FUTURES MARKET FAILURE?

PHILIP GARCIA, SCOTT H. IRWIN, AND AARON SMITH

In a well-functioning futures market, the futures price at expiration equals the price of the underlying asset. This condition failed to hold in grain markets for most of 2005-2010, calling into question the ability of these markets to perform their price discovery and risk management functions. During this period, futures contracts expired up to 35% above the cash grain price. We develop a dynamic rational expectations model of commodity storage that explains how these recent convergence failures were generated by the institutional structure of the delivery system. When delivery occurs on a grain futures contract, the firm on the short side of the market provides a delivery instrument (a warehouse receipt or shipping certificate) to the firm on the long side of the market. The firm taking delivery may hold the delivery instrument indefinitely, providing it pays a daily storage rate. The futures exchange sets the maximum allowable storage rate at a fixed value. We show that non-convergence arises in equilibrium when the market price of physical grain storage exceeds the maximum storage rate on delivery instruments. We call the difference between the price of carrying physical grain and the maximum storage rate the *wedge*, and demonstrate theoretically and empirically that the magnitude of the non-convergence equals the expected present discounted value of a function of future wedges.

Key words: Agriculture, basis, bubble, commodity futures, convergence, delivery, grain, storage.

JEL codes: G13, G14, Q11, Q13.

Futures prices for corn, wheat, and soybeans on the major U.S. exchanges have recently exhibited patterns that call into question their role as venues for the efficient discovery of cash prices. Specifically, the price for these futures contracts has repeatedly failed to converge to the price of the underlying commodity on the expiration date. Between 2005 and 2010, many Chicago Board of Trade (CBOT) corn, wheat, and soybean contract expirations exhibited convergence failure, with futures contracts expiring at prices up to 35% greater than the prevailing cash grain price (see figure 1).[1] The magnitude and persistence of this non-convergence distinguishes it from idiosyncratic pricing anomalies that have arisen in the past due to market manipulation in the form of "corners" and "squeezes" (Kyle 1984; Peck and Williams 1991; Pirrong 1993, 2004; Allen, Litov, and Mei 2006). In spite of the convergence failure, these contracts continued to be actively traded. Average daily trading volume in the CBOT corn, soybean, and wheat contracts doubled between September 2005, when non-convergence first appeared, and

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Philip Garcia is the T.A. Hieronymus Distinguished Chair in Futures Markets and Director of the Office for Futures and Options Research in the Department of Agricultural and Consumer Economics at the University of Illinois at Urbana-Champaign. Scott H. Irwin is the Laurence J. Norton Chair of Agricultural Marking in the Department of Agricultural and Consumer Economics at the University of Illinois at Urbana-Champaign. Aaron Smith is a professor in the Department of Agricultural and Resource Economics at the University of California at Davis. The authors thank Peter Koziara and Gene Kunda for assistance with data collection. Pat Fishe and Dwight Sanders provided useful feedback on the manuscript. The editor David Hennessy and three anonymous reviewers provided comments that improved the article significantly. The authors also thank conference participants at the 2011 CFTC Conference on Commodity Markets and the 2011 NCCC-134 Conference, and seminar participants at the UC-Davis Department of Agricultural and Resource Economics, Iowa State University Department of Economics, the Economic Research Service of the USDA, and the Chicago Mercantile Exchange for helpful comments. This material is based upon work supported by Cooperative Agreement with the Economic Research Service, U.S. Department of Agriculture, under Project Numbers 58-3000-9-0078 and 58-3000-9-0076. Correspondence may be sent to: adsmith@ucdavis.edu.

[1] The CBOT merged with the Chicago Mercantile Exchange (CME) in 2007 and became known as the CME Group. We refer to the corn, soybean, and wheat contracts as CBOT contracts because they originated on the Chicago Board of Trade, but we use the term CME when describing actions taken by the CME group.

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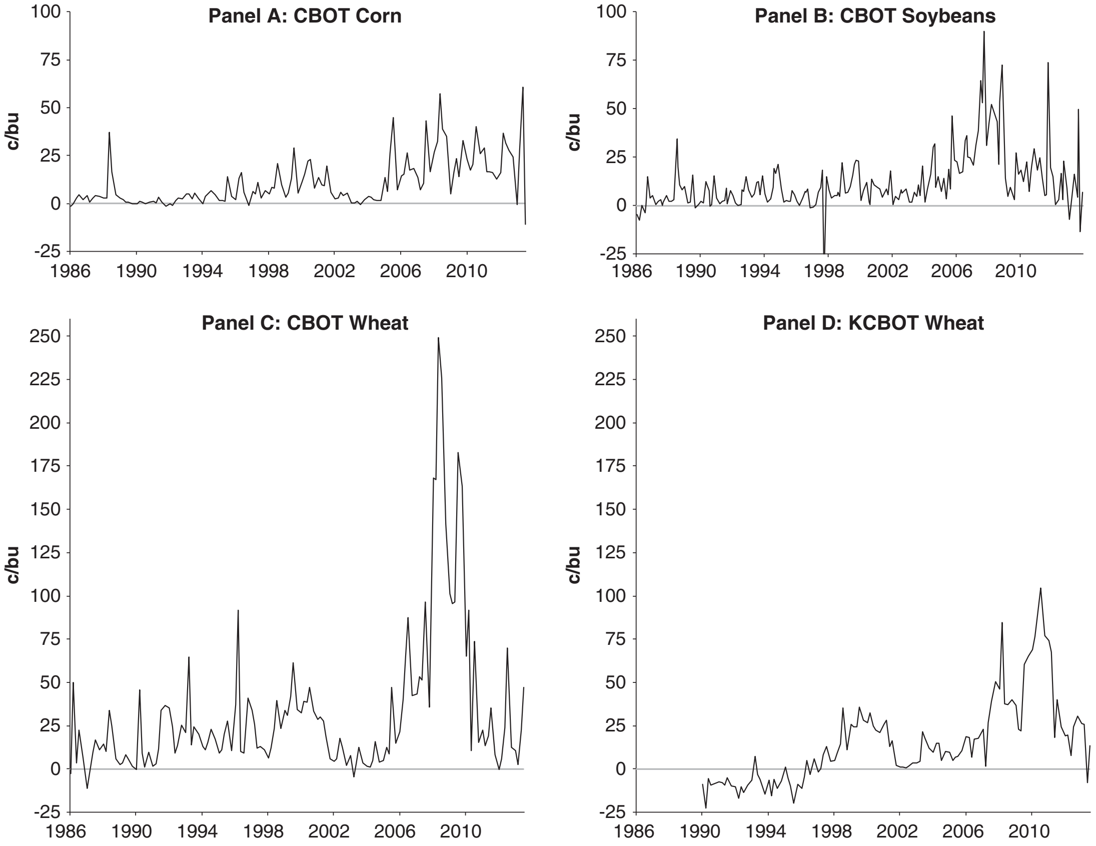

Figure 1. Futures price at expiration minus cash price, 1986–2013

Note: The cash price is at the cheapest-to-deliver location averaged over the first five days of the delivery month. See online appendix for calculation of this price.

September 2008, when non-convergence was at its worst.[2]

This wave of convergence failures in the face of increasing trading volume generated a heated public debate about its possible causes.[3] Many blamed new financial index traders in grain futures markets. For example, a report by the United States Senate Permanent Subcommittee on Investigations (USS/PSI 2009) claims that commodity index trading caused the non-convergence in wheat markets. The USS/PSI report maintains that index fund capital overpowered arbitrageurs, who may have been limited by credit constraints and uncertainty over the time it would take to realize arbitrage profits.

We show in this article that a rational expectations commodity storage model explains persistent non-convergence, and that theories that appeal to bubbles or irrational traders are inconsistent with the empirical facts. The root of the problem is that, unlike many commodities, grain futures contracts are not settled by physical delivery of the commodity.[4] With physical delivery, arbitrageurs are able to force convergence by acquiring inexpensive grain in the cash market and delivering it at futures contract

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[2] For comparison, average daily trading volume doubled in NYMEX crude oil, tripled in COMEX gold, and remained the same in COMEX copper during this same period. None of these contracts experienced convergence failures.

[3] See Irwin et al. (2011) and USS/PSI (2009) for thorough reviews of the recent convergence problems in grain futures markets and the debate about causes.

