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Stocks-to-use ratios and prices as indicators of vulnerability to spikes in global cereal markets

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Abstract

We identify critical stocks-to-use ratios (SURs) for major grains and for an index of total calories from these grains. The latter appears to be a promising indicator of vulnerability to large price spikes when the current price shows no cause for concern. More generally, our results suggest that stocks data, though no doubt unreliable, can be valuable complements to price data as indicators of vulnerability to shortages and price spikes.

JEL classifications: C51, C52, Q11

Keywords: Commodity Price; Stocks-to-use Ratio; Storage

Food price volatility, and policies to address it, are topics of continuing international controversy. One reason for this is that the interpretation of commodity price behavior and risk exposure remains in dispute among economists.

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Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article.

There is a well-established model of commodity price behavior based on storage arbitrage. The model, in the tradition of Gustafson (1958a,b) (see e.g., Deaton and Laroque, 1992; Gouel, 2013; Samuelson, 1971; Scheinkman and Schechtman, 1983; Wright and Williams, 1982, 1984), generates price behavior consistent with many stylized facts of observed commodity price behavior. In the model, stocks can buffer supply shocks, and as discretionary stocks decline and the probability of a price spike increases, the markets transition from “normal” to “fragile.” Despite the straightforward arbitrage-related logic of the model, its analytical underpinnings can be daunting. Its practical usefulness is limited by the quality of available data on prices, production, consumption, and stocks. It is not simple to infer the relationships between production outcomes, prices, and stocks, from observations of market data.

This article addresses the question of how to utilize global market information available at an annual frequency (including imperfect information on global stocks) in order to strengthen the capacity to issue early warnings of possible shortages and price spikes, and thus enhance food security and emergency policy responses to threats to food security. For the purpose of this article we assume that, though price data are problematic and spatially heterogeneous, large price spikes recorded in a central market indicate periods of high consumer prices and reduced consumption, at least for a substantial number of global consumers.

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Here we focus on information available at the start of the crop year, relevant to the next harvest. We consider just four types of data: prices, production, consumption (broadly defined), and stocks of the three major grains, wheat, maize, and rice. We provide evidence that the observed behavior of stocks is more closely related to the behavior of price than is production. We also show that the observed behavior of stocks is similar to that predicted from the price series using an estimate of the standard storage model based on those price observations alone. However the variation from predicted values based on price observation raises the possibility that observations of stocks might be useful as supplemental advance indicators of "abnormal market conditions" even if price data are already available. Some informal tests lend support to this hypothesis.

1. The behavior of prices, production, and stocks

Information on the behavior of the world's grain markets is scarce and of highly variable quality. The dominant indicators are prices, generally measured in an organized market at a specified location for a specified grade of the product. Most consumers live far from that market, and many of them consume varieties and qualities of grain quite different from that traded on the exchange, and at quite different prices. Especially in developing countries, local prices frequently vary markedly from the reported global price (Gilbert, 2011; Jones and Kwiecinski, 2010; Porteous, 2012; Rapsomanikis, 2011).

The nominal price data used in this article are from World Bank/GEM Commodities, for the marketing years ending in 1961–2007.[1] The marketing years for wheat, maize, and rice end in May, August, and July, respectively.[2] We take the annual price to be the monthly average of price observed in the last month of the marketing year. We also study the market for the three grains together as a market for aggregate calories, following the lead of Roberts and Schlenker (2009, 2010). The calories price is constructed as the average of wheat, maize, and rice annual prices with world wheat, maize, and rice production in calories as weights. World wheat, maize (corn), and rice (milled) production data are from USDA/FAS/PSDO. The weight-calories conversion rates are from the USDA/National Nutrient Database. All annual price data are deflated into real price indices using the annual Manufactures Unit Value Index (MUV) from World Bank/GEM Commodities. Note that this index behaves very differently from the United States Consumer Price Index, especially in recent decades; results using the latter could be substantially different. The stocks-to-use ratios (SURs) data are constructed from the wheat, rice, and maize marketing-year ending stock and domestic consumption, from USDA/Foreign Agricultural Service. Because China has in most years of the sample interval managed its stocks virtually independently of the global market, we focus on the global SUR calculated as ratio of world stocks excluding Chinese stocks over world use excluding China.

Beginning in 2006, implementation of increasing United States federal mandates and subsidies boosting the diversion of maize to production of grain bioethanol as a gasoline additive and substitute, and legislation boosting biodiesel based on oilseeds in Europe, have jointly caused a previously unanticipated rapid ramp-up in biofuel demand, larger and more persistent than any recent weather-related supply shock. This has clearly constituted a huge shock to the global market, and its enduring nature (in contrast to typical supply shocks such as droughts or floods) also has increased the demand for stocks.[3] We exclude consideration of biofuels here. We want to establish the nature of normal market behavior and its interpretation, before this new disruptive influence caused market prices to soar to successive new spikes.

