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Global Biofuels: Key to the Puzzle of Grain Market Behavior

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In the last half-decade, sharp jumps in the prices of wheat, rice, and corn, which furnish about two-thirds of the calorie requirements of mankind, have attracted worldwide attention. They have alarmed consumers, destabilized and even toppled some governments, and induced new temporary market distortions and bans.

These jumps in the prices of these three major grains have also revealed the chaotic state of economic analysis of agricultural commodity markets. Economists and scientists have engaged in a blame game, apportioning percentages of responsibility for price spikes to bewildering lists of factors, which include a surge in meat consumption caused by unprecedented increases of income of the vast populations of China and India; idiosyncratic regional droughts and fires; speculative bubbles; a new "financialization" of grain markets; the slowdown of global agricultural research spending; jumps in costs of energy and fertilizers; shifts in interest rates; the decline of the dollar; the surge in biofuels demands; bans on genetically modified plants; and climate change. Several observers have claimed to identify a "perfect storm" in the grain markets in 2007/2008, a confluence of some of the factors listed above.

The continuing confused state of the economics of grain price volatility may seem odd. After all, grain markets have many of the features of textbook competitive models. The products are relatively uniform. Their primary producers and ultimate consumers are atomistic price takers. Prices and outputs in the United States and other developed countries are unusually well measured by the standards of most goods and services in the world economy, with data freely available from

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institutions including the US Department of Agriculture, the Food and Agriculture Organization of the United Nations, and the World Bank. Indeed, many pioneering empirical works in economics are related to agriculture, following the lead of the remarkable study of Ernst Engels (1821–1896) on the relation between expenditure on food consumption and income (for an overview in this journal, see Chai and Moneta 2010). Pioneers in econometrics estimated demand functions for agricultural products using random short-run disturbances in supply as a way of identifying a demand curve (Stock and Trebbi 2003). Other agricultural economists estimated early dynamic models of supply response (Nerlove 1956) and of technology change and diffusion in agriculture (Griliches 1957). Given the longstanding empirical attention paid to agricultural markets and the many attractive features of commodity market data, why is there so little clarity on the causes of recent fluctuations in grain prices?

In this paper, I will show, using data on price and production, that the most basic Marshallian model of agricultural supply and demand, in which annual production is all consumed in the same year, does not explain major annual movements of the three major grains.[1] However, the Marshallian model explains price movements surprisingly well until 2004 *if* extended to recognize two key kinds of substitution: the substitution of one of the major grains for another (for example, wheat substituted for corn or rice consumed by humans or for corn consumed by farm animals); and the substitution, via storage, of grain harvested in one year for grain harvested and consumed in later years. Until 2004, storage and intergrain substitution were the two essential keys to understanding the economics of grain market behavior in a Marshallian microeconomic model. However, the kind of intertemporal price smoothing via storage observed up to 2004 is not evident in price and storage behavior since then. In particular, even when different types of grains are aggregated, large increases in price occurred in years when stocks carried over to the next year were also increasing. Many economists, puzzled by this phenomenon, concluded that competitive microeconomic models could not explain recent market behavior. Those who searched farther afield came up with confusing lists of causative factors, ranging from yield effects of global warming, to income surges in China and India, to financial speculation.

There was also great confusion as to the distributional effects of the huge grain price increases. Important institutions that had recently argued that low food prices exacerbated food insecurity and poverty by cutting incomes of farmers in low-income countries now issued reports that the sharp rise in food prices had worsened the plight of the hungry and poor.[2] The Renewable Fuels Association in 2011

[1] Soybeans and rapeseed (including canola) are two major oilseeds (not generally included in "grains") that compete with the grains for land, and are inputs for diesel biofuels, and are important substitutes with grains as sources of calories for humans and farm animals. Although they are important, for tractability, here I limit the discussion to the three major grains.

[2] Swinnen and Sqiucciarini (2012) note that in statements three years apart the Food and Agriculture Organization claimed that the falling price trend "threatens the food security of hundreds of millions of people," and that "rising food prices . . . worsen the food deprivation suffered by 854 million

denied claims that corn ethanol production caused high food prices, but declared in a November 15, 2013 news release that reducing the requirements for ethanol production would lead to sharply lower prices for farmers.[3]

The price jumps since 2005 are best explained by the new policies causing a sustained surge in demand for biofuels. The resulting reduction in available per capita supply of food and animal feed could not be accommodated by drawing on available stocks, as they had in the past when there were temporary shortages created by yield shocks. Instead, the necessary adjustments included an expansion of global net acres planted to grains, especially in Latin America and the former Soviet Union, and by reduced per capita consumption of grains and products from animals fed on grains. (There was no noticeable increase in crop yields from trend in the United States.) Thus to solve the puzzle of recent grain market behavior it is necessary to incorporate into the market model—in addition to substitution between grains as sources of calories, and substitution between successive harvests via storage—a third key substitution, that of biofuels for petroleum-based fuels.

The rises in food prices since 2004 have generated huge wealth transfers to global landholders, agricultural input suppliers, and biofuels producers. The losers have been net consumers of food, including large numbers of the world's poorest peoples. The cause of this large global redistribution was no perfect storm. Far from being a natural catastrophe, it was the result of new policies to allow and require increased use of grain and oilseed for production of biofuels. Leading this trend were the wealthy countries, initially misinformed about the true global environmental and distributional implications.

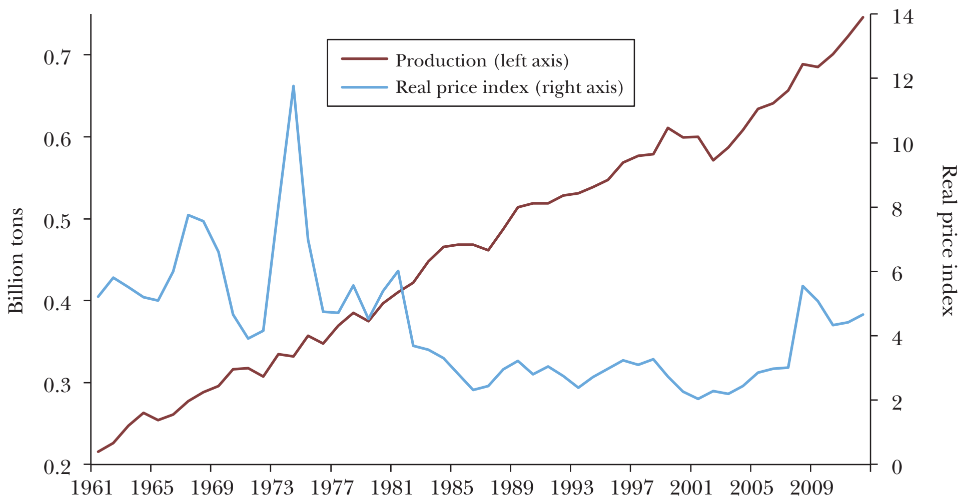
Grain Market Behavior through 2004

In this section, I discuss the behavior of grain markets from 1961 through 2004, identifying 2005 as the first year of a new market regime. I begin with a simple supply-demand model in which production is seasonal with one grain harvest per year. Over time, the yield has a positive trend due to persistent productivity increases.

people." Similarly Oxfam, which had previously claimed that as a consequence of low prices "over 900 millions of farmers are losing their livelihoods," later declared that high food prices had pushed millions of people in developing countries "further into hunger and poverty." A February 2008 US Department of Agriculture report declared "Strong expansion of corn-based ethanol production in the United States affects virtually every aspect of the field crops sector, ranging from domestic demand and exports to prices and the allocation of acreage among crops. A higher portion of overall plantings is allocated to corn. Higher feed costs also affect the livestock sector . . ." (p. 5). Five months later, in a letter to Jeff Bingaman, Chair of the Senate Committee on Energy and Natural Resources, the Secretary of Agriculture with the Secretary of Energy, after endorsing Bingaman's statement that the issues were complex, cautioned against "hasty judgments driven by highly questionable agenda-driven calculations," then went on to state: "Our preliminary analysis . . . suggests that current biofuels-related feedstock demand plays only a small in global food supply and pricing."

