

Featured Article

The Economics of Grain Price Volatility

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Abstract *Recent volatility of prices of major grains has generated a wide array of analyses and policy prescriptions that reveal the inability of economists to approach a consensus on the nature of the phenomenon and its implications for policy. This review of market events and their economic interpretations finds that recent price spikes are not as unusual as many discussions imply. Further, the balance between consumption, available supply, and stocks seems to be as relevant for our understanding of these markets as it was decades ago. Though there is much to be learned about commodity markets, the tools at hand are capable of explaining the main forces at work, and of giving good guidance to policymakers confronted with a bewildering variety of expensive policy prescriptions.*

Key words: Storage, speculation, volatility, food security.

JEL Codes: Q02, Q11, Q13.

Introduction

The resurgence of volatility in many global commodity markets has generated a wide array of economic interpretations. In this article I survey some of these interpretations and the associated evidence, with reference to some relevant literature, but making no attempt at a comprehensive review of what has been written on the issue.

This is a complex topic, and even the basic economics needed to begin to understand key phenomena has implications that are not necessarily well known by analysts and policymakers. A well-grounded annual model of a market for a storable staple product subject to random shocks to excess supply has been available since [Gustafson \(1958\)](#), but though its basic logic, “buy low, sell high,” is widely accepted as a wise aspiration, some of its implications are not intuitive, and not well understood. Furthermore, influential empirical assessments of the model have questioned its relevance, discouraging observers from investing the effort needed to understand its operation, and to develop improved tests of its relevance to commodity price behavior.

In the absence of a widely accepted model, creative economists have presented interpretations of recent market behavior emphasizing the role of interest rates, “speculative bubbles,” financial manipulation or input costs in price volatility. Discredited notions of welfare-improving international buffer stocks, guided by selected experts able to consistently out-guess the market when prices are volatile, have been rehabilitated in some policy proposals. Indeed the atavistic tendency to pillory commodity traders and speculators in times of crisis appears to have survived intact into the twenty-first century, despite the efforts of those who followed Gustafson’s intellectual lead.

In this article I review the main features of the model. Then I discuss the analytic and numerical problems that underlie the early negative conclusions on the relevance of the model, and discuss subsequent econometric results that are much more positive. I show how the workings of the model help us understand the role of interest rates and financial flows in commodity markets. Special cases of the model also show the futility of efforts to establish the existence of “bubbles,” even in retrospect, from price behavior. I also try to give a brief review of questions that remain unresolved, and what still needs to be done to increase our understanding of commodity markets.

Wheat, rice, and corn are highly substitutable in the global market for calories (Roberts and Schlenker 2009, 2010), and when aggregate stocks decline to minimal feasible levels, prices become highly sensitive to small shocks, consistent with the economics of storage behavior. In this decade, aggregate stocks of grain calories available to participants in the global grain market stocks declined, due to the imposition of new and substantial biofuels mandates on markets subject to otherwise fairly normal ranges of shifts in yields and demands, making markets unusually sensitive to all short-run disturbances including the Australian drought and other regional grain production problems, as well as biofuels demands in excess of mandates induced by spikes in petroleum prices.

To protect their own vulnerable and politically influential consumers, key exporters restricted supplies in 2007, exacerbating the price rise. Understandably, vulnerable importers are now building strategic reserves and some are attempting to secure agricultural land in friendly neighboring countries.

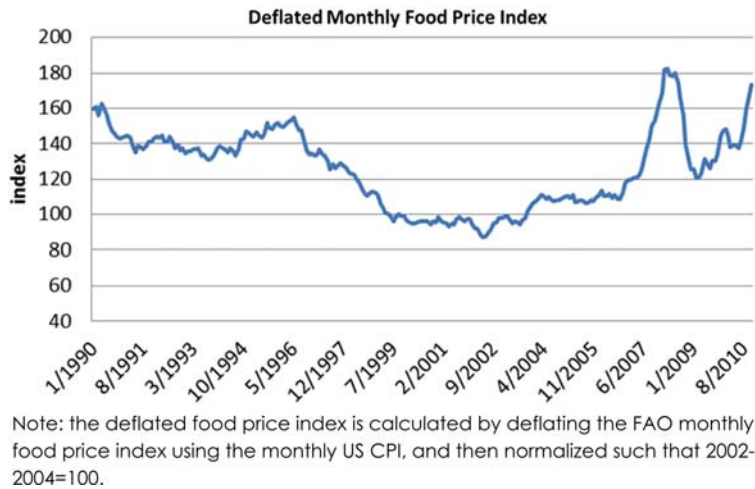
Measures motivated by heightened concern about food security can be very costly, and often are ineffective or even exacerbate the problem (Tangermann 2011; Anderson and Martin, 2011). Here I do not address policy alternatives. Instead I concentrate on the prior question of the economics behind the recent price spikes in the major grains and associated market volatility.

Price Volatility: Recent Evidence

Around eight years ago, world food prices as represented by the United Nations FAO food price index shown in figure 1 began a persistent upward drift that by 2006 had moved the index almost 20% higher than the 1998–2000 average.¹ In that year prices started to accelerate, and by

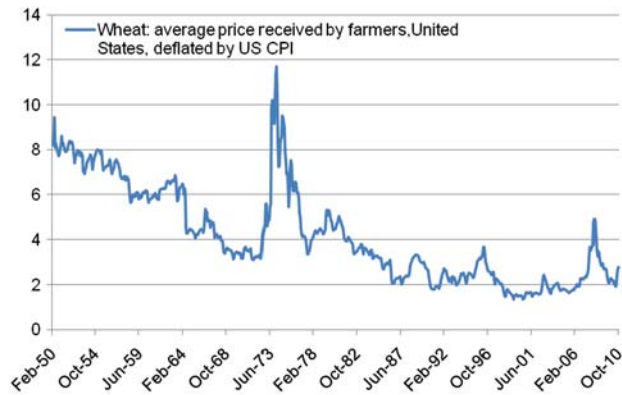
¹Although we must focus on aggregate numbers here, it is important to note that they mask a tremendous amount of variation between countries, due to trade barriers, exchange rate movements, domestic price and tax policies, and transport costs. As trade barriers, tariffs and transport costs have changed abruptly, the scope of various international markets has also been redefined. Furthermore, in large or

Figure 1 UN FAO food price index (Jan. 1990 – Jun. 2010) (2002/04 = 100).



Source: FAO

Figure 2 Price of wheat (1950–2010) in dollars per bushel deflated by U.S. CPI (1982–1984 = 1).



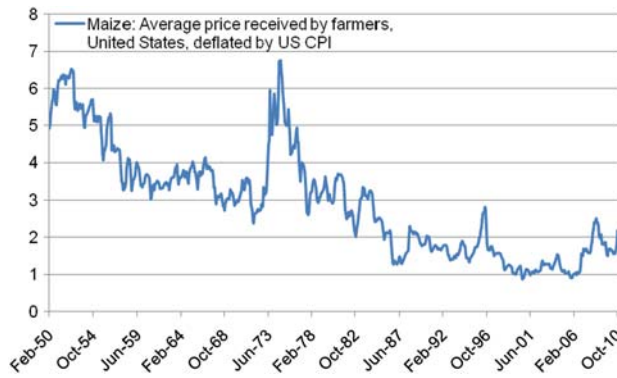
Source: USDA

October were on a sharp uptrend that continued until summer 2008. Prices then fell sharply, but have since exhibited unusually sustained volatility up to the present (late 2010).

The degree of volatility in the figure is all the more striking in that an index tends to smooth the ups and downs of individual index components. In this article I focus on the short-run price behavior of the major grains, corn, wheat and rice, shown in figures 2, 3 and 4, which between them provide the world's population with most of its food energy. The deflated dollar prices of wheat and corn both show marked downward trends from 1950 to 2001. Note that the persistence of these trends through the 1990s appears more evident than in the aggregate index shown in

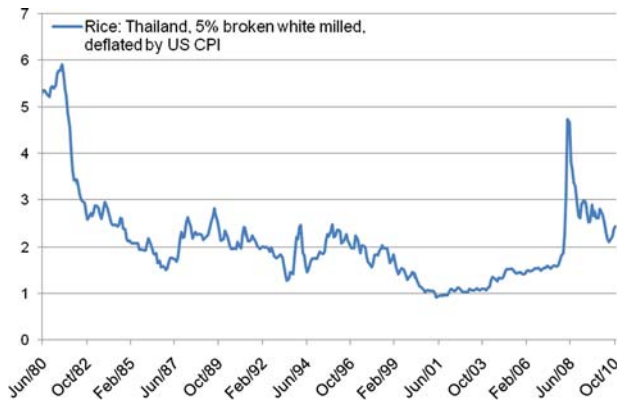
landlocked countries international prices often face widely varying prices; for many consumers, international prices and policies discussed here have little relevance, as noted below. Indeed, the size of the global market is a stochastic variable, shrinking as exporters close off their borders in the midst of cascading market panics.