Aspects of real price behavior that get policymakers' attention are exemplified in the global price of wheat. Deflated price trended downward since the 1950s, as wheat production outpaced demand growth. Maize and rice prices followed similar downward trends. These are their most important dynamic features from the perspective of human welfare. These trends are principally attributable to the remarkable success of plant breeders and farmers in continually developing and adopting new crop varieties with enhanced response to increased application of fertilizers, and to innovations in production and transportation of fertilizers that have greatly reduced their cost. As prices of these grains trend downward, they generally fluctuate moderately, within a reasonably well-defined range. To obtain an accurate view of price volatility, we need to remove the influence of the trends from measures of variation in real grain prices. We de-trend real prices assuming a log-linear trend, estimated from 1961 to 2007. We use a similar method to de-trend production of each grain.

Episodes of higher "volatility," more informatively characterized as intervals with steep jumps in price, followed by precipitous falls back to the trend, are prominent but sporadic features of the data. These fluctuations are asymmetric, there being no equally prominent troughs to match spikes, and at locally low prices the probability of sudden falls is negligible.

Many analyses of price volatility have focused largely on production disturbances and productivity slowdowns. The link between production variation and grain prices is less easy to establish than one might expect (Greenfield and Abbassian, 2011). A first problem is that production data are derived from different sources, many of dubious reliability. For the case of

[1] We take the marketing year definition from USDA/FAS, recognizing that the definition of the marketing year is problematic, since the grains are produced in both hemispheres, and multiple annual rice crops are grown in some countries. See for example Greenfield and Abbassian (2011) for a discussion of this issue.

[2] See http://www.fas.usda.gov/export-sales/myfi_rpt.htm. Details and sources are available directly from the authors.

[3] Indeed one of the authors has discussed the key role of biofuels in reducing stocks and making grain markets vulnerable to disruption by otherwise minor shocks (Wright, 2011).

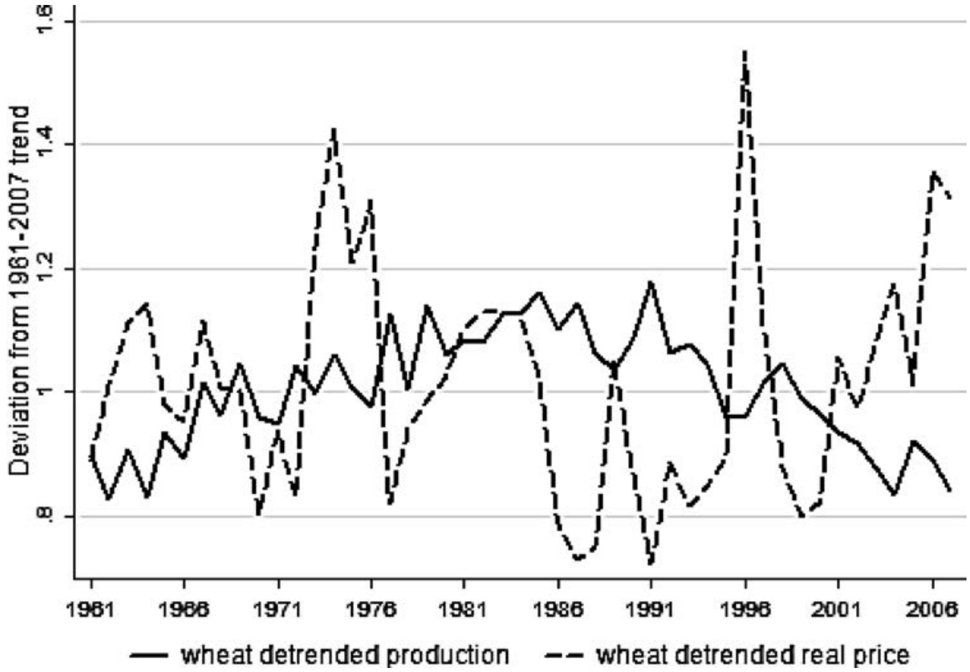


Fig. 1. Wheat de-trended production and de-trended real price in log scale.

wheat, Fig. 1 displays the logarithms of the de-trended real price and de-trended production. For annual fluctuations the correlation coefficients between production and real prices, both adjusted to remove log-linear trends, for wheat, maize and rice, are only −0.33, −0.09, and −0.21, respectively. Obviously, available production data are not closely correlated with price, indeed the highest price peaks do not generally coincide with the worst harvest years.

The reason for the failure of production deviations from trend to match price spikes is attributable largely to an extremely useful attribute of the major grains: they can be stored for years without excessive deterioration. When discretionary stocks are available, an output shortfall can be cushioned by a drawdown of those stocks. But storability is not always useful in moderating a shock to demand or supply. When stocks are already minimal, their cushion is not available. Markets in aggregate cannot borrow food from future production, so price must rise to cause current consumption to fully accommodate a shortfall.

Storage greatly affects price behavior. A convenient measure of the adequacy of stocks is to normalize them in the form of the SUR, the ratio of stocks to consumption, broadly defined. Storage can also transmit effects of a shock in one grain market to the price of a substitute grain in a later period, further complicating inferences about the underlying drivers of price volatility. A grain price might not rise much after a bad harvest shock. But if a drop in the output of grain calories occurs when calorie stocks are low, large spikes in the price of each of the major grains are likely to occur, as seen in 1975. In sum, to understand grain price spikes, one must look at production and consumption disturbances in the context of the current stocks of all the major grains.