[4] For example, energy futures traded on NYMEX, such as WTI crude oil, heating oil, RBOB gasoline, and Henry Hub natural gas, are settled by F.O.B. delivery into a pipeline or storage facility. Delivery on COMEX metals futures such as gold, silver, and copper are settled by a transfer of title (or warrant) to units of the commodity held in a licensed facility. For more information on energy and metals delivery specifications, see http://www.cmegroup.com/rulebook/NYMEX/index.html.

prices until cash and futures prices equalize. When delivery occurs on a grain futures contract, the firm on the short side of the market provides a delivery instrument (a warehouse receipt or shipping certificate) to the firm on the long side of the market. The delivery instrument is a security that can be exchanged for grain at any time. The long-side firm taking delivery may hold the delivery instrument indefinitely, although the firm must pay a daily storage rate while it holds the instrument.

Our theoretical model shows that non-convergence arises in equilibrium when the market price of physical grain storage exceeds the cost of holding delivery instruments. The maximum allowable storage rate on delivery instruments is set by the futures exchange, and historically has not varied much over time. However, the price of physical grain storage has varied substantially over time with changing inventory levels. Plentiful inventories generate a high price of physical storage and small inventories cause the price of storage to become negative, as firms receive a convenience yield for holding the commodity (Working 1948, 1949; Brennan 1958). We call the difference between the price of carrying physical grain and the maximum storage rate the *wedge*, and show that the magnitude of non-convergence equals the present discounted value of future wedges over the period that the wedge is expected to remain positive.

A divergence of prices from the present value of future payoffs defines a bubble. Rational bubble models specify a price process that includes a bubble component that is expected to grow on average at the discount rate (e.g., Diba and Grossman 1988; Froot and Obstfeld 1991). In such models there is no arbitrage opportunity for rational traders to exploit. To incorporate this notion, we include in our model the possibility of a bubble solution in which the magnitude of the non-convergence (i.e., the basis) is driven by a non-fundamental noise term. We find that the empirical facts are inconsistent with the presence of such a bubble.

A separate branch of literature dispenses with the assumption of rational expectations for at least some traders and produces bubbles by introducing frictions such as noise trader risk (e.g., De Long et al. 1990; Shleifer and Vishny 1997), synchronization risk (Abreu and Brunnermeier 2003), or short sales constraints (Scheinkman and Xiong 2003). These frictions prevent arbitrageurs from eliminating bubbles. Market commentators have suggested that frictions may underlie convergence failure. For example, on July 21, 2009, Thomas Coyle, the Chairman of the National Grain and Feed Association, testified to the USS/PSI that "…disproportionate participation of investment capital has been the significant contributing factor to a disconnect between cash wheat values and wheat futures prices." Our analysis provides no support for frictions-based models as explanations of convergence failure.

Three recent studies examine the causes of the convergence failures. Each study is informative, but they do not provide a complete picture of the underlying economic forces that generate such large episodes of convergence failure. Heath's (2009) work is closest to ours; he develops a two-period theoretical model and shows how a cap on futures contract storage rates can induce non-convergence when the "capped" rate is below the market price of physical storage. However, his theoretical model does not show how relatively small differences in storage costs could lead to the large magnitudes of non-convergence that occurred recently. He also does not conduct formal tests of model predictions, nor does he explain why the market price of storage may vary. Irwin et al. (2011) identify a correlation between non-convergence and the occurrence of large carrying charges in corn, soybeans, and wheat. However, the authors did not explain why this correlation could arise or how it could be an equilibrium outcome. Aulerich, Fishe, and Harris (2011) argue that the long's carry-induced incentive to hold delivery instruments can be modeled as an embedded real option to exchange the delivery instrument for another contract. The option becomes more valuable as the relative volatility of cash and futures prices increases; if the option value becomes large enough, the cash and futures market can disconnect. A limitation of this framework is that it does not explain what drives the initial non-convergence.

We estimate an econometric model to test the predictions of our theory for CBOT corn, soybeans, and wheat, and Kansas City Board of Trade (KCBOT) wheat. We regress the change in the basis on a set of explanatory variables including grain inventory at deliverable locations, a credit spread measure (e.g., 3-month commercial paper minus 3-month treasury bills), the relative cash and futures price volatility (to account for real option effects), the market position of commodity index traders (to represent index fund pressure), and inventories of materials and supplies divided by total sales for food products manufacturing firms (to capture convenience yield). The empirical evidence strongly supports our rational expectations model. Specifically, we find that high inventory in deliverable locations raises the wedge, and the wedge is greatest early in the crop year when inventory is at its largest. We find no evidence of a bubble in grain futures prices caused by commodity index traders. Graphical analysis shows how the wedge, driven by inventory levels, explains the occurrence and magnitude of the non-convergence. In addition, we show that lowering the cost of delivery does not provide a solution to non-convergence. In 2009 the CME tried to expand delivery points in the wheat market to no avail, which is consistent with our theory.

Our results imply that convergence can be restored by raising the storage rate on delivery instruments. The CME recognized this point (Seamon 2009) and introduced the Variable Storage Rate (VSR) system in 2010, which raises and lowers the storage rate for CBOT wheat depending on market conditions. The VSR system initially produced a larger maximum storage rate, which reduced the wedge and restored convergence in CBOT wheat. By early 2013, the maximum storage rate had returned to its pre-VSR level. Despite its success, the VSR has been controversial. For example, market commentators blamed the rising VSR for causing the price of grain storage to increase in 2010 and 2011. Our theoretical and empirical results show that the causation operated in the opposite direction, and the success of the VSR provides further evidence in support of our explanation.[5]

How a Storage Price Wedge Causes Non-convergence

In this section we describe the institutional details of the delivery process for CBOT and KCBOT futures, and then we present a conceptual model of the delivery market to explain non-convergence.

Institutional Background

As noted by Pirrong, Haddock, and Kormendi (1993, p. 9), “The delivery terms of futures contracts specify the types and grades of deliverable goods, and denote the places and times of delivery that must be met to avoid default on an outstanding contract.” These terms evolve over time to reflect changes in the commercial standards for market transactions. If futures contract terms become misaligned with prevailing standards, then the contract may no longer serve as a useful hedging instrument and its continued existence is threatened. Grain futures contracts traded at the CBOT and KCBOT specify a par delivery location and grade for each contract. Delivery at non-par locations and grades is permissible at fixed premiums or discounts.[6]

In a competitive market with costless physical delivery at one particular location and date, arbitrage will force the futures price at expiration to equal the cash price. If the futures price exceeds the cash price, the cash commodity would be bought, futures sold, and delivery made. If the cash price exceeds futures, then futures would be bought, the buyer would stand for delivery, and then would sell the commodity in the cash market. This type of riskless arbitrage prevents the law of one price from being violated. In such a well-functioning delivery system, only a minimal number of futures deliveries are needed because long and short futures position holders are indifferent to offsetting their positions rather than making and taking delivery. As Hieronymus (1977) notes, “A futures contract is a temporary substitute for an eventual cash transaction. In markets that work, delivery is rarely made and taken;

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[5] Of course, convergence could be forced by changing the delivery mechanism to one that forced load-out (like NYMEX energy futures contracts, see footnote 2) or cash-settled to a spot price index. These mechanisms would have their own challenges such as managing potential bottlenecks in the flow of grain and finding a spot price that is representative and free from manipulation. We do not consider these mechanisms further in this article.

[6] Additional details on the CBOT and KCBOT delivery systems can be found in Irwin et al. (2011), Aulerich, Fishe, and Harris (2011), and the Exchange Rule Books located at http://www.cmegroup.com/rulebook/CBOT/I/7/7.pdf and http://www.kcbt.com/rule_book_kcbt.html.

futures contracts are entered into for reasons other than exchange of title."

In reality, delivery arbitrage is more complex. When a futures contract allows multiple delivery days, locations, and grades, as is the case for CBOT and KCBOT grain contracts, delivery will occur at the "cheapest-to-deliver" date, location, and grade because the shorts, or makers of delivery, seek the lowest cost alternative for sourcing the commodity to satisfy delivery obligations (Stulz 1982; Johnson 1987). The value of these delivery options to the short (timing, location, and grade) in grain markets may vary over time (Hranaiova and Tomek 2002; Hranaiova, Jarrow, and Tomek 2005). Furthermore, both longs and shorts involved in the delivery process incur costs, which in turn determine arbitrage bounds for the convergence of cash and futures prices at delivery locations.