Figure 3 Corn, average price received by farmers in dollars per bushel deflated by U.S. CPI ((1982–1984 = 1).



Source: USDA

Figure 4 Rice, real price, Thailand, 5% broken white milled.



Source: IMF

figure 1. Along their downward paths, episodes of sharp price spikes, followed by precipitous falls, are prominent features of the data, interspersed by longer intervals of less extreme variation. The price series are asymmetric; there are no steep troughs to match the spikes.

These features of price behavior are shared by other commodities as indicated in figure 5, which includes prices of soybeans and petroleum, as well by all food. Prices of many minerals tend to display similar behavior.

The overall downward trend in grain prices can be attributed principally to the remarkable success of (largely public) plant breeders as well as farmers in continually developing and adopting new crop varieties offering higher yields, and to the development and diffusion of cheap and plentiful supplies of inputs complementary to the new biotechnology. These achievements have, to the surprise of many prognosticators, thus far overcome the Malthusian challenges posed by a decline in the world supply of agricultural land available for expansion and a large increase in world population. Figure 6 shows the remarkable increases in world (human and livestock) consumption of energy from the major grains that have occurred just since 1990, even as the scope for expanding the area of cultivated land has diminished or disappeared in most countries.

Figure 5 Long run movements of prices normalized commodity price indexes deflated by the U.S. CPI

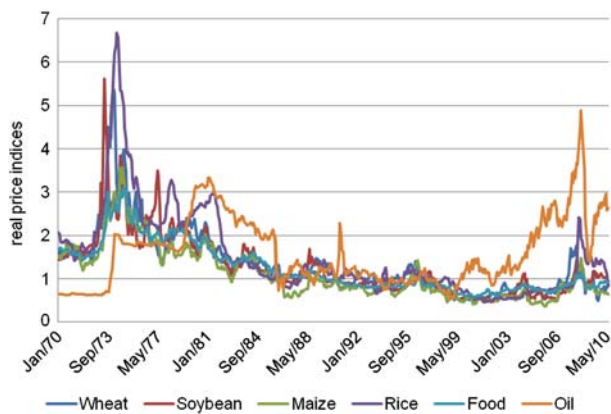
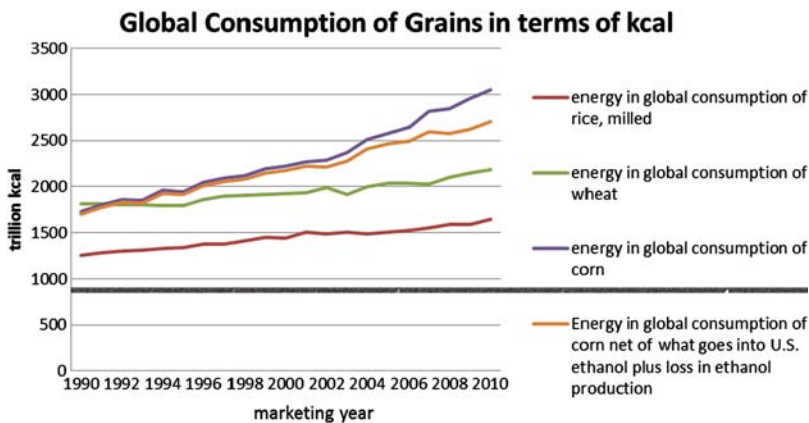


Figure 6 Global consumption of energy from major grains



Over this period, corn has become increasingly dominant as a source of grain energy, reflecting, until 2002, the high share allocated to animal feed, and the high income elasticity of demand for animal products, and the high rate of growth in the demand for animal products in the developing world in general, not just in China and India. Note that, since 2002, biofuels use of corn has become another important source of global demand for corn energy.

For the modest and focused purposes of this article, the figures discussed thus help set the stage. Each of the grain commodities discussed is storable from one crop year to the next.² This complicates the analysis greatly; the market clearing condition is not necessarily “current consumption equals current supply” if stocks are being changed. Storage is an endogenous response that in the short to medium run alters the implications of exogenous or predetermined variables on the market. In the study of price variability as distinct from price trends, our interpretation

²I neglect soybeans not because I believe them unimportant, but because I do not have the time and resources to include them here, other than in reference to substitution in production for corn. Other commodities that deserve attention in a more ambitious study include palm oil, sugar, potatoes, and cassava.

of events should recognize and incorporate the economics of storage as intertemporal arbitrage.

The basic economics of storage arbitrage has been recognized at least since the biblical account of Josef's interpretation of the Pharaoh's wife's dream of seven fat and seven lean cows. In the 1920's, Holbrook Working made large advances in understanding the empirical relation between commodity stocks and futures prices. Williams (1936) made advances in conceptualizing a market model. The remarkable work of Gustafson (1958) introduced a market model that derived numerically the storage demand consistent with the characteristics of consumer demand, yield distribution, cost of storage and interest rate, given maximization of expected profits with an infinite horizon. That is, he introduced what economists would later call a rational expectations market model. This work appeared in a technical bulletin and received scant recognition for many years, but publications by Johnson and Sumner (1976) and Gardner (1979) helped bring the model to bear on questions of agricultural policy, many of which depended crucially on intertemporal allocations of commodities. Numerical simulations conditioned on best guesses of key parameters were used in these studies and in Wright and Williams (1982a,b; 1984) to generate qualitative implications regarding market behavior, in addition to the sporadic emergence of price spikes like those that have recently caused a great deal of concern. Before considering whether these implications have been consistent with what we have seen recently in the markets, in the next section I sketch some basic elements of the model.

The Nature of Grain Storage

Consider the annual economic model of price behavior in a market for a storable staple product subject to random shocks to excess supply in the tradition of Gustafson (1958). According to this model, to interpret the behavior of grain market prices, and identify the causes of high volatility, it is crucial to understand the relation between prices and stocks.

An important feature of the major grains (and of most minerals) is that the marginal cost of storage per period, including physical protection, insurance, and spoilage, in practice is usually positive but (in climatically appropriate locations) modest, and the assumption of constant unit costs is a generally reasonable approximation.³ The size of global grain stocks is usually not constrained by storage capacity.⁴

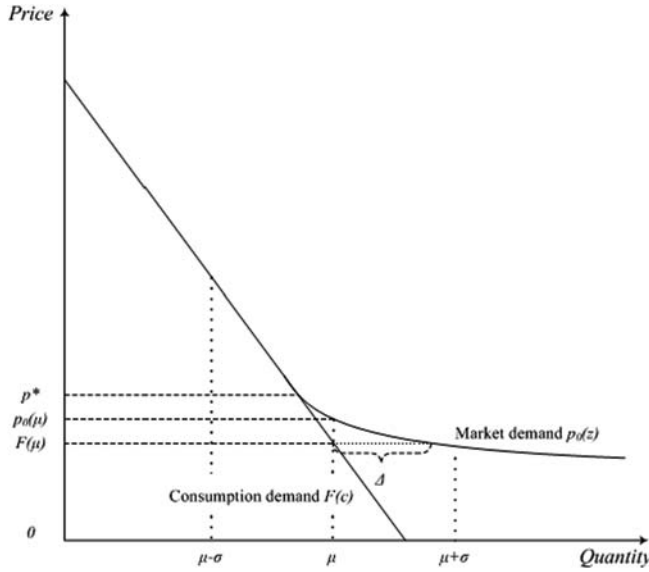
The model discussed here focuses on annual variation and inter-year carryover from the end of one crop year to the beginning of the next. Thus, we ignore interesting questions of intra-year storage, when stocks to use ratios will typically be higher. Initially the focus is on aggregate market behavior, ignoring issues of spatial variation and product heterogeneity, as well as trade barriers, subsidies, and taxes, all of which tend to segment markets and affect the relation between reported global prices and prices faced by consumers.⁵ The observation that spikes occur only if stocks are near minimum levels reflects the constraint that intertemporal

³Paul (1970). Deterioration is not important for grains stored in appropriate environments but can be serious in hot and humid environments.

⁴In contrast, storage of extra water in a reservoir, or petroleum in above-ground tanks, incurs no extra cost until it reaches full capacity, beyond which extra storage is infeasible in the short run.