This discussion raises the possibility of using the SUR as an indicator of current volatility, and as an indicator of increasing exposure to volatility. Though stocks data are notoriously imprecise (see Greenfield and Abbassian, 2011; Intergovernmental Group on Grains, 1997) they avoid the problems of deflation that plague price data.

As a preliminary exploration of whether the SUR systematically relates to price behavior. Correlation coefficients of SURs and de-trended real prices in the sample period are −0.40, −0.50, and −0.17, for wheat, maize, and rice, respectively.

In sharp contrast to production, the SUR seems to be a good indicator of vulnerability to shocks in each market. This does not mean storage drives price. Stocks are endogenous. They reflect the history of past production and consumption (and waste), and past conscious choices of market participants. They forge a link between past consumption and production and current consumption possibilities. Intertemporal arbitrage can turn an anticipated shock in output into a more gradual price adjustment, and can moderate the immediate effects of an unanticipated shock, if stocks are available.

The uses of each of the major grains are distinct but they overlap, and they compete for inputs such as fertilizer and land. The dynamics of the deflated price series are very similar for the three major grains, giving empirical support to the hypothesis of strong substitution at the margin. The correlation coefficients of the real price series for calories and the real individual price series for wheat, maize, and rice (all de-trended) are 0.83, 0.86, and 0.91, respectively. Assuming perfect substitution, we can study the market for the three grains together as a market for aggregate calories. The possibility arises that an index of the aggregate calories supplied by the three major grains better reflects the state of the market for the major grains than does any of the three component grains.

2. Review of the storage model

In line with the findings of a close relationship between stocks and prices described above (for a discussion see Carter et al., 2011), we explore the empirical implications of the simple competitive storage model at the world level. Rather than incorporating more complexity, we focus on the empirical usefulness of the standard model to identify SUR levels that imply high risk of a price surge.

Time is discrete. Available supply is the sum of stocks carried from the previous period plus net supply shock (net "harvest"). Total market demand is defined as the sum of consumption plus storage demand. Storers are risk neutral, face a constant discount rate $r > 0$, and form rational expectations. Supply shocks (net of any demand disturbance), denoted by ω_t here, are $i.i.d.$ with compact support $[\underline{\omega}, \overline{\omega}]$.

Total net expected profits from storing $x_t \geq 0$ units from period t to period $t+1$ are given by

$$\frac{1}{1+r} E_t \left[p_{t+1} x_t \right] - p_t x_t, \tag{1}$$

where E_t denotes expectation conditional on information available at time t, and p_t, p_{t+1} denote prices at periods t and $t+1$, respectively. If storers decide on a positive level of stocks, then the hypothesis of an arbitrage-free equilibrium requires that total net expected profits are equal to zero. If discretionary stocks were zero and expected price for next time period (net of financial and storage costs) were below the current price, then storers would want to maintain negative levels of stocks. At the individual storer level, this could be done by borrowing units of the commodity. However, this is not feasible for the market as a whole. This defines a threshold price, p^*, above which discretionary stocks are constrained to be no less than zero (a "stockout").

The inverse consumption demand for the representative consumer is denoted by $F : \mathbb{R} \rightarrow \mathbb{R}$, with $F' < 0$. We assume that $F(\bar{\omega}) > 0$. Total available supply is denoted by z_t. By definition, $z_t \equiv \omega_t + x_{t-1}$. That is, total availability of the commodity in period t is furnished by contemporaneous production in period t, plus previous storage.[4] Given the level of total available supply z_t and consumption c_t, equilibrium price is

$$p_t = F(c_t) = F(z_t - x_t). \tag{2}$$

A stationary rational expectations equilibrium (SREE) in this model is a price function p which describes the current price p_t as a function of available supply z_t and which satisfies, for all time t,

$$p_t = p(z_t) = \max \left[F(z_t), \frac{1}{1+r} E_t p(\omega_{t+1} + x_t) \right], \tag{3}$$

where E_t denotes the expectation taken with respect to the net supply shock to be realized at time $t+1$, and

$$x_t \equiv \begin{cases} z_t - F^{-1}(p(z_t)), & \text{if} \quad z_t < z^* \equiv \inf\{z : p(z) = 0\} \\ z^* - F^{-1}(0), & \text{if} \quad z_t \geq z^* \end{cases} \tag{4}$$

The existence and uniqueness of the SREE as well as several of its properties are proved for various versions of the storage model in Scheinkman and Schechtman (1983), Deaton and Laroque (1992, 1995, 1996), Cafiero et al. (2011), and Bobenrieth et al. (2002, 2012). We assume no convenience yield.[5]

3. Econometric estimation

This section discusses our empirical estimation strategy. Here we present a general overview of the method, technical details of the estimation procedure can be found in Cafiero et al. (2012).

For our econometric estimation we follow the approach of Deaton and Laroque (1992, 1995, 1996) in using only price data (for a discussion on data availability, see Greenfield and Abbassian 2011). Cafiero et al. (2012) show that, conditional on information on the harvest shocks and the consumption demand structure, their Full Information Maximum Likelihood (ML) approach performs markedly better than the other two econometric methods that are by now standard in empirical estimations of dynamic economic models with micro foundations for commodity prices: Generalized Method of Moments and Pseudo Maximum Likelihood. In this article we implement ML.

