as a way to buffer against sudden changes in prices. Proposals currently on the table address increased volatility in an *ad hoc* fashion mostly addressing issue of stocks, both virtual and real. While stocks fulfill a buffering role, they also remove commodity from the market and thus at the times of tight supply might put additional strain on it. Management of stocks also comes with a high cost of governance.

It might be possible to deal with price volatility itself in the longer term by strengthening market fundamentals, by securing supply and by introducing innovation and new technology.

2.5.2 *Dealing with the Effects of Increased Price Volatility*

Price volatility affects both macro and microeconomic aspects. On the macroeconomic level, price volatility influences balance of payments of both importing and exporting countries. If volatility attains a significant level, it may affect the ability of governments to plan and provide economic security and economic growth. Although price hikes draw attention to net food importing countries that see their import bills soaring, the effects of price decreases are naturally felt in net exporting countries.

Dealing with effects of increased price volatility calls for income stabilisation. One way to income stabilisation uses price stabilisation described earlier. However, price stabilisation is not a necessary condition for income stabilisation, which can be achieved by designing efficient safety nets. In the developed countries with well-established agricultural policies, many programs already contain instruments to aid income stabilisation. Where this is the case, it is important that income support be decoupled from production to minimise production and trade distortions.

Commodity price risk management uses financial instruments for managing price risks rather than reducing price volatility itself. Risks are not transferred to the government but are reallocated among private traders. Among those instruments are futures and forwards contracts, commodity swaps, call and put options, commodity-indexed bonds and long-term contracts. There is renewed interest in the range of options based on market-based risk management instruments that might help countries and individuals generate more stable and predictable incomes. Use

of market-based risk management instruments requires the proper functioning of derivatives markets. However, while crop insurance and futures markets work relatively well in developed countries, extending them to developing countries might not always be feasible.

The backbone for successfully coping with commodity price volatility relies on strong institutions and management. A further development of market-based instruments that react to market signals, while at the same time helping to mitigate the effects on incomes, is important. A possible development of financial derivatives could also play a role. For this to take place, a transparent regulation of commodity exchanges is a pre-requisite. Safety nets could be developed, or where they exist, be reinforced to mitigate effects of volatile prices. Currently, many developing countries are lacking safety nets as well as access to efficient saving instruments. The best long-term solution to commodity price volatility would be product diversification.

Third Challenge of Volatility: When Is Volatility Excessive? What Policies Should Be Employed?

The level of volatility is commodity-specific, differing across sectors and commodities within a sector. A question to answer is whether volatility should be prevented, risking obstruction of market signals, or whether addressing consequences of price volatility aiming at income stabilisation is more desirable.

2.6 Concluding Thoughts

Although volatility has always been a feature of agricultural commodity markets, the evidence suggests that volatility has increased at least in some commodity markets. There seems to be an overlap between periods of high prices and increased volatility. Volatility peaks also seem to coexist with decreased stocks. The chapter abstained from considering the development of fundamentals and macroeconomic factors, such as exchange rate developments.

Persistence of volatility points to uncertainty in developments of market fundamentals coupled with structural and monetary policy. Higher price volatility means higher costs of managing risks (such as higher margins on futures contracts and higher premiums for crop revenue insurance). However, with increasing biofuels production, a tightened interdependence between crude oil and commodity markets can be expected which could result in increased transmission of crude oil price volatility into agricultural commodity markets. It is likely that higher costs of risk mitigation would eventually translate into higher consumer prices.

Increased volatility highlights the presence of greater uncertainty on the market. Two broad sets of policies could be employed: (1) those that target volatility itself, such as price and supply controls, and (2) those that deal with the effects of price volatility while letting markets work, such as risk management instruments, safety nets etc. Policies based on price and supply controls do not appear to have an impressive precedent, and reduce market signals. Policies mitigating volatility

or the effects of volatility should aim to address uncertainties and focus on risk management while keeping markets working.

It remains impossible to capture future price variability. However, elements from the past that resulted in the past and present variability remain active.

Appendix 1: Description of Price Series Used in Section 2.2

World grains, oilseeds, and meats: compilation of various sources by World Bank Commodity Price Data (Pink Sheet), available at <http://go.worldbank.org/2O4NGVQC00>

- Barley (Canada), feed, Western No. 1, Winnipeg Commodity Exchange, spot, wholesale farmers' price
- Wheat (US), no. 2, soft red winter, export price delivered at the US Gulf port for prompt or 30 days shipment
- Maize (US), no. 2, yellow, f.o.b. US Gulf ports
- Wheat (US), no. 1, hard red winter, ordinary protein, export price delivered at the US Gulf port for prompt or 30 days shipment
- Rice (Thailand), 5% broken, white rice (WR), milled, indicative price based on weekly surveys of export transactions, government standard, f.o.b. Bangkok
- Sorghum (US), no. 2 milo yellow, f.o.b. Gulf ports
- Soybeans (US), c.i.f. Rotterdam
- Soybean oil (Any origin), crude, f.o.b. ex-mill Netherlands
- Soybean meal (any origin), Argentine 45/46% extraction, c.i.f. Rotterdam beginning 1990; previously US 44%
- Meat, beef (Australia/New Zealand), chucks and cow forequarters, frozen boneless, 85% chemical lean, c.i.f. U.S. port (East Coast), ex-dock, beginning November 2002; previously cow forequarters
- Meat, chicken (US), broiler/fryer, whole birds, 2-1/2 to 3 pounds, USDA grade "A", ice-packed, Georgia Dock preliminary weighted average, wholesale

World dairy prices: FAO compilation of average of mid-point of price ranges reported bi-weekly by Dairy Market News (USDA). Available at <http://www.fao.org/es/esc/prices/PricesServlet.jsp?lang=en>

- Butter, Oceania, indicative export prices, f.o.b.
- Cheddar Cheese, Oceania, indicative export prices, f.o.b.
- Skim Milk Powder, Oceania, indicative export prices, f.o.b.
- Whole Milk Powder, Oceania, indicative export prices, f.o.b.

EU market prices for representative products (monthly) Available at <http://ec.europa.eu/agriculture/markets/>

Appendix 2: Theoretical Consideration

The CME calculation of historical volatility calculation is the annualised standard deviation of the first difference in the logarithmic values of nearby futures settlement prices. Mathematically, it can be written as

$$\text{Volatility} = \text{STDEV}_{\text{Day1}}^{\text{DayN}} \left(\ln \frac{\text{Settle } PxT}{\text{Settle } PxT - 1} \right) \sqrt{252}$$

where 252 is the estimated number of trade days in a year to convert volatility into annualised terms.

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