Delivery on CBOT and KCBOT grain futures contracts is not satisfied directly by physical grain, but instead by issuing a warehouse receipt in the case of KCBOT wheat or a shipping certificate in the case of CBOT corn, soybeans, and wheat.[7] A warehouse receipt is a legal document that provides proof of ownership (title) of a certain grade and quantity of a commodity at a given storage facility; for example, 5,000 bushels of number one hard red winter wheat in firm *x*'s warehouse in Kansas City, Kansas. Crucially, warehouse receipts used in the futures delivery process are negotiable, and thus transferable between parties. A shipping certificate is also a legal document, but rather than representing actual grain in storage, it provides the holder the right but not the obligation to demand load-out of the designated commodity from a particular shipping station; for example, 5,000 bushels of number two yellow corn loaded on a barge at firm *y*'s shipping station on the Illinois River at LaSalle, Illinois.[8] The advantage of a shipping certificate is the flexibility it offers to makers of delivery because the grain can be sourced over time and space. Like warehouse receipts, shipping certificates are transferable. Neither warehouse receipts nor shipping certificates have expiration dates, and hence are in theory infinitely-lived instruments. Holders of these delivery instruments can redeem them by selling in the secondary market, exchanging them for grain (load-out), or re-delivery them by taking a short futures position and holding to the next expiration.

"Regular firms" play a key role in the CBOT and KCBOT delivery systems. Only firms approved by the exchange as regular for delivery are allowed to issue warehouse receipts or shipping certificates. Firms must meet certain exchange requirements to be eligible for regularity, such as a minimum net worth of $5 million, and have storage warehouses or shipping stations within the delivery territory of the futures contract. Regular firms are the source of all delivery instruments for their designated warehouses or shipping stations.[9] If a maker of delivery is not a regular firm, he/she must buy a receipt or certificate from a regular firm, another holder of a receipt or certificate, or have taken delivery on a previous long futures position. A regular firm that is short is the only party that has the ability to make an "original" delivery with a newly-issued delivery instrument. Regular firms are typically large commercial grain firms, such as Cargill, Bunge, and Archer Daniels Midland.

Firms issuing delivery instruments must: (*a*) have an equal quantity of grain in storage at the delivery location; (*b*) have an equal amount of grain in storage at a facility near the delivery location, or (*c*) be able to source the grain as needed to fulfill their contractual obligation. In the case of (*c*), the exchange enforces this requirement by stipulating the maximum number of delivery instruments that a firm may issue. The maximum for each firm is determined by the amount of storage space it controls. These restrictions imply that firms holding short futures positions cannot make unlimited deliveries.

Because grain is costly to store, a long taking delivery on a CBOT or KCBOT grain futures contract incurs a storage cost for as long as it holds the delivery instrument. This fee is assessed daily and the rate is set by the futures exchange rather than the market.

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[7] CBOT corn and soybean delivery was based on warehouse receipts prior to the March 2000 contract. CBOT wheat delivery was via a warehouse receipt prior to the July 2008 contract.

[8] In the case of a shipping certificate, title to the grain does not change hands until load-out of grain occurs at the shipping station.

[9] The exchange does not allow non-regular firms to issue delivery instruments because there is no guarantee that these firms have access to sufficient physical commodity to complete the delivery process. If firms were to promise delivery and not follow through, it would compromise the contract.

This daily storage rate is actually the maximum that can be charged by regular firms, but there is little evidence that regular firms have charged less than the maximum fee to takers of delivery. Historically, the storage rate has been fixed for long periods of time. As an example, the maximum storage rate for CBOT wheat futures contracts was fixed at 15/100 of a cent per bushel per day (about 4.5 cents per month) from the early 1980s until June 2008.[10] In an attempt to address recent convergence problems, however, the CME broke with its long practice of fixed storage rates and implemented a variable storage rate (VSR) rule for wheat beginning with the September 2010 contract (Seamon 2009). The VSR is keyed to the level of term spreads (difference in price across futures contract maturities on a given date) in the period immediately preceding the expiration of the nearby contract. The impact of the new rule on market performance is a source of considerable controversy, particularly among grain traders.

Representative Agent Model of the Delivery Market

To explain non-convergence and illustrate our main result, we begin with a stationary representative agent model. The representative agent behaves competitively according to rational expectations and is risk-neutral. In the next section, we proceed to a multiple agent model with frictions to allow for alternative explanations such as firm heterogeneity, transaction costs, and bubbles.

The representative firm enters period t with an endowment of I_{t-1} units of the commodity and faces cash market net demand

$$P_t = f(I_{t-1} - I_t, \varepsilon_t) \tag{1}$$

where P_t denotes the spot commodity price. In period t, the firm chooses how much of the commodity to store for possible sale in the next period (I_t), and how much to sell in the current period ($I_{t-1} - I_t$). Uncertainty enters the model through the net demand shock ε_t, which we specify to be stationary and ergodic.

We divide the price of grain storage into two components: the warehousing cost and the convenience yield. The warehousing cost, δ_t, is exogenous and includes the rental fee for warehouse space, handling and in- and out-charges, and insurance. The market price of physical storage may differ substantially from δ_t due to convenience yield, a concept introduced by Kaldor (1939) and developed further by Working (1948, 1949) and Brennan (1958). Convenience yield is typically motivated as an option value generated by transactions costs associated with sourcing the commodity (Telser 1958) or by the possibility that inventories could be driven to their lower bound (Routledge, Seppi, and Spatt 2000). Two options are particularly relevant in grain markets. First, having grain in storage allows firms to take advantage of merchandizing opportunities that require immediate access to grain. Second, filling binspace with grain imposes an opportunity cost because that space cannot be used for anything else (Paul 1970). For example, holding wheat in storage reduces opportunities to take advantage of merchandizing opportunities in corn. The first option increases a willingness to hold inventory and is likely to have high value when inventory levels are low, whereas the second reduces willingness to hold inventory and is likely to have high value when inventory levels are high.[11]

We abstract from the underlying forces that generate convenience yield and specify it as a monotonically non-increasing function of inventory, denoted by $y(I_t)$. This formulation is consistent with the empirical regularity first established by Working (1948, 1949), who used Chicago wheat storage data to show that the price of storage increases with the level of inventories. Combining the cost of storage and convenience yield, the market price of storage in our model is $\delta_t - y(I_t)$. Following Williams and Wright (1991) and Routledge, Seppi, and Spatt (2000), among

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[10] We were unable to determine the exact date when this rate was first implemented for the CBOT wheat futures contracts, as the records are currently sealed in the exchange archive. Figure 3.4 in Peck and Williams (1991) suggests the rate was implemented in the early 1980s.

[11] The second option implies a negative convenience yield, which is not common in the literature but is implied by a model of the opportunity cost of binspace (Paul 1970). Botterud, Kristiansen, and Ilic (2009) find evidence of a negative convenience yield in the hydro-dominated Nord Pool electricity market. When hydro reservoirs are close to full, the possibility of overflow implies an opportunity cost to holding water in the reservoir. This is the mirror image of the option value generated in the rational storage model of Routledge, Seppi, and Spatt (2000) by the possibility that inventories may hit their lower bound.

others, a stationary rational expectations equilibrium exists and implies[12]

$$(2)\qquad P_t = \frac{E_t[P_{t+1}]}{1+r_t} - \delta_t + y(I_t)$$

where r_t denotes the cost of capital. Futures contracts trade for one period before expiration, and equilibrium implies $F_{t,t+1} = E_t[F_{t+1,t+1}]$, where we denote the futures price in period i for delivery in period j as $F_{i,j}$.[13]

Each expiring futures contract is converted into a delivery instrument. This instrument may either be converted immediately into grain or held until the next period for possible re-delivery, depending on which alternative yields the largest payoff.[14] Holding a delivery instrument requires the agent to pay an exogenous storage rate γ_t. By specifying γ_t to be exogenous, we capture the essence of the CBOT and KCBOT delivery systems.[15] Next, we show how non-convergence arises when γ_t is less than the market price of grain storage, $\delta_t - y(I_t)$.