Informed by prior work on the implicit cost of capital in commodity markets, we implement our estimators with a real discount rate of 2%. We use a linear inverse demand function relating price to consumption,

$$F(c) = a - b \cdot c. \tag{5}$$

The use of de-trended prices and linear demand impose conditions on the implied de-trended model, which we acknowledge in the estimations. The ML parameter estimates shown in Table 1 for maize and rice are strikingly similar, as are the implied values of their threshold prices p^*. The slope coefficient on consumption, b, is somewhat lower for wheat. In addition, the stockout price is lower for wheat. The results imply 5 stockouts in the sample for wheat, and 6 for maize and rice in the 47-year sample. For the aggregate of these grains, the results imply only

[4] For simplicity, we set deterioration, and the direct cost of storage, both at zero.

[5] Bobenrieth et al. (2004) present a storage model of backwardation with a marketing cost function consistent with some of the informal arguments in the literature that relates convenience yield to the cost of sales.

Table 1
ML estimates

	a	b	Log-likelihood	Threshold Price p^*	Number of stockouts
Wheat	0.9085 (0.0398)	0.7912 (0.0263)	14.1718	1.2360	5
Maize	0.8917 (0.0312)	0.9729 (0.0278)	3.1982	1.2977	6
Rice	0.9132 (0.0230)	0.9747 (0.0395)	0.3474	1.3053	6
Calories	1.0072 (0.0339)	0.9748 (0.0187)	14.7095	1.4005	2

Note: Standard error in parentheses.

two stockouts. It makes sense that stockouts in aggregate grains should be less frequent than for each grain individually.

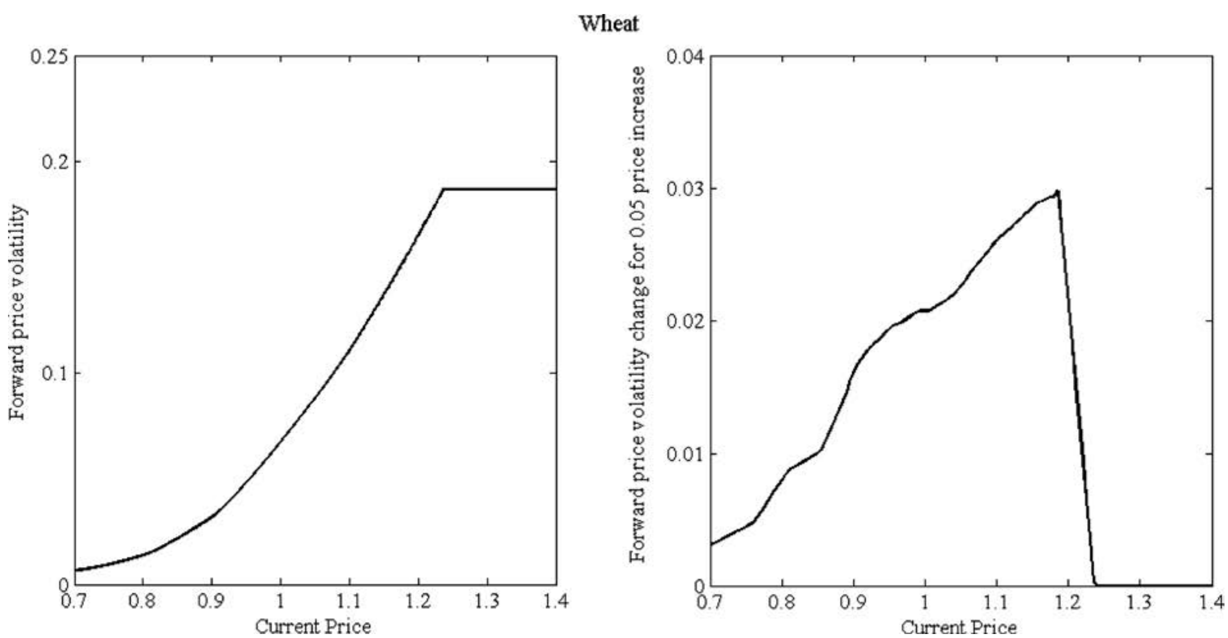
For identifying periods of market vulnerability to shortages (typically associated with price jumps) it is not so much the precise location of the stockout that matters, but the location of a price (or a range of prices or SURs) with conditional variance for the next time period that is highly responsive to changes in available supply. Based on our ML estimates, we derive the relation between the de-trended price level and the variance of next year's price. Fig. 2, left-hand panel, shows the relation for wheat.

Well before the market enters the stockout regime, as stocks fall and price rises, the probability of a stockout or of a price spike in the next period begins to increase substantially. The right-hand panel of Fig. 2 shows the increase in variance for the next time period from step increases in current price, as a function of current price. In the neighborhood of 1.05 there is an inflexion point (the behavior of the conditional variance for maize and rice at that price is similar). This suggests that an increase of vigilance about price spikes is warranted around a de-trended price of 1.05.

Assuming prices and stocks are measured accurately, and that the empirical model is correct, stocks data would add no information to that available from price data. We next explore this possibility.