⁵Transaction costs associated with adding or removing stocks are also assumed to be negligible.

Figure 7 The role of stocks in buffering shocks



transfers via storage are unidirectional; negative storage, “borrowing from the future,” is not feasible for the market as a whole. This reality makes modeling storage behavior interesting and challenging.

To obtain a concrete grasp of the model, consider a storable agricultural staple crop such as wheat, sown annually. In year $t-1$, when the crop harvested in year t is sown, the harvest in year t , h_t , is random due to weather and other disturbances with known distributions of outcomes realizations that cannot be predicted one year in advance. The market demand for the grain, illustrated in figure 7, is the horizontal sum of two demands. One, assumed to be linear in the figure, is the demand for consumption in the current period, c_t ; the other is the demand for grain stocks in excess of essential working levels, x_t , carried forward for later consumption. To keep things simple, deterioration is ignored.

In any period, regardless of the economic setting (monopoly, competition, state control of resource-allocations) two accounting relations hold. The first defines available supply A_t as the sum of the harvest and (non-negative) stocks carried in from the previous year:

$$A_t \equiv h_t + x_{t-1}.$$

The second states that consumption is the difference between available supply and the stocks carried out:

$$c_t = A_t - x_t.$$

Assuming competitive storage, stocks x_t are positive (net of minimal working stock levels) only if the expected inter-year returns cover costs. (Competition between storers prevents them from making positive expected profits.) This means that the current price of a unit stored must be expected to rise by the sum of the cost of storage k and the interest charge at rate r on the value of the unit stored. Given available

supply, A_t , storers carry stocks x_t from year t to year $t + 1$ following a version of the age-old counsel to “buy low, sell high” represented by the competitive “arbitrage conditions,”

$$\begin{aligned}\text{Price}_t + \text{Storage Cost} &= \frac{1}{1+r} E_t[P_{t+1}], & \text{if } x_t > 0, \\ \text{Price}_t + \text{Storage Cost} &\geq \frac{1}{1+r} E_t[P_{t+1}], & \text{if } x_t = 0.\end{aligned}$$

Substituting the accounting relations, the arbitrage equations for risk-neutral competitive storers who maximize expected profits can be written as

$$\begin{aligned}P(A_t - x_t) + k &= \frac{1}{(1+r)} E_t \left[P(x_t + \tilde{h}_{t+1} - \tilde{x}_{t+1}) \right], & \text{if } x_t > 0; \\ P(A_t - x_t) + k &\geq \frac{1}{(1+r)} E_t \left[P(x_t + \tilde{h}_{t+1} - \tilde{x}_{t+1}) \right], & \text{if } x_t = 0,\end{aligned}$$

where k is marginal physical storage cost, E_t denotes the expectation conditional on information available in year t , and \tilde{h}_{t+1} and \tilde{x}_{t+1} are random variables.

When price is high and discretionary stocks are zero, the market demand is identical to the consumption demand. Those for whom the grain is a staple food are willing to give up other expenditures (including health and education) to continue to buy and eat it, so the consumption demand is very steep; large changes in price are needed if consumption must adjust to the full impact of a supply shock. In 1972/73, for example, a modest reduction in world wheat production at a time when discretionary stocks were almost negligible caused the annual price to more than double, as indicated in figure 2. However, when inventories are above minimum working stocks, storage demand, added horizontally to consumption demand, makes market price much less sensitive to demand or supply shocks. These implications of the model appear consistent with the history of the price of corn illustrated in Figure 3.

By increasing stocks when price is falling, storers reduce the dispersion of price and prevent steeper price slumps. Disposal of stocks when supplies become scarcer reduces the severity of price spikes. If the supply of speculative capital is sufficient, storage can eliminate negative price spikes *but can smooth positive spikes only as long as stocks are available*. When stocks run out, aggregate use must match a virtually fixed supply in the short run. Less grain goes to feed animals and the poorest consumers reduce their calorie consumption, incurring the costs of malnutrition, hunger, or even death.

Storage induces positive correlation in prices and is less important when harvests are positively correlated. (If so, after a large harvest, storage demand will be reduced by anticipation of another large harvest, reducing the stocks carried forward, reducing current price, and increasing current consumption.) It can smooth the price jump induced by an unexpected, persistent increase in demand such as a mandated path of increased use in biofuel production, but it cannot prevent a persistent change in price level.

Grain producers can respond to changes in relative prices of commodities by switching from one crop to another, by intensifying production, and by expanding cultivated area. They can respond to changes in input

prices by adjusting input mixes, changing technologies or switching to crops with different input requirements. Within-market-year supply response is typically negligible.⁶ For moderate transient shocks typical of agriculture, much of the appropriate response can be completed with a one-year lag.

Were there no storage, a transient bad harvest would produce no lagged supply response, as the future price would be independent of the (high) current price. However, given grain is storable, expected price is increased by a bad harvest. Anticipated supply response facilitates greater consumption of those stocks, reducing the current price rise caused by the yield shortfall. When an unexpectedly large harvest increases aggregate supplies, expected returns to production are reduced. In response, producers cut back production, and hold more stocks, buffering the price-depressing effect of the harvest increase. Thus, competitive adjustments of planned production are highly stabilizing when stocks are transient.

Large and persistent shocks to demand or supply have fortunately been very rare in grain markets. If they occur, as in the massive demand drop throughout the Great Depression, the adjustment can take much longer. For a multi-year supply shortfall or demand increase, aggregate resource constraints limit the extent of adjustment on the extensive margin, and price responses of substitute crops restrict reallocation of land between them.

The Gustafson model is believed to have no general analytical solution, even when supply is unresponsive to incentives and the consumption demand function is known. However, given the specification of demand and other parameters including the cost of capital and of storage services, the model can be solved numerically, as demonstrated in Gustafson's seminal but obscurely published work, which pioneered use of the concept of rational expectations and application of dynamic programming in analysis of a dynamic stochastic market model, before the term rational expectations had been coined by Muth (1961).⁷

The economics profession was to wait decades before the model was empirically tested. Even after the advent of computers fast enough to handle the associated dynamic programming tasks, estimation of the model presented many challenges, not least of which were lack of long time series of prices, lack of good data on aggregate stocks, and lack of an effective estimation methodology.

Empirical Relevance

One understandable reason why this model has not been more generally adopted in market analysis is that it was judged incompatible with the observed behavior of a large set of commodity prices over most of the 20th century, when it was finally empirically tested. Deaton and Laroque (1992, 1995, 1996) in a series of path-breaking papers using only price data, developed a testable version of the Gustafson model and tested it on a

⁶This is not always the case. Producers of multiple crops per year can adjust input decisions for one crop if the previous crop is short.

⁷The extension of the numerical model to the case of competitive supply by producers maximizing expected profits, and holding rational expectations, was introduced much later by Wright and Williams (1984) using producer behavior introduced in Wright (1979).

large set of commodities. In their first paper, they estimated the model using Generalized Method of Moments (GMM) to locate the price at the kink (p^* in figure 7) at which stocks go to zero. In their later papers they implemented a pseudo maximum likelihood (PML) procedure to estimate a linear consumer demand function and storage cost represented by proportional “decay” of stocks, given an *iid* normal harvest distribution and a fixed interest rate.

In their 1995 paper Deaton and Laroque declare that “The major issue ... is the failure of the model to account for the autocorrelation in any of the twelve commodities.” They go on to say that this result “is a general feature of the model.” More recently, Deaton (forthcoming) has stated, in reviewing the “slim” results of his collaboration on the estimation of the storage model, that “[W]e have a long established theory – whose insights are deep enough that *some* part of them *must* be correct – which is wildly at odds with the evidence, and it is far from obvious what is wrong...”

Meanwhile, Miranda and Rui (1996) estimated a different storage model with convenience yield (and no stockouts) and reached much more positive conclusions. Cafiero et al. (forthcoming) show that Deaton and Laroque’s (1992) numerical examples, based on specifications in Williams and Wright (1991), do not establish that the model is incapable of replicating high levels of serial correlation found in the data; a simple change in demand slope is all that is needed to show that the finding of failure in this respect is definitely not “a general feature of the model.” They also replicate Deaton and Laroque’s (1995, 1996) PML estimates, and show that their implementation introduces serious numerical inaccuracies in approximation of the kinked market demand that lead to surprisingly large biases in their estimates of the model. This in turn tends to lead to a serious underestimation of the kink price, p^* above, and hence an underestimation of the frequency of storage implied by the data. Not surprisingly, then, prices above the estimated kink are correlated whereas their estimated model indicates that they are independent. Correction of this one problem, and recognition of the possibility of fixed per-unit storage charges, leads to higher estimates of correlations for several commodities for which the corrected model converges, as well as more reasonable estimates of storage costs.