[3] http://www.ethanolcfa.org/news/entry/the-epas-rvo-proposal-cannot-stand (last accessed January 12, 2014).

Figure 1
Rice: Real Price Index and Production, 1961–2012



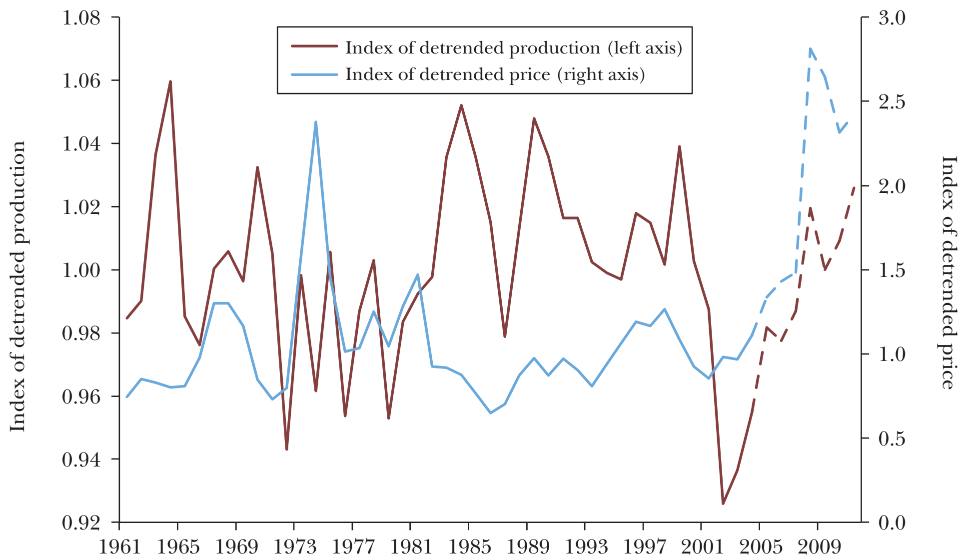
Notes: The nominal rice price from 1961 to 2012 is the calendar year annual average price for rice (Thailand 5% broken) from the commodity price dataset of the World Bank (the pink sheet). The real price index for rice is obtained by deflating the nominal price using Manufactures Unit Value (MUV) from the same dataset. The world rice production from 1961 to 2011 is the calendar year production data for rice paddy from the FAOSTAT of the UN Food and Agriculture Organization. For 2012, we use the US Department of Agriculture (USDA) production data for rice (milled) for the marketing year 2011/2012 adjusted by a ratio between the FAOSTAT 2011 data and USDA 2010/2011 data to roughly account for the difference between paddy and milled rice.

At planting time, the anticipated harvest is roughly proportional to planted area, but the realized harvest is subject to roughly proportional random disturbances, including weather fluctuations, pest infestations, and other shocks that have shown little evidence of inter-year persistence. Grain calorie consumption falls as prices rise, and has an upward trend over time due to (exogenous) population increase; I mainly ignore income and other shifters as unimportant in the short run. As a starting point, can this straightforward economic approach make sense of outcomes in the market for any of the three major grains?

Take rice, for example. As Figure 1 shows, world rice production has been following a remarkably linear upward trend, reflecting strong productivity improvements with varying but modest percentage deviations from that trend. Between 1961 and 2004, prices (deflated by the Manufactures Unit Value, which removes the direct effect of changes in the value of the dollar) followed a downward trend, interspersed with intervals of large variation characterized by price spikes—that is, sharp jumps soon followed by similarly sharp reversions toward trend.

If rice demand evolves steadily, then according to this simple model a price spike must be associated with a shift in inelastic short-run supply. However, as

Figure 2
Rice: World Detrended Price versus Index of Detrended Production, 1961–2012



Notes: The real price index is assumed to be trend stationary. The index of detrended price is obtained by taking the exponential of the residuals from regressing log real price against a constant and time. The world production is assumed to be the product of a linear function of time and a stationary shock. We regressed the log production against the log of the linear function time. We take the exponential of the resulting residuals and use the series as the index of detrended production. The correlation coefficient between the resulting two detrended series through the year of 2004 is –0.2. The dashed lines indicate a new market regime in effect after 2005.

Figure 2 shows, price spikes have not been accompanied by notable year-on-year production downturns. The largest fall in production by far, about 7 percent of trend production, occurred in 2002, a year when price rose only slightly. The simple supply and demand model clearly fails to explain behavior of rice markets during those periods in which the price displays a spike. For rice, the oft-heard argument that the workhorse supply-and-demand model does not explain grain price jumps is well-supported by the evidence—and this is true even before more recent price changes generated further doubts about the conventional market model.

Adding Storage to the Marshallian Market Model

Does the supply and demand model perform better if extended to recognize one key characteristic of a crop such as rice: grain harvested one year can, via storage, be substituted in future consumption for grain harvested later? Assume that grains can be stored from period to period, while acknowledging the reality that grain stocks cannot be negative. For simplicity ignore any cost, waste, or "shrinkage" associated with storage activity apart from a constant opportunity cost of capital, and assume planned production remains fixed at some positive level. Storers maximize expected profits, competing with other storers as well as consumers for the available supply, if the return expected from selling their grain at a higher price in the future covers the interest on their investment in stocks.

In this extended model, the available supply of a product in any year is the sum of the current harvest and any stocks carried over from the supply available in the previous year.[4] Similarly, total demand in any given year will be the amount consumed in that year and the amount that goes into storage for next year. This would all be very simple, but for one problem: How can storers' demand for stocks be determined?

The expected return to storage will vary depending on the available supply in the current period and on the market demand in the next period. If the storage demand curve in the next period were known, horizontally adding this demand curve to the known consumption demand would result in the market demand for the next period. Then we could solve for current storage demand. Unfortunately, we do not in general know the storage demand function in the next period.

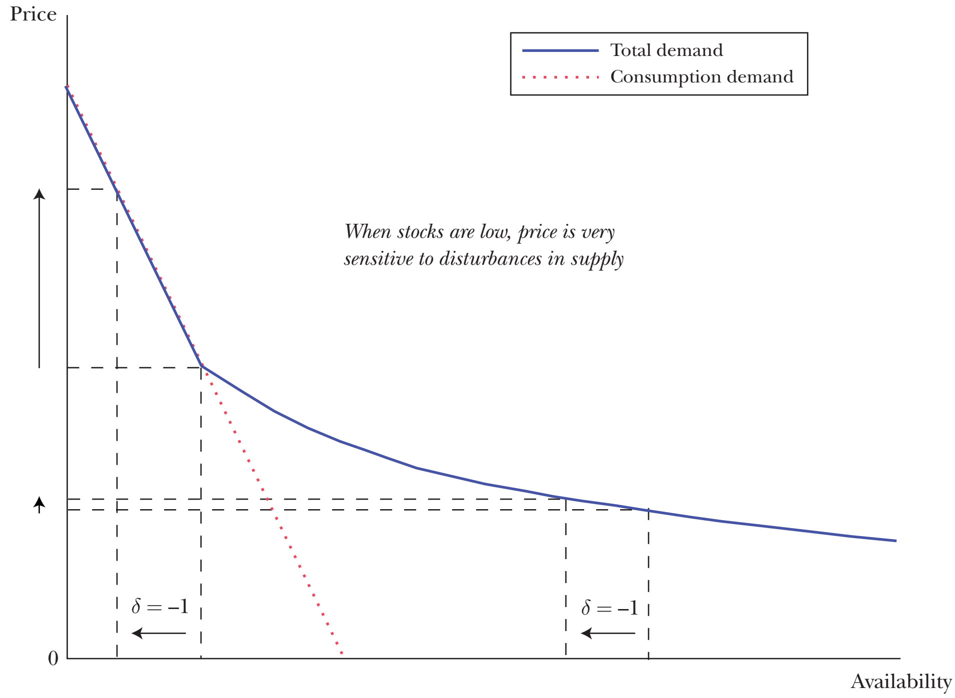
The first numerical model for solving for the storage demand was presented in the remarkable paper of Gustafson (1958), assuming what later became known as rational expectations (Muth 1961). Assuming a far future period beyond which storage is not possible, storage demand is solved by backward induction, exploiting the effects of discounting, that is, by dynamic programming (Bellman 1958). Readers unfamiliar with the topic can find what they need to understand the method as applied to a grain market in the simple exposition of Gardner (1979), or in Williams and Wright (1991).