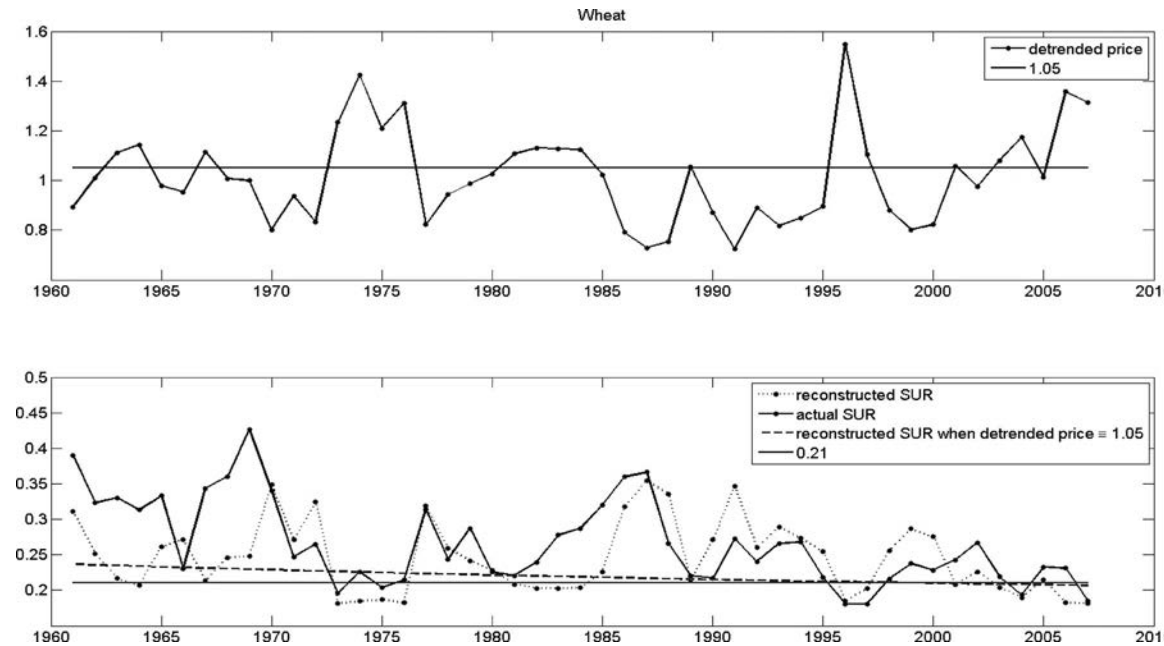
4. Implications of prices for SURs: application of the estimated model

Under the assumption that the markets for the three grains are independent, we can derive series of implied SURs for wheat, maize, rice and aggregate calories, using their respective prices as data. For each price, we calculate the implied normalized stocks and consumption from the storage demand at that price, and then adjust to make the implied stocks-to-use ratios comparable to observed trending SURs. More specifically, using the ML estimation results above to specify the storage demand and the consumption demand for each grain and for aggregate calories from all three grains, we derive the SUR implied by each observed price as the ratio of stocks to consumption at that price, normalized for magnitudes of the mean and variance, and recognizing the trend. Given our linear demand specification, time trends in prices imply time trends in the SURs implied by our estimations. The adjustment for essential stocks is calculated as a fixed fraction of consumption at the stockout price



Note: The left-hand panel is the conditional volatility of forward price for wheat. The right-hand panel is the change in conditional volatility of forward price if the current price increases by 0.05.

Fig. 2. Forward price volatility for wheat and increase in forward price volatility for increase in current price.



Note: The reconstructed SUR is the implied stock-to-use ratio by the model given observed price, considering the effects of trend in price and quantities. The actual SUR is the observed stocks-to-use ratio.

Fig. 3. De-trended price versus SUR for wheat.

p^*, where this fraction is chosen to match observed minima of the SUR data.[6]

The upper panel of Fig. 3 shows the de-trended observed global real prices of wheat from 1961 to 2007. The implied SURs for wheat are shown in the lower panel. The observed SURs estimated for the world, including essential working stocks, are also shown in that panel. The actual and implied SURs are strongly related; the model estimated from prices captures a substantial amount of information about consumption and stocks. However the two series also exhibit important differences. In the early 1960s, the reconstructed SUR is substantially below the observed series, and this is also true from 1967 to 1969, and again from 1983 to 1985.

As Fig. 4 shows, the reconstruction of the SUR for rice does not track the observed SUR nearly as well as do the reconstructions of SURs for wheat, although movements of the two series are clearly strongly related overall. The reconstruction produces a large overestimate of the SUR from 1960 to 1965, and a large and persistent underestimate after 1994. There are also substantial divergences in the early 1970s, from 1978 to 1981, and from 1985 to 1987. For rice, the observed SUR series appears to be on an increasing trend, in contrast to the reconstruction from the price data. However, variations of the measured SUR for rice and its reconstruction using the model estimated on price data do appear to be positively related.