GMM estimates of the price kink, as in Deaton and Laroque (1992), also lead to underestimates of the cutoff price (kink) and of the frequency of positive stocks in samples of prices of the size typically available from commodity markets (Cafiero et al. 2010).

In estimation of the Gustafson model, PML has the limitation that it fails to exploit the most striking aspect of the price data, the obvious skewness evident in the occasional price spikes as shown in figures 2–4, as well as the associated kurtosis. The maximum likelihood estimator (MLE) introduced by Cafiero et al. (2010) does exploit information about these higher moments, while imposing no additional assumptions on the model. Application to the global sugar market yields excellent results. The kink price rises further than in the corrected PML estimate, the implied frequency of stockouts falls, and price correlations, skewness and kurtosis implied by the model closely match those seen in the annual sugar price data. Although work remains to be done in estimating commodity market models, it now seems evident that the early strongly negative findings

regarding its empirical irrelevance were clearly ill founded. Accordingly, I now proceed to an investigation of what it has to offer, in concert with attention to the salient facts as reported, in interpreting the confusing literature focused on rationalization of grain price volatility as a guide to policy decisions.

Interpretation of Recent Price Behavior

If we wish to be relevant, we do not have the luxury of waiting for the evidence needed for formal testing of hypotheses about recent market events. Leading reviews implicitly recognize this. As stated nicely by Headey and Fan, (2008 p. 376):

“[T]he most appropriate research on this issue needs to rely on some less formal detective work, involving a mix of economic theory and reasoning, economic history, and rudimentary statistical analysis. Within the latter, the most important questions we must ask are whether individual explanations of the crisis are consistent with the stylized facts of the crisis. What are these facts?”

One Caveat

One reason this type of exercise is hazardous is that the facts can be very difficult to collect, and even more difficult for the economist necessarily reliant on secondary sources, to verify. To take one example, in previous work I have, like some other observers, highlighted India's ban on the export of non-Basmati rice in October of 2007 as an event that appears to have triggered a long run-up in the rice price through its peak in mid-2008 (Wright 2008; Cafiero et al. forthcoming). Recently I received a paper by Kubo (2010) stating that exports of substantial quantities of rice at high and rising (minimum) prices continued until the middle of 2008. What is more, the government-imposed minimum prices created a strong incentive for over-invoicing and kickbacks. One wonders, then, whether the price peaks in rice in 2008 were inflated by over-invoicing, and export data were understated.

Another example is the reported sale, in 2008, of a Japanese stock of rice imported from the United States, to comply with World Trade organization rules. Announcement of this sale has been identified as the key trigger that initiated the collapse of commodity prices in the spring of 2008 (Headey and Fan 2008 p. 379). After attempting to verify this transaction, I am reasonably confident it had not been consummated by the end of the summer of 2008, well after all grain prices had begun to fall. I have not, on the other hand, been able to verify that the rice was never exported. With respect to commodity prices, there is a decades-long debate about the correct price deflator that has not yet been resolved. Indeed, there is even a continuing argument about whether real commodity prices have been trending down or up! (Svedberg and Tilton 2010; Cuddington 2010).

Given the difficulty of verifying incidents several years past, it is no discredit to researchers that their market analyses, often reported almost immediately after the events, contain inaccuracies. In particular, assembly of accurate aggregate stock data from worldwide sources is so greatly hampered by government secrecy in many countries, and lack of real data in others, that econometricians have preferred, thus far, to focus solely on the price data in econometric estimation of commodity price behavior.

With the above caveat in mind, consider first issues that can be resolved fairly simply, by recourse to the facts as represented in the data.

The Magnitude of the Crisis: A "Perfect Storm?"

Headey and Fan (2008) characterize the food price surges of 2007-08 as a "near-perfect storm." There is no doubt that the crisis was a serious issue on the world stage. But it is important in forming policy for food security to realize that it could very easily have been much worse. This is in fact evident from casual inspection of Headey and Fan's own figure 1, which is very like figure 5 above. It is very clear that, in a world in which the global poor, overall, have higher incomes, staple grain prices at their peaks were far from the peaks attained in the early 1970s. In turn, the global production shortfalls at their worst in the 1970s were relatively modest, at most a few percentage points below previous aggregate peak harvests, far from the worst global harvests one might reasonably expect in the course of a century. A severe wheat fungus spreading across major northern hemisphere breadbaskets might quite conceivably produce a far greater crisis, even if corn and rice harvests were normal. If a worse crisis has significant probability of occurrence, then it might well be judicious to hold some stocks even when price is spiking. No paper I reviewed for this article allows for this possibility in writing about evidence of "irrational" hoarding.

Was It Oil Prices?

Many observers see a graph like figure 5 and conclude that food prices peak when oil prices jump. Oil prices make up a large percentage of farmers' variable costs, in the form of fertilizer and fuel, and those costs are inevitably reflected in high product prices, explaining why all major grains had price jumps in 2007-08. Headey and Fan (2008, p. 378) find "no critical weaknesses" with this argument.

There are in fact several critical weaknesses. One is that in the boom of the 1970s, called the "oil boom" by Baffes and Haniotis (2010), oil prices rose *after* the major grains were already spiking. The first commodity embargo of the 1970s was the U.S. ban on soybean exports, to control domestic food price inflation. In fact of the three commodity booms involving agriculture, metals and energy since World War II identified by Radetzki (2006) and cited by Baffes and Haniotis, the last is the only one that has been led by oil price rises, and the first did not involve oil at all.

Second, if oil prices caused fertilizer costs to rise, this would affect production only if it caused producers to cut back on fertilizer use. In fact, through the crisis, fertilizer producers like Saskatchewan Potash were operating at capacity and reaping huge profits. If farmers did not reduce fertilizer use, there could be no negative effect on supply. Third, fertilizer prices generally lagged the price surges in 2007/08. And even if fertilizer inputs had been cut in response to high prices in 2008, their effect could not have been seen until the next harvests, typically almost a year later. But the 2009 harvests in general showed good yields.

Was it Low Interest Rates?

One early rationalization of the price increases seen recently, emphasized by Frankel (2007), is that they are generated by low interest rates. In figure 7, a lower interest rate would shift upwards below the kink p^* , and the market demand below it. The induced stocks reduce price volatility by reducing the effects of subsequent harvest shortfalls or other negative shocks to available

supply, or positive shocks to consumer demand. But once the interest rate has fallen, if it remains low it encourages greater storage which tends subsequently to stabilize, rather than destabilize prices; the expected rate of price increase when stocks are positive is also reduced.

Price Bubbles?

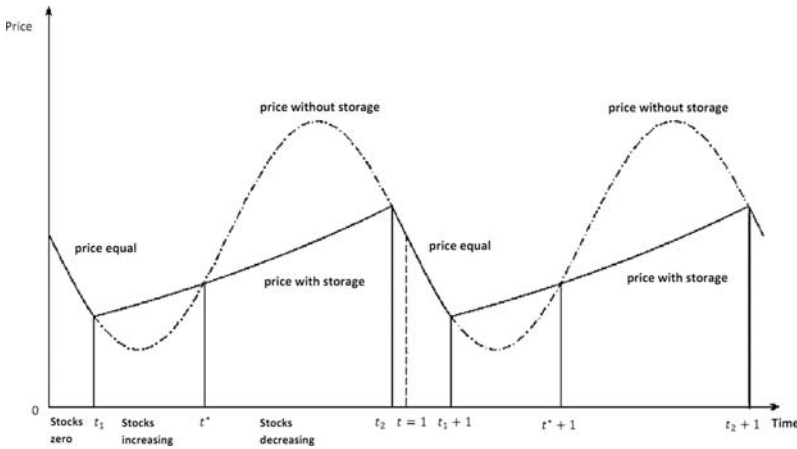
Perhaps the most prevalent explanations of recent commodity price behavior focus on “bubbles,” which every economics student knows have been of concern to investors at least since the time of the South Sea Bubble, when the modern limited liability corporation was in its infancy.⁸ A first problem encountered in evaluating these explanations is the tendency to proceed without reference to any model of speculative behavior, nor mention of any hypotheses to be tested of direct relevance to policies to be considered, nor indeed to any definition of “bubble.” Often it is unclear whether bubbles include price movements consistent with an equilibrium model, or with rationality in general, but it is frequently implicit that, whatever the nature of the bubbles under discussion, they are self-evidently undesirable if not aberrant.