In this framework, assuming no wastage, the market demand for grain shown in Figure 3 is the horizontal sum of the consumption demand and the storage demand. On the horizontal axis, availability refers both to the sum of current production and stocks carried over from the previous year ("carry-in stocks"). Consumption demand is the downward-sloping straight line, which in the figure is pictured as solid at the top and dashed at the bottom. When the current price is low, storers hold stocks to carry over to the following year. Thus, the curved area of the demand curve to the right of the kink represents the addition of "carry-out stocks" to consumption demand.

The figure illustrates that the effect of a transient exogenous harvest shock depends crucially on the initial available supply. Assume for simplicity that expected production is fixed. Assume further that carry-in stocks are so high that, if the harvest is at its mean, available supply is 7 units. If the realized harvest turns out to be one unit lower, almost one unit of stocks is consumed as a substitute for the missing production, so price need rise only a little to induce the small reduction

[4] For the purposes of this paper, stocks are defined as discretionary stocks net of the "pipeline" or "working" stocks essential for the operations of the market including, for example, grain in transit and grain needed for operation of marketing, processing or feeding activities. We also ignore a small amount of stocks that might be diverted to consumption but only at a very high and fast-increasing marginal cost, that is, stocks that might be said to have high "convenience yield."

Figure 3
Differential Price Responses to a Temporary Yield Shock

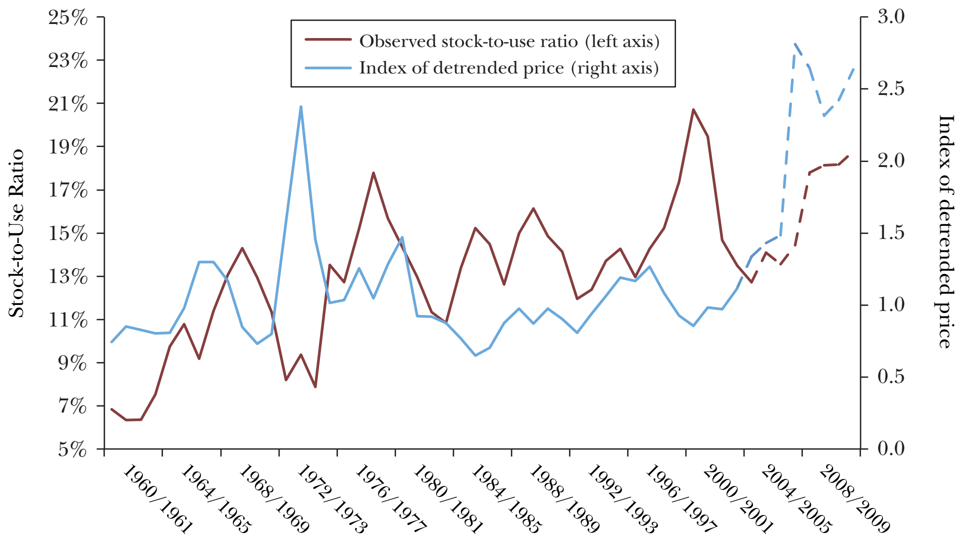


Notes: Price is the price of the grain. On the horizontal axis, availability refers both to the sum of current production and stocks carried over from the previous year. The figure illustrates that the price effect of a transient exogenous harvest shock depends crucially on the initial available supply.

in consumption needed to absorb the fraction of adjustment not covered by stock reduction. If carry-in stocks are so low that adding mean production would place available supply at the kink in demand, then the price rise must be far larger to induce the one unit drop in current consumption necessary given no mean output increase.

Figure 3 shows that in this model in which shocks come from temporary supply-side harvest disturbances, price falls when stocks rise, and price is negatively related to the ratio of stocks to consumption or "use." Figure 4 shows detrended real global rice price (as in the earlier Figure 2) as well as the observed stocks-to-use ratio. The numerator of the ratio is observed stocks, including slow-changing essential "pipeline stocks" as well as the discretionary stocks discussed. The denominator approximates consumption as "use," typically calculated as production less changes in stocks. We first estimated a trend on the sample truncated at 2004, to avoid the influence of a possible change in market regime after that year. The correlation between detrended rice price and the stock-to-use ratio is negative, –0.1355, even smaller in magnitude than the relation between rice price and current production.

Figure 4
Rice: Detrended Price versus Observed Stock-to-Use Ratio



Source: The stocks and consumption (use) data are from the Production, Supply, and Distribution (PSD) Online of the US Department of Agriculture.
Notes: In the stocks-to-use ratio, the numerator is observed stocks, including slow-changing essential "pipeline stocks" as well as the discretionary stocks discussed, while the denominator approximates consumption as "use," typically calculated as production less changes in stocks. The stocks-to-use ratio excludes Chinese stocks and use. The index of detrended price for rice is the same as in Figure 2. The trend is estimated through 2004, to avoid the influence of a possible change in market regime after that year. The correlation coefficient between the two series till 2004 is –0.1355.

Note also that the stock-to-use ratio is clearly trending upwards and positively related to price for several successive years early in the sample interval, and for the late 1990s. Apparently, adding the possibility of intertemporal substitution of rice via storage does not render the basic supply-and-demand model capable of consistently rationalizing fluctuations in the price of rice.[5]

The Importance of Substitution between Grains

In most parts of the world, wheat, rice, or corn is the strongly preferred staple food, the others being, for many consumers, poor short-run substitutes. However, in some regions including substantial parts of the vast Indian and Chinese populations, both wheat and rice figure prominently in the consumption basket. Further, as incomes increase over time, wheat is at least partially displacing rice, corn, and other staple human calorie sources such as coarse grains or tubers.

[5] Economic observers were understandably puzzled by this behavior, and looked beyond Marshallian models to explain the rice price spike of 2007/08. For example, Heady and Fan (2010, p. xiii) conclude, "The surge in rice prices stands apart as being almost entirely a bubble phenomenon."

Nonfood demands are important for corn and wheat. In many countries, an important part of the wheat supply goes to animal feed, and in Europe, wheat is also a significant input into biofuels production. Although corn is an important staple in some parts of Africa and South America, it is much more significant globally as an animal feed. Animal feed has a much higher global price- and income-elasticity of demand than does grain for human consumption. In the United States, corn is the dominant input for the grain ethanol industry. In some areas of the United States, corn competes with wheat for land (and, in the corn belt, with soy). Corn yields in the United States are often higher if corn is grown in rotation with soybeans. In parts of India, China, and other countries, wheat competes with rice for land, often in different multicrop rotations that might include both. The three major grains also compete for inputs such as fertilizer and water.