If the agent holds the instrument, then its present value equals the discounted expected value of the instrument in the next period minus the storage rate. If the agent converts to grain, then its present value equals the cash grain price. The expiring futures price, which equals the price of the delivery instrument, is therefore

$$(3)\qquad F_{t,t} = \max\left(\frac{E_t[F_{t+1,t+1}]}{1+r_t} - \gamma_t, P_t\right).$$

Note that the expiring futures price can exceed the spot price. This will occur when the value of the delivery instrument exceeds the value of spot grain and can be shown explicitly by writing the basis as

$$\begin{aligned}(4)\qquad B_t &\equiv F_{t,t} - P_t\\ &= \max\left(0, \frac{E_t[F_{t+1,t+1}]}{1+r_t} - P_t - \gamma_t\right)\\ &= \max\left(0, \frac{E_t[F_{t+1,t+1} - P_{t+1}]}{1+r_t}\right.\\ &\qquad \left. + \delta_t - y(I_t) - \gamma_t\right)\\ &= \max\left(0, \frac{E_t[B_{t+1}]}{1+r_t} + W_t\right)\end{aligned}$$

where $W_t \equiv \delta_t - y(I_t) - \gamma_t$ denotes the wedge between the price of carrying the commodity and the cost of holding certificates.

Equation (4) also shows that the level of the basis in t depends on the expected basis in $t+1$, which depends on the expected basis in $t+2$, etc. Specifically,

$$\begin{aligned}(5)\qquad B_t &= \max\left(\frac{E_t[B_{t+1}]}{1+r_t} + W_t, 0\right)\\ &= \max\left(E_t\left[\max\left(\frac{E_{t+1}[B_{t+2}]}{(1+r_{t+1})(1+r_t)}\right.\right.\right.\\ &\qquad \left.\left.\left. + \frac{W_{t+1}}{1+r_t}, 0\right)\right] + W_t, 0\right)\\ &= \text{etc}\ldots.\end{aligned}$$

To obtain a more easily interpretable expression for the basis, we define $D_{t+i} \equiv 1(B_{t+i} > 0)$ as an indicator function for whether the basis is positive in period $t+i$. Then we can write the basis as

$$\begin{aligned}(6)\qquad B_t &= \max\left(\frac{1}{1+r_t}E_t\left[\frac{D_{t+1}}{1+r_{t+1}}E_{t+1}\right.\right.\\ &\qquad \left.\left.\times\ [B_{t+2}] + D_{t+1}W_{t+1}\right] + W_t, 0\right)\\ &= \max\left(W_t + \sum_{i=1}^{\infty} E_t\left[D_{t+i}W_{t+i}\right.\right.\\ &\qquad \left.\left.\times\left(\prod_{j=0}^{i-1}\frac{D_{t+j}}{1+r_{t+j}}\right)\right], 0\right).\end{aligned}$$

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[12] In Williams and Wright (1991) and Routledge, Seppi, and Spatt (2000), the convenience yield is implicit and is only non-zero if $I_t = 0$, that is, in our notation, they would write the equilibrium as $P_t = E_t[P_{t+1}]/(1+r_t) - \delta_t$ if $I_t > 0$ and $P_t > E_t[P_{t+1}]/(1+r_t) - \delta_t$ if $I_t = 0$. Equation (1) includes this setting as a special case, but also permits more general dependence of the price of storage on inventory through the convenience yield function $y(I_t)$.

[13] Because the representative agent is risk-neutral, there is no risk premium in equation (1) or in futures prices. This assumption is consistent with the rational storage literature and the empirical fact that average payoffs on agricultural futures have been close to zero in the past thirty years (Sanders and Irwin 2012).

[14] We specify only one location, grade, and time period for delivery. As such, we abstract away from delivery options, which have been shown to be small in magnitude. For more on delivery options, see Hranaiova and Tomek (2002) and Hranaiova, Jarrow, and Tomek (2005).

[15] In the CBOT and KCBOT markets, the exchange only specifies an upper bound for the storage fee; firms are permitted to charge less than this amount. However, because we focus on the case when firms would like to charge more but cannot, this difference is irrelevant to our results. Thus, for simplicity we set the storage fee as a fixed rate.

Hence, the basis equals the expected present discounted value of future wedges for as long as the basis is positive. This implies that a relatively small wedge term in period t can have a large effect on the basis if it is expected to persist for an extended period. It also implies that current and expected future inventory levels are the main driver of the basis through their effect on convenience yield.

Only positive expected future basis values enter equation (6), so the basis has an option-like payoff structure. We could conceptualize (6) as the value of an option that gives the holder the right to exchange a shipping certificate for the physical commodity in any period. Aulerich, Fishe, and Harris (2011) also view the long's incentive to hold delivery instruments as an embedded exchange option. These authors price the option as a function of the relative volatility of cash and futures prices, whereas in our model the option value depends on expected future wedges. If changes in expectations of future positive wedges increase the ratio of cash price volatility to futures price volatility, then both models could be correct. However, relative volatility is likely to be highest when inventories are scarce and the market is in backwardation. In contrast, our formulation in equation (4) stipulates that the wedge is largest when inventories are large, which typically coincides with low relative volatility (Smith 2005), thereby contradicting the predictions of Aulerich, Fishe, and Harris (2011). In our empirical section, we use regression analysis to determine whether inventory or relative volatility better explains non-convergence.

The futures term spread is intimately related to the basis. If the deferred futures price exceeds the expiring futures price plus the costs of capital and holding delivery instruments, then there is an arbitrage opportunity. Thus, the absence of arbitrage requires $F_{t,t} \geq F_{t,t+1}/(1+r_t) - \gamma_t$. Using the equilibrium condition $F_{t,t+1} = E_t[F_{t+1,t+1}]$, equation (4) implies that the "excess" term spread is

$$(7) \qquad S_t \equiv \frac{F_{t,t+1}}{1+r_t} - F_{t,t} - \gamma_t = \min\left(0, \frac{E_t[F_{t+1,t+1}]}{1+r_t} - P_t - \gamma_t\right) = \min\left(0, \frac{E_t[B_{t+1}]}{1+r_t} + W_t\right) \leq 0.$$

Equations (4) and (7) imply that if $E_t[B_{t+1}]/(1+r_t) + W_t > 0$, then we have a futures market at full carry ($S_t = 0$) and non-convergence ($B_t > 0$). Conversely if $E_t[B_{t+1}]/(1+r_t) + W_t < 0$, then we have a futures market at less than full carry ($S_t < 0$) and convergence ($B_t = 0$). We thus generate the regularity that Irwin et al. (2011) identified; namely, that the futures market is at full carry when the basis is inflated. Our model shows that full carry occurs when plentiful inventories drive the price of physical storage above the cost of holding delivery instruments.

To further understand this result, consider the following decomposition of the expected price of storage:

$$(8) \qquad \underbrace{E_t[P_{t+1}] - P_t}_{\substack{\text{expected price of}\\ \text{physical storage}}} \equiv \underbrace{F_{t,t+1} - F_{t,t}}_{\text{futures term spread}} + \underbrace{F_{t,t} - P_t}_{\text{basis}} - \underbrace{E_t[B_{t+1}]}_{\substack{\text{expected basis}\\ \text{next period}}}$$

where we use the equilibrium condition $F_{t,t+1} = E_t[F_{t+1,t+1}]$. If the current and expected future basis equals zero, then the futures term spread equals the expected price of storage. However, equation (7) shows that the futures term spread is capped by the maximum storage rate γ_t. If the price of physical storage exceeds this cap, then the basis must widen because the maximum storage rate is not sufficient compensation for physical storage. This implication is independent of how many delivery instruments are issued—what matters is the wedge in storage costs.