A main common feature of bubbles implied in most discussions is that price rises at the rate of interest, or at a higher, “explosive” rate (Gilbert 2010), for a sustained period, then typically quickly crashes and enters a period of quiescence. Although observers are often unsure of their ability to spot a bubble in progress, there is wide agreement that serious bubbles become obvious after a sequence of price run-up and crash has been completed, apparently viewed as establishing that the rising price sequence was incompatible with the market fundamentals, the latter also typically undefined.⁹

Intuition might tempt us to assume that a necessary condition for price runs and crashes is some form of uncertainty if not a “bubble”. Pyatt (1978) reminds us that this is not the case. Consider figure 8, similar to Pyatt’s figure 2, p. 755. It shows a deterministic annual cycle of prices following a sine curve, generated by a seasonally varying continuous flow of product feeding a fixed down sloped demand, given storage of output is not possible. It also shows prices generated in the model if storage of output is allowed, given a constant interest rate, no other storage costs, and competitive profit maximization. From the beginning of the year until date t_1 output and consumption are increasing and price is falling fast. At t_1 storage begins, so although output is still increasing, consumption starts to fall from its annual maximum and price rises at the rate of interest. Stocks accumulate as production rises to its maximum, where price without storage (the dashed line) reaches its minimum, and continue to rise until t' . Then stocks are run down from their maximum as production falls below consumption. Price continues to rise, and consumption to fall, as supply falls to its minimum at m_3 , and the rise continues, at the rate of interest,

⁸Kindleberger’s (2005) book has captured the imagination of generations of students with tales of the South Sea Bubble and tulips selling for the value of a castle. A large literature in finance has argued that bubbles are not necessarily prevented by contrarian investors with limited resources.

⁹See for example Timmer (2009) p.1: “Did speculation affect the formation of rice prices during the rapid escalation of prices in world markets late in 2007 and early in 2008? Although debated at the time, in retrospect – after the sudden collapse of most commodity prices and the rapid decrease in rice prices between June and August – the answer is easy. Of course it did.”

Figure 8 Price “bubbles” and “crashes” in a deterministic model with variable supply

until price reaches its annual maximum at t_2 , and stocks run out. Price then falls fast again, as it did at the start of the previous year, until storage starts again at $t_1 + 1$. Those who consider production and demand as the “fundamentals” of this model might note that price is rising in two different intervals in which excess demand is falling (between t_1 and the date when the price without storage reaches its first minimum, after production has reached its peak, and between the first maximum of the dashed line (price without storage) and t_2 , after production reached its minimum). Clearly, if a crash after a sustained price rise defines a bubble, this example qualifies, but there is no reason for any intervention in this market.

In the above deterministic heuristic model, although one cannot infer from the direction of price change whether production or excess demand is rising or falling, it is reassuring to know that consumption on the stationary demand curve is rising when price is falling, and vice versa. This inference does not generalize to models of random production. The simple annual discrete time model illustrated in figure 7 provides some additional hints of inferential pitfalls. The figure illustrates a case where annual harvest is *iid* and has a symmetric distribution with a mass point of probability of say 0.4 at the mean. In period 0, if current stocks to be carried into period 1 are current price $p_0 = p^*$ the expected price satisfies the storage arbitrage condition; it exceeds current price by the rate of interest $r > 0$, as in a bubble. On the other hand the initial price p^* is above the median for period 1, so it is more likely to fall than rise next period. Storers will most likely (with probability at least 0.7) make a loss, and if they do, an observer could rightly comment that hoarding was “excessive when compared to the likely outcome under competitive conditions with informationally efficient expectations,” as Ravallion (1985) concluded in his pioneering study of the 1974 Bangladesh famine. However, this does not imply his further inference that the “market failed in its primary function of equilibrating notional demands through price adjustment,” if the market’s function is to maximize expected profits by arbitrage decisions focused on the conditional mean of price, as distinct from the conditional median or mode.

The problem is that the non-negative storage value, zero, appropriate for the most likely outcome (the median and mode, a harvest of 0.5) does

not maximize expected profit when initial price, for example $p_0(m)$ is just below p^* and initial stocks x_0 to be carried forward are small but positive amount. The expected profit is not the most likely profit; the expected value is not the most likely realization. With probability less than 0.3 the best ex ante choice of x_0 will be too low ex post; the bubble will continue, price will rise at a rate larger than the interest rate and consumers will be desperate for more food. With probability at least 0.7 the ex ante choice of x_0 will be too high ex post. The bubble will “burst” and price will fall. For initial prices above unity but below p^* , storage arbitrage is more likely to result in a loss than a gain. Nevertheless, storage here, by construction, maximizes expected profit. The gains, when they come, are on average so much larger than the average loss that the difference covers the average interest cost. Like commodity prices, the returns to stockholding are in general skewed.

Given linear consumer demand, in this model expected price exceeds the current price only if stocks are positive. As stocks rise towards the cutoff price p^* , the realized rate of increase tends to be larger, and volatility also increases. It might be tempting to conjecture that this increasingly volatile behavior is induced by the imminence of the stockout and the associated kink in market demand.

One might imagine that a model in which stocks are always positive and expected price for next period always rises at the rate of interest would display behavior sharply different than models with stockouts. But that is not true. If, in a model like the one above, consumer demand is changed to a case in which price goes to infinity as consumption approaches zero, there will never be a stockout in equilibrium and, as the horizon recedes, the path of successive expected prices, conditional on the current price, rises at the rate of interest. Existing analytical results can be extended to cases of this type, which have an invariant distribution of price, with infinite mean. Dynamic programming can approximate solutions to such models arbitrarily exactly, as shown by [Bobenrieth et al. \(2008\)](#). Price has runs in which it rises faster than the rate of interest, then crashes. As price rises, the probability of a continued rise falls, but its expected size, given a rise, increases. The sample paths starting at any time do not follow the path of expectations conditional on price at that date¹⁰; indeed that path of conditional expectations, rising as the horizon recedes, eventually becomes an upper bound. Although expected price always exceeds current price, the price process is stationary. Importantly, it is impossible to distinguish empirically such processes from all those generated by models such as the Gustafson model in which stocks go to zero in finite time with probability one, and conditional expected price does not always rise at the rate of interest.

None of these models is in any meaningful sense necessarily irrational or inefficient, so policy interventions cannot be justified on these grounds. However, interventions might well be attractive to governments in some circumstances. Forcing “speculators” to release their stocks for consumption when price is high will reduce current price, increasing consumer welfare. Next period, the price is most likely lower, in which case the policy appears beneficial ex post; consumers gained and the speculator appears to have

¹⁰To fix ideas here, think of a toss of a fair coin that yields +1 if Heads, -1 if Tails, each with probability one half. The outcome equals the expectation (zero) with probability zero.

been intent on manipulation if not irrationally “greedy.” But in the less likely cases in which the price would have risen, the intervention makes the outcome much worse for consumers. The higher the price, the better the chance that intervention will turn out well, so a desperate government might well consider the intervention to be a good bet if it is concerned mainly with food riots that threaten its own short-term survival.

The reality that overall grain availability increased in 2008 prompted rationalizations of the crisis in the grain markets something like the following: there were irrational or manipulative bubbles attributable to “greedy” speculators that burst in the spring and summer of 2008. In 2007, one story goes, prices got out of line in the grain markets and supplies were withheld in anticipation of greater profits later. The sharp reversals of grain price trends in different months of 2008 are viewed as confirmation of this interpretation: “bubbles” proved unsustainable, as bubbles always are, and burst at different times. Given the recent history of financial markets, an explanation dependent on greed and irrationality is both plausible and appealing.

Excess Global Liquidity

A related set of arguments points to the entry of holders of new and cheap capital into commodity futures markets in the past few years as a key cause of grain price spikes. One part of the argument has some plausibility and is favored by respected researchers in international finance. A brief sketch goes as follows. A large pool of global capital accumulated largely in China was invested in the United States housing market until that market collapsed. Hoards of these global dollars, seeking new targets, were dumped into the commodity markets through hedge funds and other investment vehicles. These new dollars caused commodity prices to soar.¹¹

All but the last sentence is plausible. The real cost of capital to major financial and commodity markets was low until the United States financial sector descended into disarray, and international dollar surpluses were a part of this phenomenon. As previously noted, lower interest rates tend to be associated with higher stocks and higher current prices, but lower expected rates of price increase. But the facts regarding key agricultural commodity market behavior noted above fail to imply any causal relation between the cash inflow and commodity price spikes. This is not surprising. No one has demonstrated that this cash increased grain stocks during price spikes in 2007/08. If the excess cash caused a bubble, it must have reduced consumption and increased stocks of grain. But in 2007/08, stocks in the relevant global markets for the major grains were, as far as we can tell, at or close to minimal levels necessary for commercial operations as prices rose to their peaks.¹² As Krugman (2008) has argued, if the cash inflow did not increase stocks, it cannot have reduced consumption and raised the market price in the short run. Calvo (2008) has countered that consumer demand could be vertical, so that price could spike due to an increase in demand for stocks by speculators without a change

¹¹ See Caballero et al. (2008) for a version of this argument focused principally on the oil market.