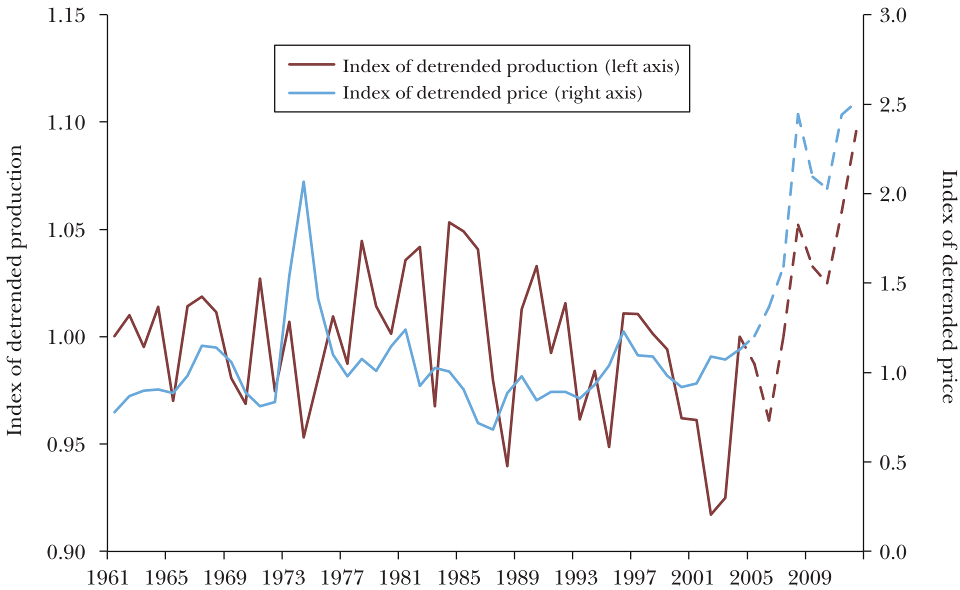
Is the substitutability between the three grains strong enough to more reasonably consider them as close substitutes rather than as essentially independent in consumption? To explore this question, consider the market for the three grains together as a market for aggregate calories, following the initiative of Roberts and Schlenker (2009), who also include soybeans, which has more distinct and higher-value markets in meal and in oil. The price of calories is constructed as the average of the annual prices of wheat, corn, and rice, with the weights being the world production of calories from each grain.[6] They found that the detrended price of calories for all grains taken together is highly correlated (at least 0.93) with the detrended real price of each grain over the years 1961–2012. Although on average the grains are consumed in ways that are quite distinct, on the margin they appear to be quite substitutable. In this aggregated market, does the supply and demand analysis perform better than it did for the rice market alone?

Figure 5 shows that the answer is no. The two largest production shortfalls from trend—measured in terms of calories produced—do not coincide with prominent price spikes. As for rice alone, production variation alone cannot explain prominent features of calorie price behavior, even prior to the onset of increased volatility after 2004.

Combine intertemporal *and* intergrain substitution possibilities in one model and the picture changes completely. Figure 6 shows that when storage of the combined major grains is considered, price behavior of aggregate calories from

[6] World wheat, maize (corn), and rice nominal price data are from World Bank/GEM Commodities. Wheat is measured as Wheat U.S. Hard Red Winter, maize is no. 2 Maize, and rice is measured as Rice Thailand 5%. The annual price is the monthly price observed in the last month of the marketing year: the wheat annual price is the May price, the maize annual price is the August price, and the rice annual price is the July price. All annual price data are deflated into real price indices using the annual Manufactures Unit Value Index from World Bank/GEM Commodities, which is a composite index of prices for manufactured exports from the 15 major developed and emerging economies to low- and middle-income economies, valued in US dollars. This index behaves very differently from the United States Consumer Price Index, especially in recent decades. Production data for the weights come from US Department of Agriculture (USDA), Foreign Agriculture Service (FAS), Production, Supply, and Distribution Online (PSDO). The weight-calories conversion rates are from USDA National Nutrient Database.

Figure 5
Calories: Index of World Detrended Price versus Index of World Detrended Production



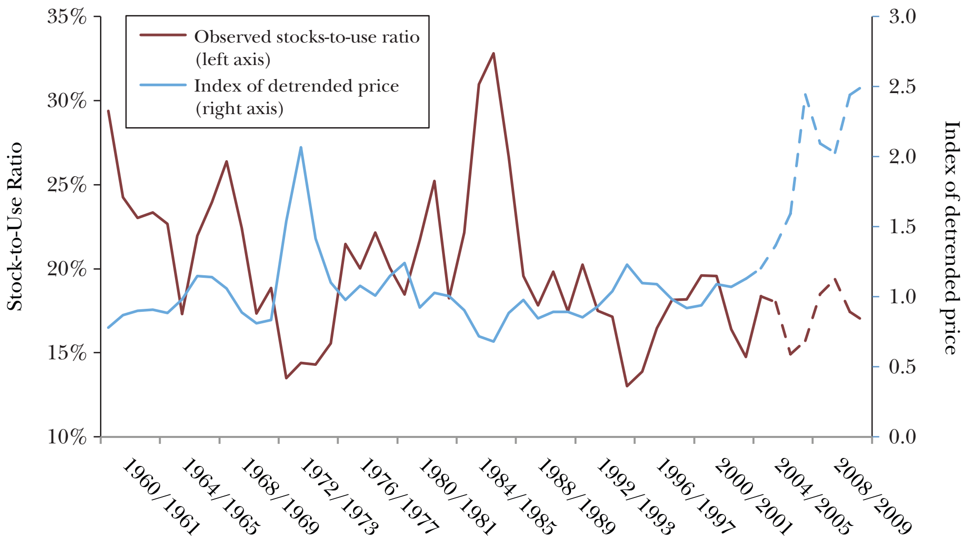
Notes: We convert the production quantities for corn, rice, and wheat to calorie units using the calorie content data from the US Department of Agriculture (USDA) National Nutrient Database. The world grains calorie production is obtained by aggregating calorie contents in the production of these three grains. The nominal price for calories is obtained by dividing the total nominal value of grain calorie production by total grain calorie production. After deflation, we obtain the detrended real price, which is detrended using the same technique as outlined in Figure 2. The world production of the three grains from 1961 to 2011 is the calendar year production data from the FAOSTAT of the UN Food and Agriculture Organization. For 2012, we use the USDA production data for corn, rice (milled), and wheat for the marketing year 2011/2012 using the technique described in the note to Figure 1 to generate the rice production data in 2012. The dashed lines indicate a new market regime in effect after 2005.

the major grains up to 2004 becomes highly intuitive. Each of the major price spikes in Figure 6 through 2004 is matched by a low observed value of the stock-to-use ratio, and the simple correlation between the two series is –0.5645.

Thus the reality of substitution between rice and the two other major grains is crucial to understanding the role of storage in stabilizing random and independent annual disturbances in production, and the role of storage is crucial to understanding intergrain substitution. Attempts to explain spikes in agricultural prices by looking only at annual production, or only at stocks of that specific grain, are futile. Rice price was rising in the early 1990s even though rice stocks were rising, because aggregate grain calorie stocks were falling, the three grains are substitutes in consumption, and aggregate stocks were falling. Likewise, the mystery of a spike in the rice price in 1973, when rice production was normal, is explained

Figure 6

Calories: Index of Detrended Price versus Observed Stock-to-Use Ratio



Notes: In the stocks-to-use ratio, the numerator is observed stocks, including slow-changing essential "pipeline stocks" as well as the discretionary stocks discussed, while the denominator approximates consumption as "use," typically calculated as production less changes in stocks. The stocks-to-use ratio excludes Chinese stocks and use. The stocks and consumption (use) data for corn, rice, and wheat are from the Production, Supply, and Distribution (PSD) Online of the US Department of Agriculture. Grain calorie consumption and stocks are constructed as for the grains calorie production in Figure 5. The index of detrended price for calories is the same as in Figure 5. The correlation coefficient between the two series through 2004 is –0.5645. The dotted lines indicate a new market regime in effect after 2005.

by substitution with the other grains and a shortage in available aggregate calories supply due to calorie stocks, combined with fairly low harvests of wheat and corn, relative to trend. Using the logic from Figure 3 earlier, low stocks make markets vulnerable to temporary harvest shortfalls.