Figure 2 illustrates this result using the classic two-period supply-of-storage framework developed by Working (1948, 1949) and Brennan (1958). For this two-period illustration, we set $E_t[B_{t+1}] = 0$. Panel A of figure 2 displays a case with high inventory (I_1) and therefore low convenience yield and a high price of storing the physical commodity. The fixed maximum storage rate implies an upper bound for the futures term spread that is lower than the physical price of storage, so the basis widens. Panel B shows a case with low inventory carryover and therefore a large convenience yield that drives the price of physical storage below the level required for

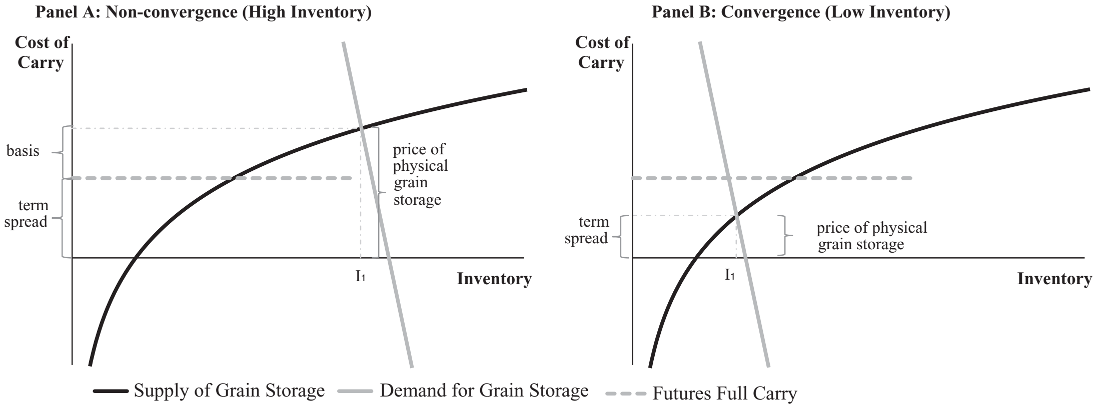

Figure 2. Convergence and the price of storage

Note: The expected price of grain storage is determined by the intersection of the supply and demand for storage. The term spread is bounded above by the dashed futures-full-carry line. The basis is positive when the price of grain storage exceeds futures full carry.

the agent to hold delivery instruments, so the basis equals zero.

The discussion above reveals a breakdown in Working's famous argument about the role of a futures market in the temporal allocation of stocks: "Thus existence of a futures market, coupled with the practice of hedging, gives potential holders of wheat a precise or at least a good approximate index of the return to be expected from storing wheat. This is an important fact which has been too much neglected in discussion of the economics of futures trading. It is through supplying a direct measure of the return to be expected from storage, and a means, through hedging, of assuring receipt of that return, or of approximately that return, that a futures market makes its most direct and powerful contribution to the economical distribution of supplies of a commodity over time," (Working 1949).

Equation (8) shows that the term spread in a futures market provides "a direct measure of the return to be expected from storage" only if the price of storing the physical commodity is less than the cost of holding the delivery instrument. Otherwise, the term spread provides a downward-biased estimate of the expected returns from storage. If market participants are less well-informed than the firms our model represents and use the term spread to guide physical storage decisions, they will underestimate the returns to storage and therefore store less than is optimal. This result shows how the futures term spread fails to reveal the price of storage in the presence of non-convergence.

Alternative Explanations for Basis Non-convergence

Before proceeding to an empirical analysis of the implications of our model, we first outline other possible explanations for non-convergence.

Index Fund Pressure

This hypothesis was raised most prominently in a USS/PSI (2009) report, which concludes that "Commodity index traders, in the aggregate, were one of the major causes of the "unwarranted changes"—here, increases—in the price of wheat futures contracts relative to the price of wheat in the cash market. The resulting, unusal, persistent and large disparities between wheat futures and cash prices impaired the ability of participants in the grain market to use the futures market to price their crops and hedge their price risks…" (USS/PSI 2009).

The hypothesized effect of commodity index funds on non-convergence in grain markets is part of a larger concern about the impact of speculation on commodity and food markets. The principal concern is that waves of index fund investment generated a series of bubbles in commodity futures prices (e.g., Masters 2008). This has led to various efforts to restrict or tax speculation in commodity futures markets.

Commodity index funds take positions only on the long side of the market. If traders on the short side of the market were unable to accommodate the increased demand for long futures positions, perhaps because of credit constraints or uncertainty over the time it would take to realize arbitrage profits, then futures prices would rise. The USS/PSI report does not mention why delivery arbitrage would not prevent cash and futures prices from decoupling. Moreover, this hypothesis carries no implications about the connection between the term spread and the basis. It also implies that changes in futures positions held by commodity index traders should be positively correlated with the basis. We investigate these implications empirically below.

Firm Heterogeneity and Market Frictions

During the recent period of non-convergence, a common refrain was that financial institutions had access to cheap capital and that holding delivery instruments provided a lucrative way to earn returns on that capital. On the other side of the market, regular firms often argue that giving up warehouse space or tying up shipping facilities in the delivery process is costly. In this section, we generalize our model to investigate the extent to which frictions such as differing capital costs and "inconvenience costs" associated with issuing delivery instruments could explain the basis.

We consider a model with two representative agents: the regular firm and the financial firm. The regular firm may issue delivery instruments and has the capacity to store grain, whereas the financial firm may not issue delivery instruments and cannot store grain. The financial firm is not necessarily a bank or a hedge fund, although some banks and hedge funds hold delivery instruments in these markets. The key feature is that the financial firm has access to cheaper capital than the regular firm. Thus, the friction in this market comes from a wedge in capital costs due to the perceived risk associated with grain handling. The financial firm has a capital cost r_t^f, which may be less than but cannot exceed the capital cost r_t faced by the regular firm. The two firms operate with identical information sets, have homogeneous rational expectations, and behave competitively in all markets.

The regular firm incurs a cost from outstanding delivery instruments that it has issued, which we term inconvenience cost. This cost is incremental to the price of storing grain in the physical market, $\delta_t - y(I_t)$, and may be related to several aspects of the firm's operations. Inconvenience cost may reflect the loss of flexibility from, in essence, giving up control of the grain in storage that backs outstanding certificates. As pointed out by Hieronymus (1977), grain in storage that is under control of the firm potentially has a high option value due to the possibility of blending with grain of different quality to increase total revenue and other merchandizing opportunities that may arise (also see Paul 1970). Alternatively, inconvenience cost could reflect futures exchange rules that require the firm to store grain that backs delivery instruments in a more costly location than it would use for unconstrained storage or because the possibility of load-out reduces the firm's available throughput capacity and thereby reduces its ability to handle grain for customers (Paul 1970). Finally, inconvenience cost can also represent transaction costs associated with issuing delivery instruments. We specify the inconvenience cost as a monotonically non-decreasing function of the number of certificates issued and held, C_t. We denote this function by $x(C_t)$.

Equilibrium in the physical commodity market is still represented by equation (2) because only the regular firm trades in that market. However, the delivery instrument market contains both agents, so it differs from the previous section. The financial firm can take delivery of a delivery instrument in period t at price $F_{t,t}$. After taking delivery, the firm can enter a futures contract to deliver the certificate back to the regular firm in period $t+1$ at price $F_{t,t+1}$. Thus, because the financial firm behaves competitively, its demand curve for delivery instruments is

$$(9) \qquad F_{t,t} = \frac{F_{t,t+1}}{1 + r_t^f} - \gamma_t.$$

The demand for delivery instruments is perfectly elastic; the financial firm will absorb as many instruments as the regular firm is willing to issue at this price.[16]

The marginal payoff to issuing a delivery instrument that is held until next period equals $F_{t,t} + \gamma_t - x(C_t)$, and the cost is the discounted price of buying the certificate

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[16] Until recently there was no limit on the number of warehouse receipts or shipping certificates that financial (non-commercial) firms could hold in grain futures markets. Under a CME rule instituted in February 2009, a financial firm is limited to holding no more than 600 receipts or certificates in corn, soybeans, and wheat. See http://www.cmegroup.com/rulebook/files/CBOT_RA0903-1.pdf.

back next period, that is, $F_{t,t+1}/(1+r_t)$. Thus, the regular firm would be willing to have C_t outstanding delivery instruments if

$$(10) \quad F_{t,t} + \gamma_t - x(C_t) \geq \frac{F_{t,t+1}}{1+r_t}.$$

Given the no-arbitrage condition $F_{t,t} \geq P_t$ and the fact that the regular firm behaves competitively, equation (2) implies that the supply curve for delivery instruments is given by

$$(11) \quad F_{t,t} = \max\left(P_t, \frac{F_{t,t+1}}{1+r_t} - \gamma_t + x(C_t)\right).$$

This curve is weakly upward-sloping because $x(C_t)$ is monotonically non-decreasing in C_t. Inserting equation (2) into equation (11) and using $F_{t,t+1} = E_t[F_{t+1,t+1}]$, we write the supply curve as

$$(12) \quad F_{t,t} = P_t + \max\left(0, \frac{E_t[B_{t+1}]}{1+r_t} + \delta_t - y(I_t) - \gamma_t + x(C_t)\right).$$

The greater the inconvenience cost, the greater is the required price, $F_{t,t}$, to issue delivery instruments.