¹² This argument does not refer to finite resources such as petroleum. As Caballero et al. (2008) indicate, in the case of oil efficient inventory response is observed as a production slowdown; oil is stored most cheaply by delaying extraction. In the case of oil prices the implications of optimal cartel response have been neglected in the recent literature on price behavior.

in consumption. The latter argument is hardly relevant to grain markets in which a prime concern is the reality that, as prices rise, they do in fact reduce consumption on the consumer demand curve, in extreme cases causing food deprivation, hunger and even death.

A less extreme version of the hoarding story, articulated by von Braun et al. (2009), is that reduced supply induces a price rise, but that outside noncommercial investors prevent stocks from falling as much as they should in a free market, raising price further. This rationale is not in general testable in the absence of a clear indicator of stock levels consistent with “fundamentals.” In any case, it does not explain spikes associated with clearly minimal stocks.

It is clear that the lack of discretionary stocks in the relevant markets indicates that spikes were not induced by a bubble caused by financial speculation. However, had speculation actually increased stocks in 2007/08, profits would have been realized only if they were released before prices reached their peaks. Such releases would have moderated the price rises. If they were held even as prices crashed, then speculators did not cause the crash. If stocks were held through the peak, would policies that forced the holders of such discretionary stocks to relinquish them earlier have been prudent *ex ante*? If the harvests in 2008 had been lower, consumers could have benefited greatly from larger available supplies.

Market Panic

Timmer (2008) has a cogent description of the relevance of consumer hoarding in the face of expected shortages as a plausible feature of bubbles and “hoarding” by consumers, especially in the market for rice in contrast to wheat, which must be converted to flour or other consumer products before use by consumers. Beyond that, discussion of bubbles and excess liquidity have utterly failed to demonstrate that stocks have been too high in the global market recently, even if one ignores the prudent precaution of saving some grain should a worse harvest follow a bad one. However, there is evidence for all to see of massive hoarding by exporter governments who have made their stocks unavailable to the global market by restricting supplies to protect (or placate) their own consumers. As has been well documented, starting with the announcement by India in October 2007 that it would ban rice exports to protect its domestic consumers from a shortfall of wheat, one exporter after another restricted, taxed or banned exports, and importers attempted to protect themselves by lowering trade barriers and buying up supplies early. All this has been reviewed elsewhere, but those vociferous about putative hoarding have focused on charges, apparently unsubstantiated, directed mainly at private traders and financiers rather than on the huge stocks held off the global market in the recent price spikes, by many regular exporters, and especially by China.

Income Expansion in India and China

Early discussions of the food crisis emphasized a link to the concurrent rapid increase in incomes in both China and India. This emphasis appears to have been misplaced. Baffes and Haniotis (2010) remark that though wheat and rice consumption grew at near 2% per year from 2003-08 in India, consumption of both grains was reported to be stagnant over this

period in China, perhaps reflecting an initial level of consumption per capita that was closer to satiation. They report that corn consumption accelerated in India, and also indicate that consumption in China lagged the global average. While there are questions about the accuracy of these data, increase in aggregate grain consumption in India and China could hardly have been unexpected by 2007. The increase of corn consumption in other countries might have been more surprising, given incomes grew more slowly on average than in India and China. We might put down the doubling of the growth in corn consumption worldwide as a very significant persistent shock, since it is the same order of magnitude as yield growth, it would be difficult to accommodate with no price change even if anticipated. Informative discussions of these issues from various viewpoints are available elsewhere.¹³

If international income growth, population growth, futures market speculation, supply shocks, irrational bubbles and global financial flows do not in the aggregate explain the recent grain price spikes, what does? The answer is that, in a market with otherwise adequate but with diminishing excess capacity, new biofuels demands could not be accommodated without substantial price spikes in markets for food calories.

Biofuel Demand

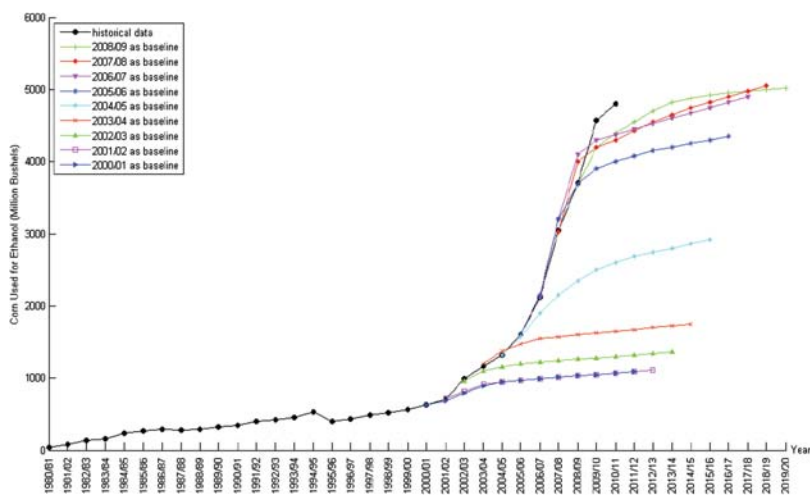
The most obvious large exogenous shock to grain markets in recent years is clearly the surge in biofuels demand; diversion of oilseeds into biodiesel in Europe, the United States, and elsewhere and conversion of corn into ethanol in the United States.¹⁴ In the United States in particular, the diversion of corn and soybeans to biofuel is now very substantial (more than 30% (net) for corn and 20% for soy) and will continue to increase under current policies using subsidies and mandates, in addition to protection from competition from more efficient Brazilian sugar-based ethanol production that might less directly stress short-run food supplies.

These diversions were introduced quickly. USDA annual projections show huge revisions of the upward path of projections (usually exceeded) for use of corn for ethanol over the next half-decade both in 2006 and in 2007 (Trostle 2008), as shown in figure 9. To put the magnitude of these diversions in perspective, a reduction in United States corn output available for non-fuel uses has happened only once since the 1970s, in 1983/84, when stocks were large. The southern corn leaf blight infestation of 1971, which cut U.S. corn output by only around 15%, was viewed at the time as a very serious shock. It directed new attention to the security of the U.S. food supply in general and in particular to the conservation of plant varieties for agriculture and diversification of genetic resources available to plant breeders. Furthermore, the mandates for diversion of United States corn for biofuel, are quasi-permanent, and indeed slated to increase. This they have had much more serious implications for supplies of corn for feed and food, relative to equivalent yield drops due to transitory, weather- or disease-related shocks.

¹³See Abbott et al. (2008, 2009), Mitchell (2008), Timmer (2008), Headey and Fan (2008) and Gilbert (2008).

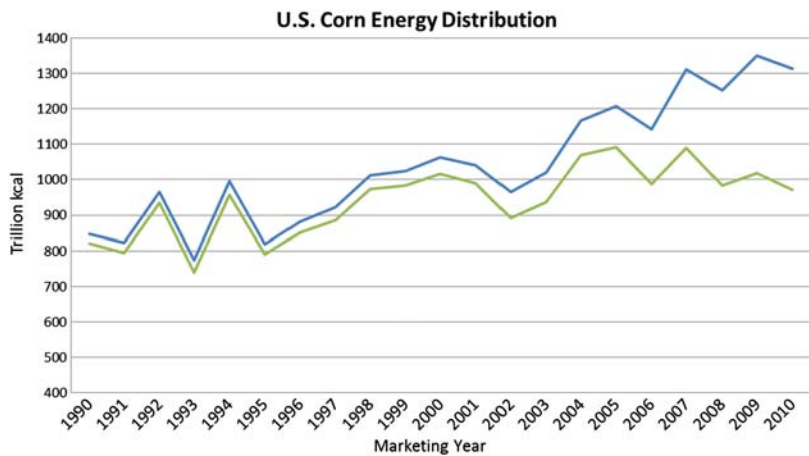
¹⁴Though Brazil is a major biofuel producer (using sugar cane), its production reportedly has not diverted large acreages from grain production.