Most empirical estimates of demand for grains and other foods ignore the distinction between stocks and consumption.[7] They typically fit or assume a market demand curve that ignores the kink shown in Figure 3 and find a slope or elasticity that averages the response of price to supply shocks above and below the kink. When discretionary stocks are low, such a smoothed market demand underestimates the response of price to a shock in available supply. The result is that if a global supply shock hits at a time when stocks are low, the resulting price jump is much higher than predicted by the model. This limitation is a common feature of computable general equilibrium models addressing policy analysis for food and agriculture,

[7] A recent example is Roberts and Schlenker (2013), which uses storage effects creatively to identify supply response, but does not model storage demand or the associated nonlinearity of market demand.

including measures to address climate change. Without a proper model of storage demand, they are incapable of assessing the effects of pre-announced, sustained increases in mandated use of grains for biofuels, discussed below.

These shortcomings of existing models are understandable, given that until recently there was no satisfactory way to distinguish empirically the kinked market demand from the consumption demand in estimation of commodity price responses to shocks. In particular, the pioneering empirical applications of the model outlined above by Deaton and Laroque (1995, 1996) to several commodities failed to replicate observed price correlations. However, in Cafiero, Bobenrieth, Bobenreith, and Wright (2011), using a more accurate numerical procedure in a model that otherwise replicated the approach of Deaton and Laroque, we obtained results consistent with observed price correlations for several commodities, including corn.

Building on this work, in Bobenrieth, Bobenreith, and Wright (forthcoming), we extended the model to include trends in prices and production while allowing consistent maximum likelihood estimation, following the approach in Cafiero, Bobenrieth, Bobenrieth, and Wright (2013). We estimated this model for each of the major grains and for aggregate grain calories, again using only global price data, up to the year 2007. The results show that a surprisingly large portion of the variation in a grain calorie price index and in stocks of grain calories prior to 2005 is explained by a simple Gustafson-style model that includes stocks, intergrain substitution, and expected profit-maximizing intertemporal arbitrage. The results also show that for the time period up to 2004 there is little reason to resort to "financialization" of the grain futures markets, irrational herding or speculation, or drops in the cost of capital to explain price spikes.

Why Has Grain Price Behavior Changed Since 2005?

Since about 2005, international grain markets have seen several of the largest price jumps since the 1970s. Careful readers of Figures 4 and 6 might also have noticed that before 2005, when prices rose, stocks typically fell, but after 2005 the relation between changes in prices and changes in stocks became positive, both for calories and for rice. Why would higher stocks of grain be correlated with higher prices for grain?

Before considering alternate explanations, I start with what I consider to be the key to this new puzzling behavior: the surge in demand for grain and oilseeds to produce biofuels.

Biofuels

The surge in biofuels production was driven by policies, led by the European Union and the United States, that allowed increased maximum shares of biofuels in blends with gasoline or diesel fuels, accompanied by mandated minimum use of biofuels for transport fuels, and supplemented in several cases by subsidies and/or import tariff policies. In the United States, as early as 1978, the US Energy Tax Act established tax credits for ethanol blenders. In 1990 the Clean Air Act Amendments mandated the use of either a refining byproduct like MTBE (methyl tertiary butyl ether) or ethanol as a gasoline "oxygenator" that would act to lower emissions of carbon monoxide. MTBE was cheaper than ethanol, and so was widely adopted. However, concerns arose that MTBE might be carcinogenic when gasoline carrying it leaked from old gas station tanks, polluting groundwater. In 1999 the California government banned use of MTBE, effective as of 2003; by 2006, 25 other states had also banned its use. As a result, there was a boost in demand for ethanol as a substitute for MTBE circa 2005. In addition, the 2005 Energy Policy Act introduced biofuels mandates as a policy instrument, in the form of 4 billion gallons of renewable transport fuels in 2006, rising to 7.5 billion gallons by 2012. In 2007 the Energy Security and Independence Act mandated an increase to 15 billion gallons by 2015. Moreover, increasing amounts of advanced biofuels—defined to include cellulosic ethanol and ethanol from Brazilian sugar cane, but not corn ethanol—were added to the annual mandate, rising to 21 billion gallons by 2022.

In the European Union, some limited support for biofuels crops began in 1988, but all such support ended in 2010 (Amezaga, Boyes, and Harrison 2010). Meanwhile, a 2003 European Union directive set biofuels targets of 2 percent of transport fuels for 2005 rising to 5.75 percent by 2010. Many countries chose to use tax incentives, allowed in another 2003 directive, to increase biofuels use. As tax incentives began to take effect, the resulting revenue losses induced states to shift to quantitative measures. Although biofuels use doubled between 2003 and 2005, the actual 2005 share reached only 1.4 percent of European Union transportation fuels (Amezaga, Boyes, and Harrison 2010). In 2009, as part of a climate and energy policy package, there was a shift to European Union use of mandates that included a 20 percent share of renewables in total energy consumption and a 10 percent share of biofuels in gasoline and diesel. Numerous other countries reportedly have enacted mandates for biodiesel or bioethanol blends.[8] World fuel ethanol demand increased from 7.5 billion gallons in 2005 to 22.7 billion gallons in 2012. World biofuels production increased from 14.7 million tons oil-equivalent in 2003 to 60.2 million tons in 2012, of which the United States and the European Union produced 27.4 and 9.9 million tons respectively.

By the standards of agricultural policy changes, the introduction of grain and oilseeds biofuels for use in transport fuels was abrupt, and the effects on the balance between supply and demand were dramatic. After 2003/04, corn used for ethanol in the United States doubled to two billion bushels in just two years, and doubled again in the following few years. In 2001, the projection from the Agricultural Baseline Database of the US Department of Agriculture was that the use of corn for fuel would rise from about 800 million bushels in 2001 to 1.1 billion bushels by 2013. However, by 2004, the actual use of corn for fuel had already risen

[8] These reportedly include Canada, China, Colombia, Costa Rica, Ethiopia, India, Jamaica, Kenya, Malawi, Malaysia, Panama, Paraguay, Peru, the Philippines, South Korea, Taiwan, Thailand, and Uruguay. New Zealand and South Africa have considered and rejected mandates (*Biofuels Digest* 2011).

to 1.9 billion bushels and was projected to reach 2.8 billion bushels by 2013. By 2009, 4.0 billion bushels of corn were being used for fuel, and the projection was 4.6 billion bushels by 2013.

Currently, biofuels use accounts for about one-third of United States corn production, net of byproducts used as animal feed. Further rise is halted by the "blend wall," reflecting the fact that much of the automobile fleet and the distribution system are not currently capable of handling a gasoline blend greater than the 10 percent ethanol (E10) fuel specified in current regulations.