Next, we show that a positive inconvenience cost implies that the delivery instrument market clears only if the regular firm faces a greater capital cost than the financial firm. The delivery instrument market clears if there exists a value C_t such that supply (12) equals demand (9), that is, if there exists C_t such that

$$(13) \quad P_t + \max\left(0, \frac{E_t[B_{t+1}]}{1+r_t} + \delta_t - y(I_t) - \gamma_t + x(C_t)\right) = \frac{F_{t,t+1}}{1+r_t^f} - \gamma_t.$$

Using equation (2) we can re-write equation (13) as

$$(14) \quad \max\left(0, \frac{E_t[B_{t+1}]}{1+r_t} + W_t + x(C_t)\right) = \frac{E_t[B_{t+1}]}{1+r_t^f} + \tilde{W}_t$$

where

$$(15) \quad \tilde{W}_t \equiv \delta_t - y(I_t) - \gamma_t + E_t[P_{t+1}]\frac{(r_t - r_t^f)}{(1+r_t^f)(1+r_t)}$$

denotes an expanded wedge that includes both the storage price wedge (W_t from equation (4)) and a capital cost wedge. If $r_t = r_t^f$, then these expressions reduce to their counterparts in equation (4).

The market clearing condition in equation (14) describes a competitive equilibrium in which expected profit equals zero for both firms. In equilibrium, delivery instruments will not be issued if the inconvenience cost to the regular firm exceeds the scaled difference in capital cost between the two firms. This result arises because the term spread in the futures market is determined by the financial firm's cost of capital, that is, from equation (9), we have $F_{t,t+1} = (1+r_t^f)(F_{t,t} + \gamma_t)$. By issuing a delivery instrument, the regular firm incurs the inconvenience cost, but by selling today at price $F_{t,t} + \gamma_t$ and buying back next period at the price $F_{t,t+1}$, it essentially gains access to credit at rate r_t^f. This lower cost of capital compensates the regular firm for the inconvenience cost. Thus, assuming a nonzero inconvenience cost, the delivery instrument market clears at positive C_t only if the financial firm has a lower cost of capital than the regular firm.

From equation (12), the basis is

$$(16) \quad F_{t,t} - P_t \equiv B_t = \max\left(0, \frac{E_t[B_{t+1}]}{1+r_t} + W_t + x(C_t)\right).$$

If the delivery instrument market clears under non-convergence, then equation (14) implies that the basis is

$$(17) \quad B_t = \max\left(0, \frac{E_t[B_{t+1}]}{1+r_t^f} + \tilde{W}_t\right).$$

The magnitude of the basis does not depend on the inconvenience cost function because the regular firm issues delivery instruments up to the point at which its marginal inconvenience cost equals the marginal gain from access to cheap capital.

This mechanism may be particularly relevant under a shipping certificate system because regular firms keep only a small amount of grain on hand to meet load out demands, and can leverage that grain by issuing multiple times as many certificates. If the exchange were to make it less costly for the regular firm to issue each delivery instrument, then the firm would issue more instruments to return its marginal inconvenience cost to its level before the reduction.

We model both firms as behaving competitively. A relevant empirical alternative could be that the regular firm has monopoly power. In the model as presented above, the regular firm faces a perfectly elastic demand for delivery instruments, so it could not extract monopoly rents by reducing supply in this market. However, if the demand for certificates were less than perfectly elastic, which could arise if the financial firm faced an increasing marginal cost of capital, then the regular firm would have an incentive to extract monopoly rents by issuing fewer delivery instruments. The effect on the model would be the same as the inconvenience cost because issuing an additional certificate would lower the price received on all certificates, that is, monopoly power would act as a negative inconvenience cost.[17]

In sum, the market frictions hypothesis implies that credit spreads affect the basis and that easing delivery restrictions should not reduce the basis. We investigate these implications empirically below.

Bubbles

The stationary equilibrium in equation (2), along with a transversality condition, ensures that the sequence in equation (6) converges as $s \to \infty$, where s reflects future time periods. This result follows from the fact that with probability one the model will enter a state with a zero basis, that is, convergence will occur someday. Also, because convergence is guaranteed on some future date, we can view the delivery instrument and grain as claims on the same future asset, namely future grain. In other words, the delivery instrument and cash purchases of grain provide two ways of obtaining future grain. The wedge term implies that the expected stream of payoffs differs across these two claims and therefore that their current prices differ.

We consider the possibility that the transversality condition does not hold and the basis contains a bubble component. Specifically, suppose the basis is

$$(18) \quad F_{t,t} - P_t = R_t + N_t$$

where $R_t = \max(E_t[R_{t+1}]/(1 + r_t^f) + \tilde{W}_t, 0)$ denotes the rational component of the basis as in equation (17) and N_t denotes a nonnegative noise component. Some algebra shows that the equilibrium condition $F_{t,t+1} = E_t[F_{t+1,t+1}]$ holds if $N_t = E_t[N_{t+1}]/(1 + r_t^f)$.

At prices characterized by $N_t > 0$, the regular firm would be willing to issue delivery instruments, and the financial firm would be willing to hold them as long as it could hedge at the price $F_{t,t+1} = E_t[F_{t+1,t+1}] = E_t[P_{t+1} + R_{t+1}] + (1 + r_t^f)N_t$. Thus, the noise term could perpetuate itself if both firms believed it would continue, thus providing an example of a rational bubble (Diba and Grossman 1988). However, because the firms in our model are infinitely lived, neither would be willing to take the other side of this hedge. Both firms know that the bubble will burst at some future date and at that time the firm on the other side of this hedge would be left holding delivery instruments or grain for which it had overpaid (Tirole 1982). To the extent that firms do not display such rationality, bubbles could arise.

Our theoretical model implies that the basis jumps up on a good crop and then steadily declines as inventory declines. Such a steady decline is difficult to explain using a bubble model. Bubbles are typically associated with spikes and crashes, and bubble models such as equation (18) imply that the basis should increase in expectation rather than decrease steadily. In addition, a bubble implies that the basis exceeds the present value of expected future positive wedges.

Preliminary Evidence for the Wedge Theory

In this section, we highlight five predictions of our model and show that they are

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[17] If the regular firm possesses market power in the grain storage market, then it would reduce the quantity of storage supplied, thereby raising the price of storage. This market power would expand the wedge. The capacity for regular firms to exert such market power would seem to be somewhat limited because there are few barriers to building storage facilities and farmers have the option of storing grain on the farm. For market power to explain an increase in the wedge, we would expect to observe a change in the local market structure consistent with the recent non-convergence episodes. We have no evidence of such a change.

consistent with the data. We proceed to a more formal empirical analysis in the following section.

The most general version of our theory as expressed in equation (17) implies the following matrix of possibilities

$$\begin{array}{ccc} & \text{convergence} & \text{non-convergence} \\ B_t & 0 & \dfrac{E_t[B_{t+1}]}{1+r_t^f}+\tilde{W}_t>0 \\ S_t & \dfrac{E_t[B_{t+1}]}{1+r_t^f}+\tilde{W}_t<0 & 0 \end{array}$$

This matrix produces two predictions:

Prediction I: The basis is either zero or positive, so that a negative basis does not occur.

Prediction II: The basis expands only when the futures market is close to full carry.

Formal empirical analysis is complicated by the nonlinear functional form of the basis in our theoretical model. However, rearranging terms in the above matrix produces the following implication for the expected basis:

$$\text{(19)} \quad \frac{E_t[B_{t+1}]}{1+r_t^f}=(B_t+S_t)-\tilde{W}_t.$$

Thus, conditional on the period t basis and term spread, next period's expected basis is negatively related to the wedge. The wedge is like the dividend on a stock; when a dividend is paid, the stock price drops. The discounted expected change in price equals the amount of the dividend, so a higher dividend implies a lower expected price. In our context, when inventory levels are high, the wedge is expected to remain positive for some period of time. The basis equals the present value of those positive wedges. For each month that passes, there is one fewer month of positive wedges to earn, so the basis drops. We expect the basis to jump up on a good crop and then steadily decline as inventory declines. Thus, we have two additional predictions:

Prediction III: Periods of non-convergence coincide with a high wedge and relatively high inventories.