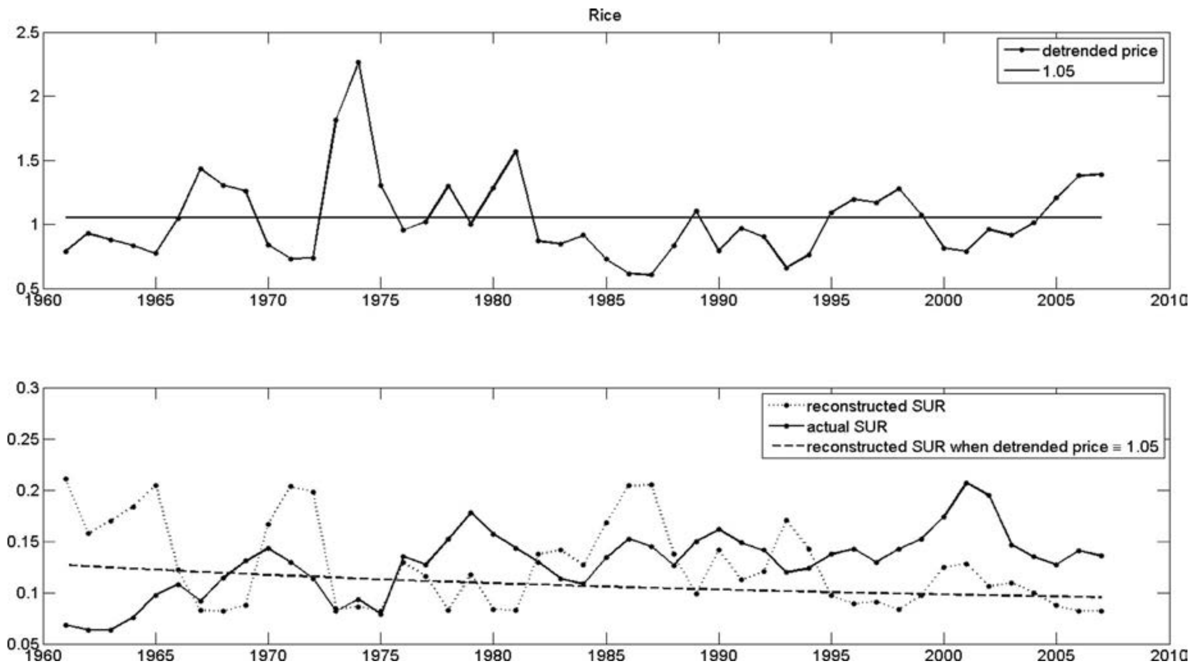
The reconstruction for aggregate grain calories offers strong evidence against the assumption that the three major grains have independent markets. As Fig. 5 shows, the reconstruction tracks the observed aggregate SUR remarkably well, especially in the early 1960s when the reconstruction substantially exceeds the observed SUR for rice, and late in the series (after 1995) when rice SURs surge above their reconstructed values. The reconstruction also tracks the actual SUR much better for calories than it does for wheat in the first half of the 1960s. The aggregate measure accounts for substitution between grain calories, and Fig. 5 suggests that substitution in stocks can be very important. Large stocks of rice appear to encourage reduced carryover of the competing grains, and vice versa.

Given that there are serious problems with the accuracy and representativeness of both price data and stocks data, we next explore, using the available evidence on infrequent episodes of price spikes, the possibility that the use of stocks series in addition to price data might improve inferences about the danger of oncoming price spikes and supply shortfalls.

5. SURs as indicators of vulnerability to price spikes

In the market for grains it is very clear that information is incomplete, and that information about the current situation at any time is difficult and costly to obtain and organize. In the United States, for example, the Department of Agriculture releases World Agricultural Supply and Demand Estimates (WASDE) reports of stocks and harvest prospects during the crop year, and these reports, which aim at nothing more than aggregating information in principle observable literally “on the ground,” very frequently cause prices on commodity markets to jump

[6] If there is a trend in the fraction of pipeline stocks we shall not recognize it here.



Note: The reconstructed SUR is the implied stock-to-use ratio by the model given observed price, considering the effects of trend in price and quantities. The actual SUR is the observed stocks-to-use ratio.

Fig. 4. De-trended price versus SUR for rice.

upon their release. Hence, before release, stocks estimates must contain information not anticipated and therefore not reflected in current prices or in other accessible data.

Further, as emphasized above, prices recorded in the global grain market come from one or at best a handful of markets, and do not accurately represent the marginal value to global consumers. Prices faced by consumers vary by quality and location, and in some countries they might reflect taxes or trade bans that distort prices. Similarly, stocks data are not accurately reported. For example, changes in unreported stock holding of farmers or traders, or of consumers (see Timmer, 2010), can be important.

Public stocks are often managed in a way that reflects government objectives rather than market reality, and in many cases the size of public stocks is kept secret for strategic purposes. Large private corporations might also see strategic value in keeping the size of their own stocks confidential. The above discussion implies that correlations between reported SURs and prices of each grain will be far from perfect. Indeed, the correlation coefficients between SUR for each market and each of the respective grain prices is negative, but none is above 0.6 in absolute value. Prices and SURs obviously contain some information and/or noise not common to both.

The usefulness of the aggregate calorie measure is confirmed by the fact that each detrended grain price is more highly correlated with the SUR for calories (−0.50, −0.57, and −0.47 for wheat, maize and rice respectively) than with its own SUR (−0.40, −0.50, and −0.17, respectively). The correlation coefficient of calories SUR and calories de-trended real price is −0.58.