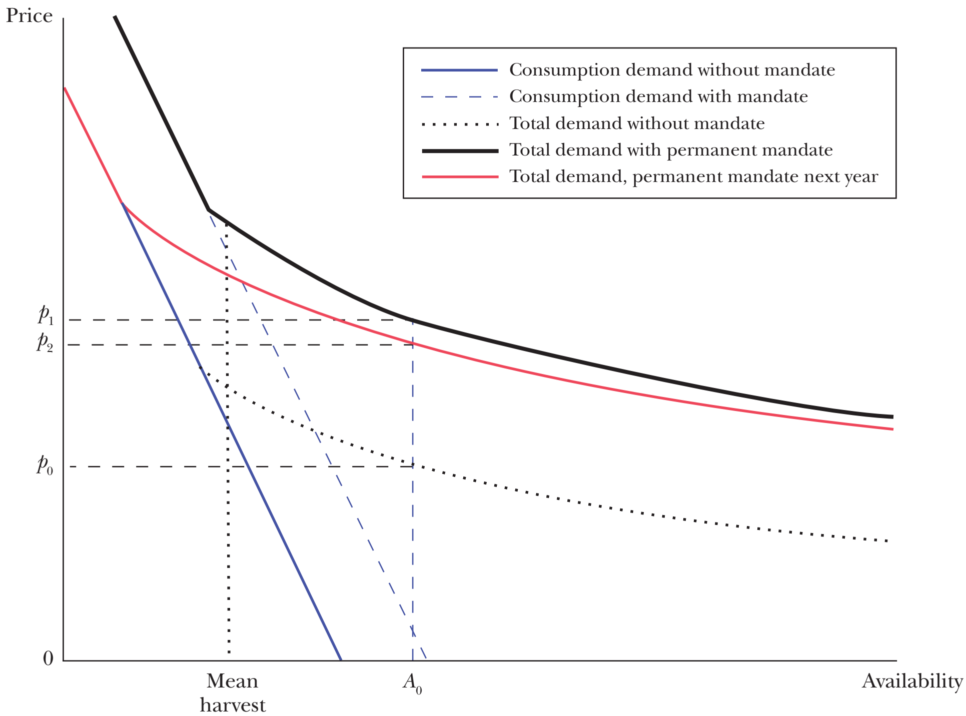
The effect of a given mandate on the evolution of prices depends crucially on whether the mandate is temporary or permanent. In the case of unanticipated imposition of a transitory (one-time) mandate for diversion of one unit from the market, the fall in consumption induced by this price rise absorbs only a small fraction of the shift; the temporary shortage is buffered by reducing storage to the next period, when the mandate will be over. In the next period, the market demand curve reverts to its original kinked form, and part of the reduction in supply will in turn be shared with future periods if the harvest is large enough to allow carry-out storage.

When initial stocks are larger than the mandate, arbitrage buffers the immediate effect of a temporary mandate just as it buffers a supply shock, by reducing carry-out stocks as illustrated in Figure 3. Note that if initial available supply is so low that no stocks are held, the immediate price rise from the mandate is far larger: the vertical distance between the new and old consumption demand curves at that supply level. In that case, the immediate price jump must be sufficient to reduce food and feed consumption enough to fully accommodate the mandate. Future prices are unaffected.

Consider now the case of the surprising and immediately-effective imposition of a mandate known to be permanent at its new level, illustrated in Figure 7. The opportunity to cushion the shock is limited by the fact that, by assumption, at any given price, the mandate increases total consumption in every future period. The outermost, thick market demand curve in Figure 7 reflects the fact that future demand curves remain at the same elevated level. The dynamics of similar permanent shifts in the market were introduced in Wright and Williams (1984). At the initial available supply A_0, upon news of the mandate price jumps to p_1, much higher than p_0. In contrast to the case of an equivalent but temporary mandate, food and/or feed consumption must immediately absorb most of the initial unit increase in mandated consumption. Depending on the details of the specification of the model, there is little or no buffering from stock adjustment. Even if there are substantial initial stocks, the slope of the consumption demand is a better guide to the size of the price jump induced by the mandate than is the slope of market demand including storage demand.

If more realistically, a permanent mandate is implemented one period after its announcement, and supply at announcement is as before, Figure 7 shows the market demand upon announcement as the second-highest, thinner demand curve. Price rises a little less, to p_2 but carry-out storage rises to a level higher than if the mandate were immediately imposed. Because the initial available supply is sufficient

Figure 7
Demand Shifts and Price Jumps upon Announcement of a Permanent Mandate



Notes: $p_2 - p_0$ represents the price rise due to anticipation of a permanent mandate next year.

to allow carryout storage, price and stocks both jump upwards in anticipation of the future, mandated demand boosts. If planned production responds (with a one period lag) to higher prices, then observed supply is also likely to increase the year after announcement.

Simultaneous jumps in prices, supply, and stocks are not observed in the behavior of storage in a market, such as the market for grain calories before 2005, in which the dominant disturbances are one-year supply disruptions. It is understandable that market observers were puzzled when prices, production, and stocks of grain calories all rose sharply between 2006 and 2008, as Figures 5 and 6 show.

This discussion of dynamics implies that sudden mandated upshifts in the rising paths of biofuels requirements for corn ethanol should have caused sharp jumps in stocks of grains at given use levels and sharp rises in price at given stocks levels. Indeed, Figures 5 and 6 (shown earlier) show simultaneous rises in price, production, and stocks of calories between 2006 and 2008, consistent with a strong shift in market demand due to anticipation of the effects of upward revision in the path of future mandates.[9] This analysis suggests that there is no need to look to "speculation" to explain episodes of increases in stocks accompanied by jumps in prices. This analysis is also consistent with the early conclusion of Mitchell (2008) that biofuels policy was the major driver of the price spikes he had recently observed and with the prior predictions of Runge and Senauer (2007) that biofuels expansion would have such effects on grain markets.

The "Asian Income Shock" Hypothesis

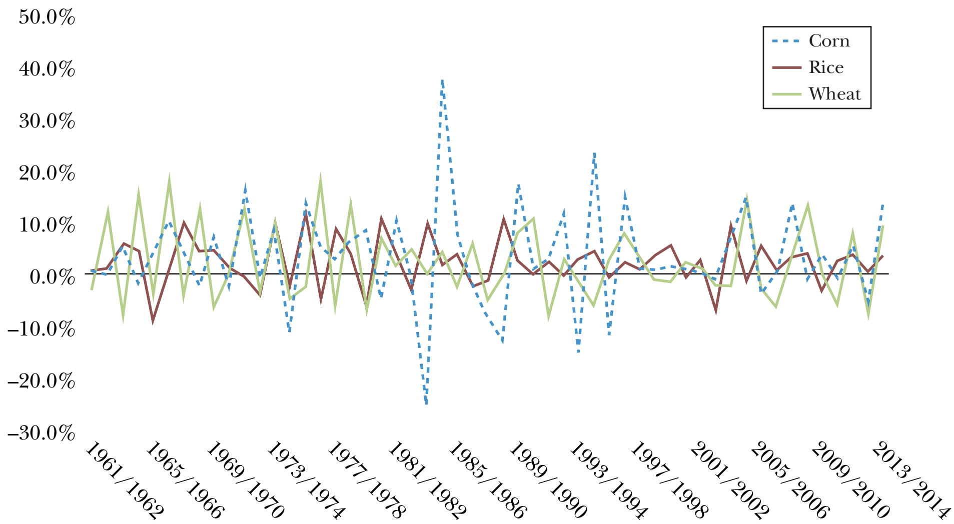
In the literature on recent grain price increases, another possible explanation points to the surge in income in India and China (for example, Krugman 2008; Brown 2012). Historically, one would expect any price shift due to national income changes to be modest; after all, annual per capita income changes in a given population are usually of the order of 4 percent in very good years, and food is income-inelastic. However, per capita incomes in both China and India have recently been growing at unprecedented rates, and their populations are large enough that income-induced variation in their consumption could plausibly have notable effects on global markets.

This conjecture faces several difficult problems. First, the idea of an "Asian income shock" in 2007–08, when prices first jumped, is implausible on its face. By then, news of fast growth prospects in India and China was hardly shocking; growth had been historically rapid and sustained for years. Second, Indian consumption of cereals actually appears to have been falling on a per capita basis during this period of sustained, unprecedented average increases in Indian income (Deaton and Drèze 2009). This observation is itself difficult to understand, but there is little doubt that an Indian grain demand surge did not happen. In China, the evidence is difficult to validate, but grain and meat demands generally appear to have risen remarkably little recently, on a per capita basis, given the high rates of income increase. Third, as other observers have noted, India and China have had scant engagement in the global grain markets in recent years (for example, Abbott, Hurt, and Tyler 2008; Baffes and Haniotis 2010; Heady and Fan 2008). Indeed, based on data from the Production, Supply, and Demand (PSD) Online website at the US Department of Agriculture (http://www.fas.usda.gov/psdonline/), the net exports from India and China of calories in the three major grains have been positive but never much more than 2 percent of world consumption since 1996, except in 2002–2003 when a jump in corn exports from China actually helped *prevent* a price spike in that period, a positive role that has received scant credit in discussions of the global grains market. To put it another way, supply of grains in China and India has generally been expanding with demand, and China and India have not greatly altered the role they play in international grains trade.