Prediction IV: During non-convergence periods, the basis declines each month by an amount equal to the wedge.

Finally, we note that only positive wedges generate non-convergence. Thus, our fifth prediction is:

Prediction V: Raising the storage rate above the physical price of storage will restore convergence.

First we show that Predictions I and II hold for each of the four contracts. For Predictions III-V, we focus on CBOT wheat, which was the poster child for non-convergence.

The Basis and the Term Spread

Figure 1 shows the cheapest-to-deliver basis (average for first five days of delivery month) for each contract expiration from 1986–2013 in CBOT corn, soybeans, and wheat and 1990–2013 in KCBOT wheat. The plots in figure 1 confirm Prediction I—the basis is positive or very close to zero in CBOT corn, soybeans, and wheat with only a few exceptions. The most notable outlier occurred in September 1997 soybeans, when the soybean futures market was deeply inverted and convergence did not occur until the end of the 10-day delivery period. A curious pattern in this regard emerges for KCBOT wheat, where the basis is consistently negative from 1990–1995 but then is almost always near zero or positive thereafter. Prior to 1996, Kansas City was the only delivery location and it appears this led to a market imbalance that favored long futures holders. Once Hutchinson was added as a delivery location in 1996 this imbalance disappeared. Overall, with the exception of 1990–1995 for KCBOT wheat, the behavior of the basis is quite consistent with the prediction from our theory that the basis is zero or positive.

With regard to Prediction II, table 1 shows the average basis for contracts that expire when the futures market is at full carry.[18] We present results for both the cheapest-to-deliver location and for a fixed location. For corn and soybeans, we use Toledo as the fixed location until the end of 1999, when Toledo ceased to be a delivery location. Beginning in 2000, we switch to the Illinois River location. We use Toledo as the fixed delivery

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[18] Here, we define full carry as an excess spread not less than \$0.01 per bushel per month, where the excess spread is S_t as defined in equation (7). Until recently, the storage rate was \$0.05 per bushel per month, so this definition implies that the market is at full carry when the spread exceeds \$0.04 per bushel per month, or 80% of the storage rate. Our definition of full carry thus matches that in Irwin et al. (2011).

Table 1. Average Basis Conditional on Futures Term Spread (c/bu/month)

	Fixed Location		Cheapest-to-Deliver		
	Full Carry	Less than Full Carry	Full Carry	Less than Full Carry	Percent at Full Carry
Corn	25.9	1.3	19.0	8.2	28%
Soybeans	38.6	2.0	26.7	9.7	14%
CBOT wheat	36.4	6.1	48.3	20.7	43%
KCBOT Wheat	28.3	1.2	35.3	5.8	34%

Note: The table shows the mean basis at expiration for contracts when the futures term spread was at full carry (defined as $S_t \geq -1c$ per bushel per month for S_t as defined in equation (7)) and contracts when the term spread was less than full carry. The fixed delivery location is Toledo for CBOT Wheat, and Kansas City for KCBOT wheat. For corn and soybeans, the fixed delivery location is Toledo before 2000 and Illinois River North after. The KCBOT sample begins in 1990, the CBOT samples begin in 1986, and all samples end in September 2013. The last column shows the proportion of contract expirations at full carry.

location for CBOT wheat and Kansas City for KCBOT wheat. We report fixed-location results because, as shown in equation (8), the price of grain storage at a particular location can be decomposed as the term spread plus the basis. This connection between basis and the term spread is less direct across different locations. The average basis levels in table 1 confirm the correlation first identified in Irwin et al. (2011), that basis expands to large positive values when the term spread is near full carry. This behavior is again consistent with Prediction II of our theory.

A Case Study of CBOT Wheat

Figure 3 provides some graphical support of our model for CBOT wheat. The figure shows the basis, the wedge, and inventory in Toledo, which was usually the cheapest-to-deliver location during this period. Each curve in figure 3 is compiled from the average over the first five days of delivery for each contract expiration between March 1986 and September 2013.

Panel A reveals three distinct episodes of non-convergence with expiring futures greater than the spot price: July 1998–July 2001, March 2006–July 2007, and May 2008–May 2010. The first and third of these episodes occurred after prices had descended from a peak and inventory had accumulated, consistent with Prediction III. The 2006–07 episode occurred during a period of rising prices, but panel C shows that inventory was also relatively high in this period, consistent with Prediction III that the basis expands when inventory is high.[19] The fact that prices were high in 2006–07 in spite of high inventory suggests that a persistent demand shock caused the price increase. This period was characterized by a strong increase in the demand for grain due to the massive expansion of corn-ethanol production (e.g., Abbot, Hurt, and Tyner 2011).

Panel B decomposes the wedge into two components. The first component (dashed line) is the maximum storage rate on delivery instruments, γ_t. Aside from a small drop in 2000, the maximum storage rate was constant at about 4.5 cents per bushel per month until 2009. This rate increased slightly in 2009 when the CME introduced a seasonal storage rate, and dramatically so in 2010 with the introduction of the VSR. The second component (solid line) shows the remaining components of the wedge, that is, from equation (17) this term is

$$(20)\quad B_t + S_t - \frac{B_{t+1}}{1+r_t^f} + \gamma_t = \tilde{W}_t + \gamma_t + \varepsilon_t = \delta_t - y(I_t) + E_t[P_{t+1}] \frac{(r_t - r_t^f)}{(1+r_t^f)(1+r_t)} + \varepsilon_{t+1}$$

where $\varepsilon_{t+1} \equiv (E_t[B_{t+1}] - B_{t+1})/(1+r_t^f)$ is the shock to the basis and the second line follows from equation (15). We plot a three-period, centered moving average of this quantity to smooth out the shocks ε_{t+1} and label this

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[19] The 2008 crop of soft red winter wheat was the largest since 1981, and was almost double the average production in the previous 6 years, so the 2008 increase in inventory in panel C appears to understate the changes in the soft red winter (SRW) wheat market; SRW is the variety priced in the CBOT contract. At the end of the 2008 crop year, SRW wheat inventory was 171m bushels, compared to 55m bushels the previous year and a previous high of 136m bushels in 1998.