Figure 9 USDA Agricultural Baseline Projection (2002–2010)



Source: USDA Feed Grains Database (2010)

Figure 10 U.S. Corn energy distribution



Source: Calculated using supply and use data from Feed Grain Database, USDA. Annual supply-use statistics provided by USDA are on a marketing-year basis

These successive revisions, along with the surge in corn demand for feed worldwide, were too great to be made up in the short run by increased yields. Figure 10 shows the total energy in available corn gross and net of total energy taken away from the food and feed market and not returned as byproducts for animal feed, that is, the total energy in corn-based ethanol plus the energy loss through production process.

It is hard to believe that, if a multi-year drought had reduced the supply of United States corn available for 2008, 2009 and 2010 to the level available in the year 2000, and corn prices had soared, that there would be any dispute that the drought was a dominant influence on the price move. In the case of biofuels, the effect of this very large exogenous diversion, ramped up over a few years, has been treated as if it were a relatively

minor market disruption in several influential policy pieces. On the other hand, [Runge and Senauer \(2007\)](#), [Mitchell \(2008\)](#) and [Abbott et al. \(2002\)](#) were early papers that recognized the implications of sharp mandated increases in corn ethanol for corn prices.

United Nations Special Rapporteur [De Schutter \(2010\)](#) notes that advocates of the position that price jumps were the result of adverse movements in food supply attribute price spikes to “factors such as a decline in the rate of growth of food production, climate change and water depletion, and the promotion of biofuels,” with a sole footnoted reference for each factor ([Trostle, 2008](#); [FAO, December 2009](#); and [Mitchell 2008](#), respectively.) His only mention of supply and demand fundamentals for corn, beyond a cogent argument against a strong role for demand growth in India and China, is to note that although corn stocks remained low when price was spiking, production remained high. De Schutter makes no mention of the quantitative implications of biofuels, and indeed mentions biofuels only once more, to conclude that “the promotion of biofuels and other supply shocks were relatively minor catalysts...” of a giant speculative bubble that explains the commodity price increases. [Baffes and Haniotis \(2010 p.12\)](#) note that the increase in use of US biofuels over one year, 2007, has been calculated by the United States Department of Agriculture (USDA) as accounting for a rise in the US CPI of only 0.1 to 0.15%. At the USDA, [Trostle \(2008 p.25\)](#) does note that a fifty percent rise in the price of staple foods represents an increase of less than one percent in the percentage of income spent on food by a representative consumer, but adds balance by remarking that the same percentage increase means a 21 percent increase in the total food expenditure for a consumer in a low-income country. [Baffes and Haniotis \(2010 p.12\)](#) also frame the effects of corn ethanol policy as follows:

“Clearly US maize-based ethanol production, and (to a lesser extent, EU biodiesel production) affected the corresponding market balances and land use in both US maize and EU oilseeds. Yet, worldwide, biofuels account for only about 1.5 percent of the area under grains/oilseeds (Table 3). This raises serious doubts about claims that biofuels account for a big shift in global demand.”

Perhaps those doubts would be less serious if, instead of measuring the effect on supply in terms of a highly heterogeneous input, land, with average yield far below that of the United States, the effect of corn diversion alone were stated as “about 30% of United States corn output,” or “greater in calories than the entire increase in global calories available from wheat or rice since 2002,” as is evident from figures 8 and 9 above.

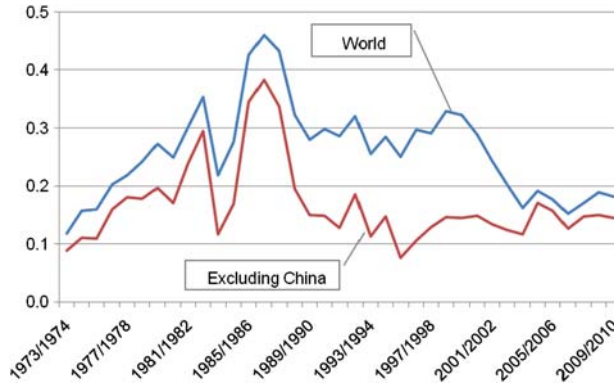
Baffes and Haniotis offer the further comment:

“Even though widespread perceptions about such a shift played a big role during the recent commodity price boom, it is striking that maize prices hardly moved during the first period of increase in US ethanol production, and oilseed prices dropped when the EU increased impressively its use of biodiesel. On the other hand, prices spiked while ethanol use was slowing down in the US and biodiesel use was stabilizing in the EU.”

Although the factual underpinnings of these claims are not clear,¹⁵ they raise the valid question of whether the timing of events in the corn market

¹⁵European Biodiesel Board, July 20, 2010, shows that European Union biodiesel production began to increase at a faster rate in 2004, and grew almost linearly from 2 million metric tons to 9 million by 2009. Annual soybean prices received by United States farmers grew from \$5.74 per bushel in 2004/05

Figure 11 Corn stocks to use ratios



match the argument that fundamentals are important in the recent price spikes. Storage is not itself a fundamental, but an endogenous response to market incentives.¹⁶ According to the Gustafson (1958) model outlined above, storage arbitrage affects our interpretation of the relation of prices to fundamentals. Headey and Fan (2008) attribute some importance to stocks, but see as a difficulty the fact that average corn stocks outside China, which they see as having no direct role in events recent global market events, were the same in the years 1990-2000 and 2005-2008. We now turn to the question of whether fundamentals, as mediated by storage, are consistent with the spikes we have seen recently in the market for corn and other grains.

Recent Grain Price Spikes: A Story of Supply, Demand and Stocks

If the role of storage is important for the timing of price spikes, then we should expect to observe such spikes only if relevant stocks-to-use ratios are unusually low. What does the evidence reveal? Consider figure 11, which shows global stocks to use ratios for corn and the same ratio excluding China. According to the Gustafson model, low points of the stocks-to-use ratio should be associated with spikes in annual prices.

As figures 11 and 3 indicate, price spikes tend to occur when world stock-to-use ratios are low. For the market to function effectively, a virtually irreducible minimum amount of grain must be held in the system to transport, market, and process grains. Though international stocks data are notoriously imprecise, minimum working stocks carried over from one corn crop year to the next (excluding China), are apparently around twelve percent of use.¹⁷ Price spikes occur when discretionary stocks are

to between \$9.58 and \$10.10 in the years 2007/9 through 2009/10. Energy Information Administration figures show United States corn ethanol production was 264, 358, 449 and 629 thousand barrels per day in the years 2005-2008, when corn prices were spiking.

¹⁶There is some confusion on this point in the literature. (See De Schutter 2010). Headey and Fan (2008) argue that a weakness in arguments that declines in stocks are a factor in food price crisis is that declines in stocks "only represent effects of other factors."

¹⁷Near minimum stock levels, small additional fractions of stocks are placed on the market only when the incentive is very high. These stocks may be in relatively inaccessible locations, given current transport costs, or perform valuable roles in keeping the system operating efficiently, such as avoiding the

negligible. Comparison of figure 11 with figure 3 confirms that stocks are very unresponsive to price at these minimum levels.

According to the stocks-to-use ratio, excluding China, which usually does not engage very significantly in the global market, we should expect price spikes around 1973/4, 1983/4, 1996, 2003/4, and 2007/8. What do the prices show?

The fact that stocks were tighter in 1996 than recently at first glance apparently raises doubts about the relevance of the theory to many observers. Indeed Headey and Fan (2008) noting that stocks were as tight in the 1990s as in 2007/08, conclude that stocks do not importantly explain price behavior. In addressing several large gatherings of economists and policy makers recently, at conferences specifically focused on commodity price behavior and attended by many responsible for policies on food security and price volatility, I have asked the audience to tell me when was the last time the real price of corn was as high as in 2007/08. Many answer "1973." Perhaps one or two respondents in all those audiences have answered "1996," when the price of corn was in fact significantly higher than recently, if appropriately deflated.¹⁸ There is merit in addressing the facts before assessing policy options. Note also from figure 5 that the oil price was low and stable around 1996, laying to rest the oft-heard "rule" that commodity prices spike only when energy prices surge. All the other low points in stocks to use correspond ratio to price peaks, except 2002/03. The figure shows why corn prices did not spike then. At that time China, contrary to its usual practice, sold huge amounts of grain into the global market; few besides Dawe (2009) have noticed its highly stabilizing role. Some recent studies (including Headey and Fan, 2008) have stated that Chinese trade has not recently been a factor in global grain market instability.