There is one important exception to the above argument. China has been increasing its imports of soybeans rapidly, and the calorie value of those imports is

[9] Such anticipation effects are discussed in Carter, Rausser, and Smith (2012).

Figure 8
Percentage Production Change from Prior Year: World less China



Note: World and China production data for marketing years 1960/61 to 2013/14 are from the Production, Supply, and Demand (PSD) Online database of the US Department of Agriculture.

significant relative to global grains trade. (Exactly what China is doing with those soybeans is not obvious; there are reports that stocks of domestic-origin soy production in China are rising.) On the other hand, this extra soybean demand is balanced by a surge in world supply of palm oil, a substitute for soybeans and canola oil in cooking and biodiesel, that is somewhat larger than the increase in Chinese imports in caloric terms. So despite unsolved puzzles regarding declining Indian per capita cereal consumption and increasing Chinese soy imports, an Asian income shock does not seem to be a major cause of recent grain price increases, although strong competition for land from oilseed producers no doubt limited acreage available for expansion of grain production.

Grain Harvest Shortfalls

An unusually prolonged drought in Australia, drought and fires in Russia and other production shocks figure prominently in discussions of the price spikes in 2007–08. Of course, at any given time, it is usual to observe production problems somewhere in global agriculture. Have these problems been unusually bad in the years since 2005, and are shortfalls increasing in severity or persistence, as many public discussions of this topic seem to imply? Figure 8, showing year-on-year changes in production of each grain, presents the answer quite clearly.

There had been no really significant global production downturns since 1997 until the bad corn harvest of the 2012 crop year. The most volatile harvests were in corn between the years 1975 and 1996. The data suggest that production of major crops is indeed becoming less variable relative to its mean as yields increase, contrary to frequent opposing claims.[10] There is no hint of increased downturns due to global warming in the data. Conjectures that higher carbon dioxide levels have actually increased recent production might be more plausible, but they give no help to those arguing that low harvests explain recent grain price rises.

Prices of Fertilizer, Energy, and Other Inputs

The prices of inputs, in particular fertilizers and fuels, are another popular choice as a driver of market volatility. However the facts say otherwise, at least for the United States. The ratio of a US Department of Agriculture index of prices received by US farmers to an index of prices they paid for inputs, interest, wages, and taxes, in real dollars, has been higher than in 2005 for every year through 2012. Indeed, this change is reflected in the soaring cash rents and land values in the Midwest corn belt (for discussion, see Zulauf and Rettig 2013a, b). Any increases in agricultural input prices have been considerably outstripped by the surge in grain prices.

Interest Rates

Before the grain price surge began, Frankel (2006) pointed out that interest rates are a potentially important influence on commodity prices. In the context of the storage model, an interest rate shift can cause the storage demand function to shift and price to jump. During the financial crisis starting in mid-2008, credit rationing or a jump in interest rates available to traders might well have influenced the drop in commodity prices at that time, by reducing storage and increasing consumption. Since then interest rates have remained very low, and so are not a major explanation of recent grain market behavior.

Bubbles in Prices?

A last rationale for the apparently changed behavior of grain markets in recent years is a story of price bubbles and market manipulation. The story is that powerful investors have chosen to raise the stocks of grains in an attempt to create a shortage and drive up prices, so that they can later sell the stocks at a higher price.

Many discussions of the grain price spikes since 2006 identify "bubbles" in price behavior. There is a common opinion that bubbles are easy to recognize after they have occurred, and that they represent irrational behavior of a kind that might be discouraged or mitigated by appropriate policies against speculation. There is a prevalent opinion that the price spikes in grains in 2007–2008 were speculative bubbles induced by financial flows into grain markets. Timmer (2010, p. 3) states the thesis nicely:

> The actual price panic that resulted, however, had little rationale in the fundamentals of supply and demand. Speculative fervor spread from the crude oil

[10] For example, the coefficient of variation of yield from a linear trend between 1996 and 2011 was at least 29 percent lower than between 1940 and 1995 for wheat, rice, soy, and corn in the United States, and the decrease was significant at the 5 percent level for corn and rice (Zulauf and Hertzog 2011).

> and metals markets to agricultural commodity markets . . . . Prices spiked, first for wheat, then for corn. And then they collapsed when the speculative bubble burst. . . . There is a clear case to be made that the sudden spike in wheat and corn prices was heavily influenced by financial speculation.

Similarly, Piesse and Thirtle (2009) infer bubbles in the 2007–2008 price behavior of soybeans, wheat, and corn and a "panic" in the case of rice, while Headey and Fan (2010, p. xiii) single out the rice price surge as "almost entirely a bubble phenomenon." One source of confusion is that economists find bubbles difficult to define. Brunnermeier (2008) includes a key feature of most definitions offered by finance economists: "Bubbles refer to asset prices that exceed an asset's fundamental value because current owners believe they can resell the asset at an even higher price." But price behavior consistent with this definition can be stationary (Bobenrieth, Bobenrieth, and Wright 2002) and can exhibit behavior typical of prices of grains with occasional spikes but no corresponding troughs (Bobenrieth, Bobenrieth, and Wright 2008). There may be frequent "runs" in which price rises faster than the interest rate (the criterion for "exuberance" in Phillips, Wu, and Yu 2011), then collapse. Indeed, it is not possible to establish the existence of a bubble by rejecting the "no bubble" null hypothesis (Bobenrieth, Bobenrieth, and Wright forthcoming).

Examples of Losers and Winners: Global Poor Nonfarmers and US Landholders

Biofuels policy, including the mandatory diversion of grains and oilseeds from food and feed to transport fuel, led by the United States and the European Union, and followed by many other countries rich and poor, has in effect replicated a classic policy in the agricultural sector of transferring wealth from consumers to producers. Output of calories is transferred from a market with low demand elasticity—the global market for human food and animal feed—to another market with a very high price elasticity—in this case, the global market for motor vehicle fuels. The result of this shift is that price rises greatly in the first market, price falls very little in the second, and producer revenues increase.

I have found nothing in the literature on how this worked out in practice for consumers beyond simulated changes in the number of people below certain international poverty measures. Despite the concerted efforts of countries, notably India, and international organizations including the UN Food and Agriculture Organization (FAO) and the World Bank, we apparently actually know embarrassingly little about how food consumption and prices have evolved at the individual or household level on a worldwide basis. We do know that prices vary widely between countries, and that many grain importing and exporting nations buffered the initial shocks of higher food prices in 2007–08 at substantial budgetary cost, aggravating the price fluctuations in the global market (Anderson, Ivanic, and Martin 2013).

However, for African economies including Kenya, Ethiopia, and Senegal, recent evidence indicates that corn and wheat prices seem to have risen about as much as or more than global prices between 2005 and 2011. Meanwhile, in China, rice prices appear to have gradually risen to above the new higher global price levels, and, in India, close to global levels (Baltzer 2013).

Overall, it seems reasonable to conclude that there has indeed been something like a doubling of the real price paid by the world's landless poor for the world's dominant calorie staples since 2004—along with similar induced increases in prices of many other food mainstays. This change is barely perceptible to the citizens of wealthy countries, who spend a much lower share of their income on calories. Farmers lose if they are net grain consumers, as most poorer farmers are. Landless laborers lose unless their wages rise enough to pay for the more expensive grain. The urban poor unambiguously lose from higher grain prices.

If the absolute number of urban poor living below the $1 per day poverty level have not changed since 2002, then using Chen and Ravallion (2007, table 5, p. 16761) we can estimate their number at 282 million—a conservative estimate given ongoing urbanization of global poverty. Rough back-of-the-envelope calculations suggest that this group (not much smaller than the population of the United States) lost at least $5 billion in 2012 from cereal price rises from the levels prevailing in 2004 before the expansion of biofuels.[11] Rural landless groups and small farmers who are net food buyers likely lost much more in aggregate than this much smaller urban group living below the poverty line. However the effects are much more difficult to calculate accurately, because higher food prices might positively affect incomes of workers working on larger farms, thus partly offsetting the loss from higher cost of cereal consumption.