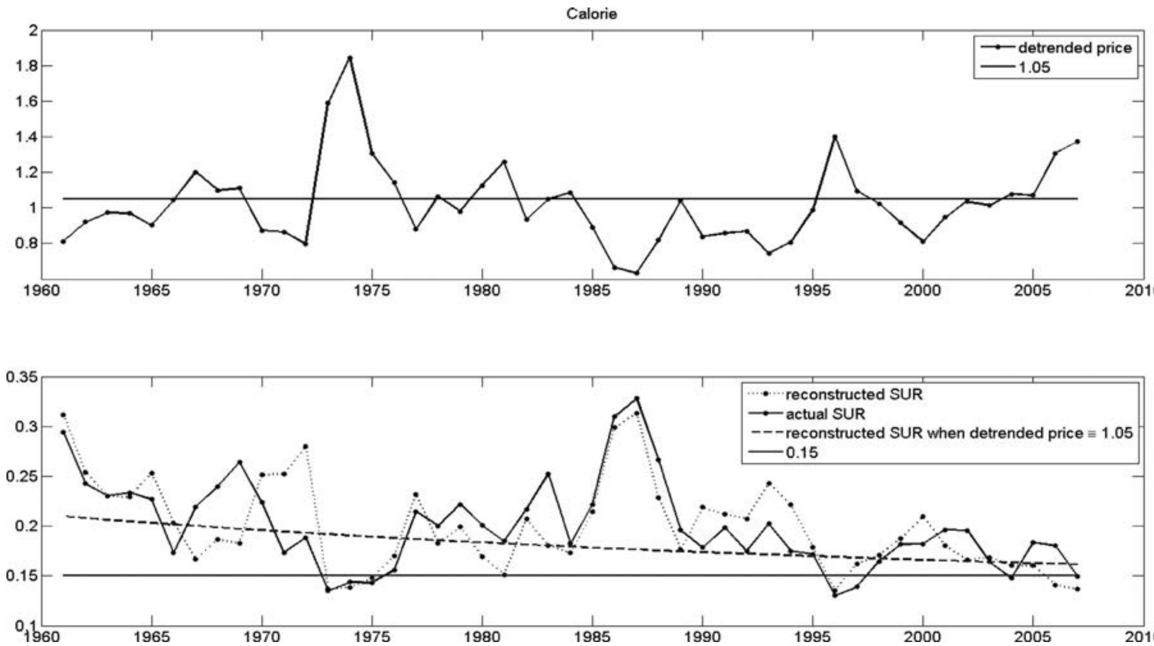
We now address the key question: In a world with unreliable but widely available price data, can unreliable stocks data add valuable, though error-ridden, information about market vulnerability to near-term shortages of supply and spikes in price?

Suggestive evidence is provided by transition probabilities constructed from the data for prices and SURs calculated from market observations. Tables 2 and 3 show the transition matrices for prices and stocks of calories, respectively, using five bins in each. Clearly transitions from any bin tend to go to nearby bins. Large jumps in calorie prices are uncommon in general, but there is an 11% chance of jumping from the lowest price bin to the highest. On the other hand, there is no jump from highest to lowest SUR bin. This suggests that, when price jumps or spikes occur starting at a low price, the SUR is likely to be closer to a warning (low) level.[7] We investigate this possibility in the next section.

6. Can SURs signal warnings of shortage not evident in grain price?

We assume here that, even though reported prices and stocks are not highly correlated, severe supply shortages always coincide with "price spikes." Consider the case of wheat. It is immediately apparent that, after accounting for trend, two spikes dominate the figure, one in 1973–1976, the other in 1996. In

[7] The corresponding matrix generated by the model assuming normal harvest disturbances shows much lower probability of a transition from low to high price. However the model assumes no errors of price observation.



Note: The reconstructed SUR is the implied stock-to-use ratio by the model given observed price, considering the effects of trend in price and quantities. The actual SUR is the observed stocks-to-use ratio.

Fig. 5. De-trended price versus SUR for calorie.

Table 2
Transition matrix for de-trended calorie price

		To				
		80 to 100	60 to 80	40 to 60	20 to 40	0 to 20
From	**80 to 100**	0.500	0.250	0.000	0.250	0.000
	60 to 80	0.300	0.300	0.200	0.200	0.000
	40 to 60	0.111	0.222	0.333	0.222	0.111
	20 to 40	0.000	0.300	0.100	0.200	0.400
	0 to 20	0.111	0.000	0.333	0.222	0.333

Note: 80–100 stands for the bin from 80 percentile to 100 percentile.

Table 3
Transition matrix for calorie SUR

		To				
		0 to 20	20 to 40	40 to 60	60 to 80	80 to 100
From	**0 to 20**	0.625	0.125	0.125	0.125	0.000
	20 to 40	0.200	0.300	0.300	0.200	0.000
	40 to 60	0.222	0.333	0.111	0.333	0.000
	60 to 80	0.000	0.300	0.200	0.100	0.400
	80 to 100	0.000	0.000	0.222	0.333	0.444

Note: 0–20 stands for the bin from 0 percentile to 20 percentile.

both of these cases, the price in the year preceding the spike was well below unity. Thus price gave no warning of the impending shortage. The next largest spike, in 2006–2007, occurs after a price close to unity; in this case price gave some indication that the market could well tighten. Other lesser "spikes" of about 10% or more above the mean occur around 1963–1964, 1967, 1981–1984, and 2004. Large spikes are obviously quite rare in the available data. Even adding lesser spikes does not give us a sample useful for statistical analysis. Hence we must resort to a less formal analysis of the evidence.