Many empirical studies have addressed short run market behavior, and found that other factors are often more highly correlated with shocks than are short run price shifts, or assigned percentages of "blame" to a laundry list of market events that were identified by (non)causality tests on monthly or weekly data. Others such as von Braun et al. (March 2009) have questioned why stocks were not lower in 2008 if biofuels surges were causing corn prices to spike. I leave the evidence from causality tests in the capable hands of Irwin and Sanders (this issue). But adding a stylized illustration of biofuels demand, in the form of a fixed mandate, to figure 7 helps clarify why apportioning percentage shares of blame for price volatility makes little sense, and why studying short-run price response to high-frequency "drivers" is not necessarily informative about the larger forces shifting the market in a sustained fashion. Figure 12 shows heuristically how introduction of an unanticipated biofuels mandate of Δ , equal to stocks held when consumption equals mean production μ , affects the market for feed and food uses, assuming supply response to the mandate is zero. In the figure, without mandates, when there have been several harvests close to the mean, consumption approaches μ and price approaches $F(\mu)$. If a biofuels mandate is introduced at the same time, the identical

use of half-empty railcars. The small feasible changes in these stocks are ignored here; they have negligible effects on food supply or price volatility. For a model of the supply of these stocks, see Bobenrieth, Bobenrieth and Wright (2004).

¹⁸Von Braun et al. (March 2009) reproduce figure 4 from Abbott et al. (March 2009) p. 13 as evidence that corn prices in 1996 were far lower than in 2007/8 without noticing that they are not deflated, and that the real prices reverse the relationship.

Figure 12 The effect of a biofuels mandate on storage demand and prices

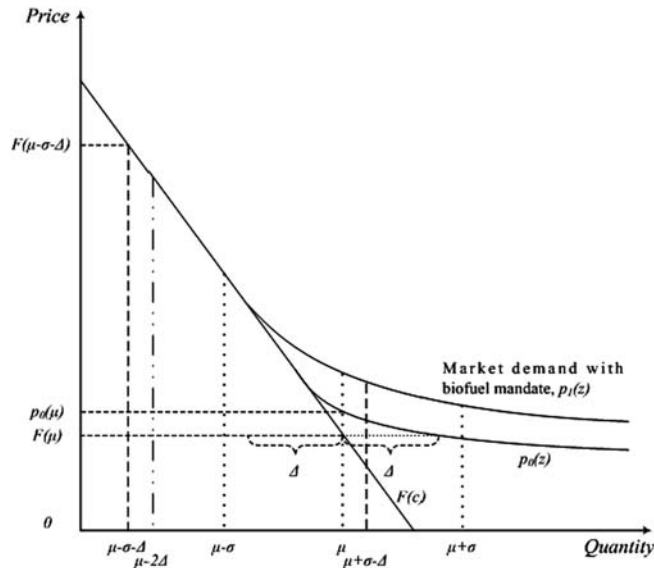
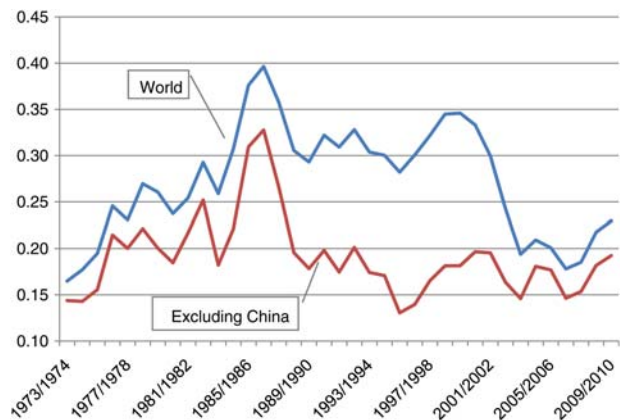


Figure 13 Ending stocks of calories from the major grains*



*World grains (wheat + corn + milled rice) ending stocks to use ratio with and without China (all quantities converted into Calorie content assuming for wheat, 3338Kcal per Kg, for corn, 3650 Kcal per Kg, and for milled rice, 3656 Kcal per Kg).

production shock implies a price around the top kink; in the market for food and feed, the mandate acts in the short run like a leftward shift in the harvest distribution. If another equally bad harvest arrives, available supply for food and feed falls to around $\mu - 2\Delta$ and price jumps up to near the top of the dashed line, just below $F(\mu - \sigma - \Delta)$. With no mandate, this second consecutive yield shock moves price much less, only about as far as the top kink in market demand. In the short run the effects of a supply shock are greatly amplified by the presence of a new and permanent large demand shock like biofuels mandates. On the other hand one can see that, after several good harvests, if mandates do not increase the levels of prices and stocks will tend to be higher than otherwise. Future prices reflect the mandate.

Another notion is that supply responses will solve the problem. In fact there was a large acreage response of corn after mandates were ramped up in 2007. But this clearly came as the response of a large temporary shift away from soy. But in the United States the land constraint on aggregate adjustment appears strong. On the other hand there is strong evidence for global substitution of grain calories in consumption, at the margin.

Modeling crop acreage responses and inter-grain substitution is a task beyond the resources available for this study. A more promising line of investigation is suggested by figure 13, which shows world stock-to-use ratios for the sum of the three major grains (corn, wheat, and rice), adjusted by calorie weights.¹⁹ Around 1996, the world aggregate stock-to-use ratio was much higher than recently. But the world figure was distorted by the huge holdings of China, whose exports were negligible in that period. If China's effect is removed, the ratio around 1996/97 looks as tight as observed in 2007/08. The lack of stocks in both episodes left the market susceptible to large price spikes from small supply disturbances. One possible objection to this assertion is that the ratio was about as tight around 2002-2004 and yet the price changes observed then were much smaller. But in that period, in contrast to the other episodes, China made substantial exports of corn and rice, increasing available supplies in the global grain market. Thus the recent history of grain markets supports two conclusions. First, the price spikes of 2008 are not as unusual as many discussions imply. Second, the balance between consumption, available supply, and stocks seems to be as relevant for our understanding of these markets as it was decades ago. According to the ratio excluding China, while recognizing that country's exceptional exports in 2003/4, we should expect price spikes around 1973/4, 1983/4, 1996, and 2007/8. The spikes in fact occurred in those years.

Conclusions

The recent history of grain markets supports two conclusions. First, the price spikes of 2008 and more recently are not as unusual as many discussions imply. Second, the balance between consumption, available supply, and stocks seems to be as relevant for our understanding of these markets as it was decades ago.

The storability of grains causes the price response to a change in supply to vary with the level of available supply. The major grains—wheat, rice, and corn—are highly substitutable in the global market for calories. When their aggregate supply is high, a modest reduction can be tolerated with a moderate increase in price by drawing on discretionary stocks. But when stocks decline to a minimum feasible level, a similarly modest supply reduction can cause a price spike. In a free market, poor consumers with little wealth may be forced by high prices to spend much of what resources they have on food and reduce consumption at great personal cost. Others who are richer reduce consumption very little even when prices soar.

¹⁹This discussion extends the discussion of the relation of maize stocks to prices, associated with Figure 11 above, to the aggregate of the three major grains. The figure and the associated argument draw on the work of *Dave* (2009). See also *Roberts and Schlenker* (2010).

In 2007/08 the aggregate stocks of major grains carried over from the previous year were at minimal levels, much less than they would have been without mandated diversions of grain and oilseeds for biofuels which were so substantial that they could not be made up by a few years of yield increases, even if yields had not suffered due to years of global underfunding of research and diversion of research resources from production-increasing research. Lack of stocks rendered the markets vulnerable to unpredictable disturbances such as regional weather problems, the further boost to biofuel demand from the oil price spike in 2007/08, and the unprecedented extension of the long Australian drought which would not, absent the mandates, have caused any great concern. However, supplies were sufficient to meet food demands without such great jumps in price, had exporters and importers not panicked, leading to a cascade of export bans and taxes that cut off importers from their usual suppliers. Such panics, which are perhaps inevitable in such circumstances, constitute the real “excess hoarding” that keeps stocks from the needy in times of global stress on supplies such as the current period of excessive support of biofuels production.

If mandates are held at current levels, and petroleum prices do not rise higher, then it is likely that over time the market will adjust to a less volatile equilibrium, on a higher price path than without biofuels that will make participants in the global grains markets pay a high price (estimated by Roberts and Schlenker (2010) to be \$155B annually) for misguided policy. If the political power of those favored by biofuels policies is sufficient, it is possible that mandates could expand to outrun yield increases for many years, and keep grain prices as high and volatile as they are today, preventing poor consumers from continuing to benefit from innovations in agriculture like those that have increased food supplies and lifted so many out of desperate poverty over the past century.

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