In real 2012 dollars, real increase in value of US farm operations from 2004 to 2012 is at least $800 billion (USDA 2013; Zulauf and Rettig 2013a), far higher than total US official overseas development aid expenditures over this period, which have never been above $40 billion per year. However, this amount is only a small fraction of the aggregate global wealth transfer: for example, it does not count the gains to landholders in other countries, nor to agricultural input providers and ethanol refiners globally. Most of the global transfers from higher grain prices no doubt remain within national borders, from landless consumers and small landholders, to commercial farmers, agricultural input providers, and others controlling key assets in the marketing chain.

[11] Local price information summarized in Baltzer (2013) can support an increase of around $200 per ton of rice between 2012 for this group and perhaps $180 per ton of wheat (reflecting a lower wheat price rise in India). If the average consumer in this group consumes the cereal calories reported for the urban consumers in a set of available UN Food and Agriculture Organization (FAO) studies, or has the cereal calorie consumption of the very poor in India (Deaton and Drèze 2009, p. 47, table 2), such a consumer paid roughly $22 more for annual cereal consumption in 2012 than in 2004, assuming no reduction in grain calorie consumption, and the aggregate loss to all of this poor urban group is around $6.2 billion. If they were forced by the income effect to cut calorie consumption, the increased expenditure was smaller, but the human costs were very likely even higher.

Some economists warned back in 2007 and 2008 that the biofuels mandates would affect food consumers around the world, but their words went unheeded. For example, Runge and Senauer (2007) made some of the points presented here. They noted that in March 2007, soon after President George W. Bush announced a major expansion of ethanol biofuels, corn futures rose to the highest level in ten years, and also that wheat and rice prices had risen to decade highs because they were substitutes for corn in production and consumption. With impressive foresight, they argued: "By putting pressure on global supplies of edible crops, the surge in ethanol production will translate into higher prices for both processed and staple foods around the world."

Similarly, a World Bank paper by Mitchell (2008) argues that the most important factor in the rapid rise in food prices that had been a burden on the poor in developing countries was "the large increase in biofuels production in the U.S. and the EU. . . . Without these increases, global wheat and maize stocks would not have declined appreciably, oilseed prices would not have tripled, and price increases due to other factors, such as droughts, would have been more moderate. Recent export bans and speculative activities would probably not have occurred because they were largely responses to rising prices." Abbott, Hurt, and Tyler (2008) was another informative early paper that in a comprehensive review identified biofuels demand as one of three major factors in grain price increases.[12] The most important analytical element in this paper that I have added to Mitchell (2008) and Abbott, Hurt, and Tyler (2008) is the discussion of the dynamic response of stocks to a pre-announced path of increased biofuel diversion, which shows why stocks might not fall to smooth a sharp rise in price after a surprising sustained shift in demand.

But many other observers in important institutions with an interest in food—the World Bank (Baffes and Haniotis 2010; Baffes and Dennis 2013), the International Food Policy Research Institute (von Braun and Torero 2009), and the US Department of Agriculture (Trostle, Marti, Rosen, and Westcott 2011)—have, like the Farm Foundation, tended to deemphasize or to ignore biofuels, in favor of a long list of other factors potentially affecting grain prices. "Complexity" and "perfect storm" are words seen frequently in their reports. Surprisingly, academic development economists have not paid much attention to the transfers from poor consumers due to higher food prices: a brief review reveals no papers

[12] However, you would never guess at this conclusion of the study if you read only the Preface by the President of the Farm Foundation, which funded the study. He chose to summarize its conclusions thus: "Today's food price levels are the result of complex interactions among multiple factors—including crude oil prices, exchange rates, growing demand for food and slowing growth in agricultural productivity—as well as the agricultural, energy and trade policy choices made by nations of the world. But one simple fact stands out: economic growth and rising human aspirations are putting ever greater pressure on the global resource base." Later, in his preface to Abbott, Hurt, and Tyler (2009) arguing that the current situation was "remarkably different" than at the time of the 2008 report, he proved able to summarize the latter more succinctly: "Released in July 2008, *What's Driving Food Prices?* identified three major drivers of prices—depreciation of the U.S. dollar, changes in production and consumption, and growth in biofuels production."

on the effects of high grain prices or of biofuels on the global poor in the *Journal of Development Economics* or the *Journal of Development Studies* between 2009 and the writing of this paper in 2013.[13]

Conclusion: The Economics, Politics, and Sustainability of the Regime Change

The behavior of the prices of the major grains reflects their substitutability and their storability. Before the introduction of increasing biofuels mandates in 2005, grain price dynamics reflected the long-run role of crop yield increases in outrunning population increase and the short-run effects of transient supply shocks, which are much more likely to cause price spikes when stocks are low relative to anticipated consumption.

Since 2005, rises in grain price levels have been induced by the sustained increases in demand for grain and oilseed calories. Shifts in demand for biofuels where initiated in Europe and the United States by mandates for grain use in biofuels, along with increases in permissible shares of biofuels used in blending with gasoline or diesel that became attractive when petroleum prices were high. The persistence of the shifts in biofuels demand meant that storage could not buffer consumers as they can during a temporary harvest shortfall.

In this new regime, the world grain market will continue to be sensitive to small shocks, and price levels will remain high overall as long as continued shifts in total calories demanded generated by biofuels demand outrun the expansion of supply. The political economy of biofuels expansion reflects the fact that policies originally widely supported as reducing the emission of greenhouse gases have been captured by the beneficiaries of the large induced wealth transfers.

Will producers and agricultural landowners worldwide be able to ensure that shares of biofuels in transport fuels will continue to rise in the medium term, offseting the yield increases that have traditionally benefited global consumers? Environmentalists have grown skeptical of the claimed reductions in greenhouse gas emissions associated with biofuels; indeed, the net effects of biofuels on emissions are now more widely believed to be at best dubious, due to inevitable induced land use changes (Searchinger et al. 2008) that increase greenhouse gas emissions. In the United States, the expansion of biofuels is currently restricted by rules that limit the use of ethanol in regular gasoline (the so-called "blend wall"), in combination with the fall in demand for gasoline due to reduced driving and higher fuel efficiency of automobiles. Further, the Environmental Protection Agency has proposed to modify regulations in a way that reduces expected growth in corn ethanol demand.

[13] Some papers published in agricultural economics journals addressed this topic, including an IFPRI study by Headey and Fan (2008) and World Bank studies such as Ivanic and Martin (2008).

The loss of support from environmentalists, and the proposed EPA ruling to reduce the renewable fuels standard might be signs that the expansion of biofuels will slow or even reverse itself at least until we have second generation biofuels that do not compete with food production, and more effectively reduce greenhouse gas emission. However the biofuels lobbies in Europe and the United States remain strong and influential.[14] Governments in the United States and the European Union have the power to allow expansion of corn ethanol and other biofuels sufficient to outpace any feasible domestic grain supply expansion if petroleum prices remain high. They can, for example, continually increase the proportion of biofuels approved for blending with regular gasoline or diesel fuels far above the current 10 percent in the United States. If they do, many governments in developing countries are likely to follow their lead, as they have in the past. The roughly $800 billion increase in US farm real estate values since the start of the new biofuels regime is evidence that land investors expect governments to continue to allow biofuels demand for grain to expand, regardless of the effects on the environment and on poor grain consumers.

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[14] Many environmentalists supported recent European Union votes to cap biofuels use in transport fuels at 6 percent or less, and to ensure that indirect land use effects be considered, but I understand that these votes appear likely to be effectively nullified in response to pressure from biofuels beneficiaries. In the United States, the proposed EPA ruling is open for comment and is being vigorously opposed by farm and biofuels lobbies.

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