Consider the two largest spikes. Was there evidence of market tightening in the SUR data not available from inspection of price in the previous year? As discussed earlier, in answering this question, it is useful to focus on one possible critical indicator, a price (or implied SUR) level around which the conditional variance of next period's price becomes increasingly sensitive to a further increase in current price (or a further fall in implied SUR). Earlier, we have already identified 1.05 as a reasonable critical price. For each grain, we calculate the SUR implied by the critical de-trended price of 1.05.

From inspection of the wheat price series it is clear that at such a price (given by the horizontal line at 1.05) vigilance about price spikes is warranted. For each grain, we calculate the SUR implied by the critical price of 1.05. They follow a negative trend, consistent with our specification structure. Other specification choices might well imply different threshold levels, though our choice is not obviously inconsistent with the price history through 2007. The specification and the sensitivity of critical indicators to this decision are obvious issues for further investigation.

With respect to the first major spike in 1973, in the prior year the SUR was above the constructed "critical" line and in this strict sense not sending a warning. However, comparison of the SUR for 1972 with its reconstruction (a point on the dotted line) shows that the SUR was relatively closer to the critical level than was the price. The wheat SUR was not unusual, but it was less optimistic than the wheat price in 1972.

In 1995, before the second large spike, the wheat SUR was at about the critical level, while the price was about 15% below its critical line. In this sense, the SUR was indicating a warning, whereas price revealed no similar cause for concern. Of the other smaller spikes, the SUR adds little to the evidence from the price level except in 1966, when it indicates an impending spike in 1967 not signaled by the previous price.

The dominant spike in rice price in Fig. 4 occurred in 1973–1975. There were lesser spikes in 1967–1969, 1980–1981, and around 2006–2007. In 1972, before the largest spike, the SUR was at its critical level, adding a warning signal not at all evident in the rice price that year, which was quite low. For the lesser spikes, without further insights into the evident uptrend in the SUR it is difficult to detect variations that might have been useful as warnings of market tightening.

In sum, while recognizing the inevitable hazard of over-interpreting sparse data using informal analysis, we conclude that the SUR indicates a warning signal of one of the two highest price spikes since 1960, in 1995 in the case of wheat, and in 1972 for rice. Hence there seems to be good reason to consider the SUR in addition to price in interpreting the risk of market tightness and scarcity in grain markets.

Fig. 5 shows the SUR for calories along with its reconstruction from aggregated calorie prices. The first and quite remarkable implication of this figure is that the reconstructed SUR traces the observed values much better overall than does the similar figure for rice, and much better in the early years than observed for wheat alone. This suggests our assumption of high substitutability between calories from different grains is justified.

For calories, one dominant spike occurs in 1973–1975, and other spikes occur in 1967, 1980–1981, 1996, and 2006–2007. The 1973 spike is preceded by an SUR below its critical level, at a time when price was quite low. Thus, overall SUR signaled a warning not evident in calorie prices in 1972. Of the lesser spikes, the SUR gave warnings stronger than information evident in price in 1966, and again in 1995. The spike at the end of our series, in 2007, likely reflects at least in part anticipation of higher demand due to new biofuels legislation in the United States and the European Union. Such large unanticipated demand shocks are not in the prior histories of these markets, nor are they well reflected in our estimates.[8] The critical SUR for calories gives a warning not matched by information from current price one year before two of the other three spikes.

Interestingly, the SUR for calories appears to be a better indicator of spikes in prices of wheat, maize and rice than is the SUR for any grain individually. The aggregate measure takes account of interaction between supplies of different grains in determining overall supply-demand balance in each market.

[8] As noted earlier, truncation of the sample interval at 2007 was a compromise between concern for sample size and desire to avoid as far as possible contamination from the effects of the new policy regime including the large, persistent and unprecedented demand shift.

7. Conclusion

In this article we have presented a procedure to construct, using global commodity price data and a simple commodity storage model estimated on those price data, stocks-to-use ratios (SURs) consistent with the price series. These match observed SURs quite well. We have also confirmed the strong relationship between prices and SURs as indicators of the state of grain markets. More generally, we have demonstrated the relevance of the standard storage model for understanding the relations between stocks and prices of commodities.

Our example of a series of critical values for SURs for aggregate grains, adjusted for a trend implied by the model, seems to be a good indicator of vulnerability to large spikes when the associated price shows no cause for concern, based on the small number of large spikes observed in the past five decades. More scientific election of a set of critical values, or a band of critical values, is an obvious topic for further research.

Empirical economists have generally assumed that stocks data are so unreliable that empirical estimation must rely on prices alone. Our results suggest that stocks data, though no doubt unreliable, can be valuable complements to imperfect price data as indicators of vulnerability to shortages and price spikes. Research to develop more formal empirical methods for optimally utilizing the imperfect information from both sources in evaluating the state of grain markets appears well justified.

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