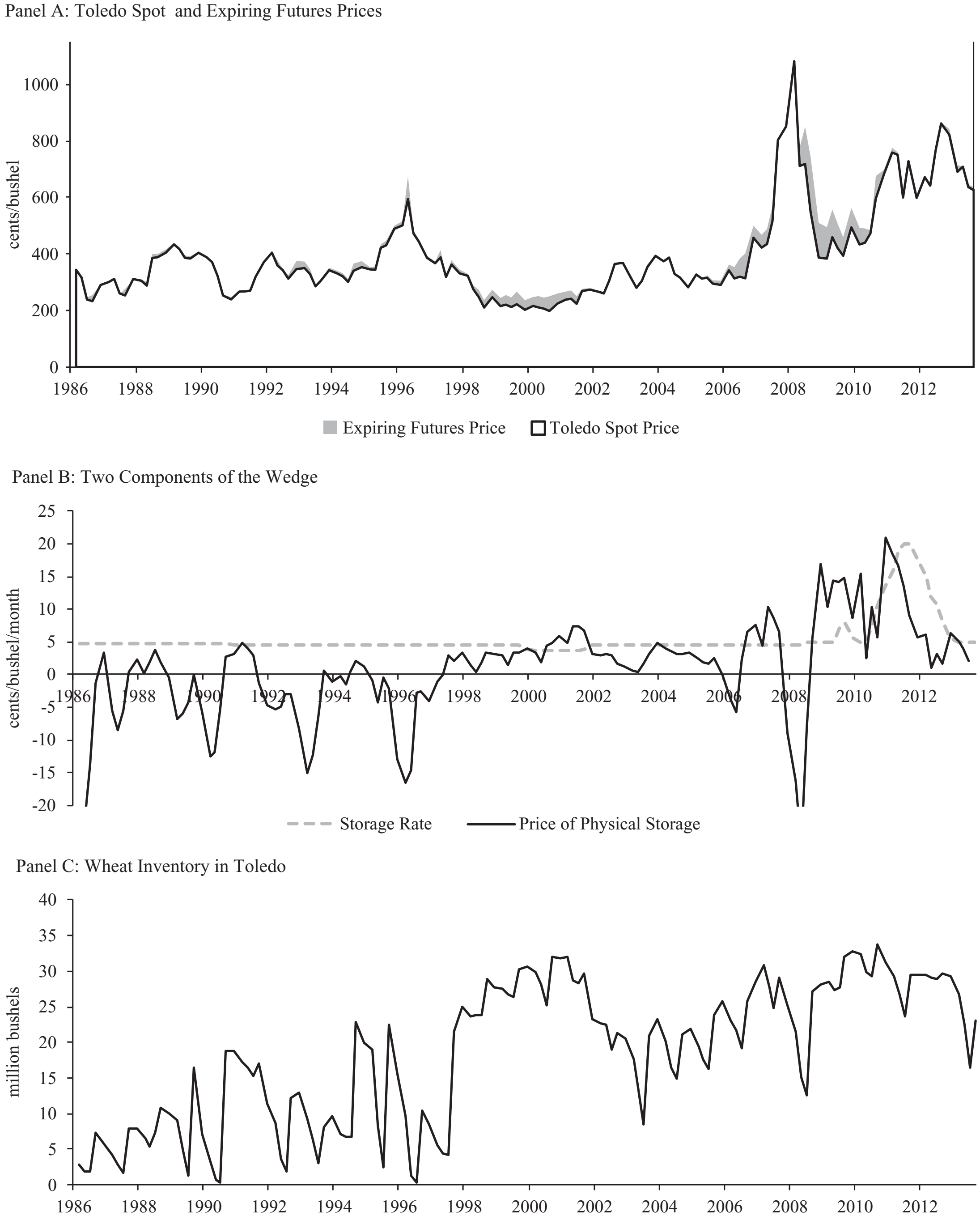

Figure 3. Elements of Non-convergence in CBOT wheat, 1986–2013

Note: This figure shows average data for first five delivery days of each contract from 1986–2013 for the CBOT wheat futures contract and Toledo. Panel B decomposes the wedge using equation (21). Panel C shows total wheat inventory in deliverable locations in Toledo.

curve the price of physical grain storage. The wedge is the difference between the two curves. Comparing panels B and C, this curve is closely related to inventory, which is consistent with the wedge being driven by fluctuations in the demand for physical storage as stated in Prediction III.

The basis reached its highest point in 2008 as a large crop replenished inventories and lowered prices. In Toledo, the cash price dropped almost in half from a peak of $10.82 in March 2008 to $5.49 in September. During that period, the basis expanded from $0.11 at expiration of the March contract to $1.95 at expiration of the September contract. The basis declined steadily in the ensuing two years, reaching $0.90 in July 2009 and $0.10 in July 2010. Prediction IV states that the basis declines each month by an amount equal to the wedge, so the decline in the basis from 2008–2010 implies a wedge of about $0.08 per month. The storage rate was $0.05 for all of this period except a few months in the summer of 2009 when it rose to $0.08. Adding the implied wedge to the storage rate indicates that the price of physical storage was $0.13 from 2008–2010, as illustrated in panel B of figure 3. Thus, the large basis in the fall of 2008 is consistent with a high price of physical storage in the ensuing two years.

The VSR was introduced in July 2010 and provides a test of Prediction V; it stipulates that, if the futures term spread exceeds 80% of full carry over a period of time, then the storage rate increases by $0.03 per month for the next delivery cycle. If the term spread is below 50% of full carry, then the storage rate decreases by $0.03 per month in the next delivery cycle (see Seamon 2009 for further details).

The introduction of VSR coincided with a futures market that was close to convergence. A month later, the devastating effects of the Russian drought on wheat production became clear and Russia imposed an export ban. These events generated an increase in the international demand for U.S. wheat and therefore increased the demand for storing wheat for later sale. Wheat inventories thus remained high and the price of storage increased. Reflecting this higher price of storage, the VSR increased gradually over the following year, reaching its peak of $0.20 in May 2011 before declining steadily back to $0.05 as inventory levels declined. By 2013, inventory levels were at their lowest levels since the 2008 spike and the futures market was converging consistent with Prediction V.

With the aid of figure 3, the reasons for the recent and dramatic failures of convergence come into sharper focus. Demand and/or supply shocks to the underlying commodity created a surge in inventories, which in turn drove up the price of physical grain storage. This market price of storage substantially exceeded the maximum storage rate being paid on CBOT and KCBOT grain futures contracts. In the case of CBOT wheat, panel B shows that the gap between the two was very large for much of 2008–2010, and hence the very large delivery location basis. The gap between the two series only began to narrow with the implementation of the VSR rule, which started with the September 2010 contract.

Regression Analysis to Explain the Wedge

In our regressions, we approximate the wedge as in the previous because the wedge itself is unobservable. Data on the physical price of grain storage essentially do not exist. Some grain elevators post storage prices, but these prices do not include convenience yield. Moreover, posted storage prices rarely change, so they represent a small fraction of the variation in the price of storage. This feature of the market explains why in the development of our theory we divide the price of grain storage into two components (warehousing cost and convenience yield) and why we emphasize the convenience yield.

Based on equation (19), we estimate the regression

$$(21)\qquad B_t - \frac{B_{t+1}}{1+r_t^f} + S_t = \beta' Z_t + v_{t+1}$$

where Z_t denotes a vector of explanatory variables. The subscript t represents contract expirations, so the elapsed time between observations ranges from one to three months. Thus, in our regressions, we scale the left-hand side by the number of months elapsed between t and $t+1$ to reduce heteroskedasticity. Equation (20) shows that the dependent variable in equation (21) equals the wedge plus noise; a high wedge in period t indicates a high basis in period t that is expected to decline by next period. We use variables predicted by theory and known from prior empirical work to affect the price of storage.[20] Details on all variables used in our regressions are presented in the online appendix. Unit root tests indicate that all variables are covariance-stationary.

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[20] Using the analogy of the wedge to a stock dividend, we estimate the magnitude of the dividend from the negative of the change in price.

We begin by using inventory as our only explanatory variable to establish a correlation between inventory and the wedge, as implied by our theory. Then, in the next section, we add variables to address other possible explanations for non-convergence. We provide the estimated results for the three CBOT contracts individually and the KCBOT wheat contract in table 2. For each commodity, we measure the basis using the cash price at a fixed location because, as shown in equation (8), the price of grain storage and therefore the wedge at a particular location can be decomposed as the term spread plus the basis.[21]

Consistent with our theoretical model, table 2 shows that inventory in deliverable locations is strongly related to the basis in all cases and yields similar coefficient values across commodities. The inventory variable enters in logs, so a coefficient of 4.26 (CBOT wheat) implies that a 10% increase in inventory (in log terms) leads to a 0.426 cent increase in the wedge. During the 2004 to 2008 period, deliverable stocks approximately doubled, which corresponds to an increase in log inventory of 0.69. In response to such a doubling of inventories, the coefficient implies an increase in the change in the basis of $4.26 * 0.69 = 2.94$ cents per month. For comparison, the CBOT storage rate on delivery instruments was 4.5 cents per month during most of this period, so the inventory effect is substantial.

To assess the possibility that a high wedge draws inventory into delivery locations rather than the other way around, we use instrumental variables estimation. We use national crop-year beginning stocks of the commodity as an instrument. This variable is determined by the size of the most recent harvest and prior-year aggregate storage decisions, which are unlikely to be caused by an anticipated future wedge in storage costs. In all cases, this proved to be a strong instrument (1st stage $F > 10$). The instrumental variables estimates were close to the OLS estimates reported in table 2. Only in the case of corn does the Hausman test suggest the presence of endogeneity, but the difference in the coefficients is not large.

We test whether the parameters are significantly different before and after October 2006. We choose this date based on the finding in Carter, Rausser, and Smith (2013), that the demand for corn inventory increased significantly in the fall of 2006 due to an increase in the demand for current and future corn caused by the growth in ethanol production. These authors show that this shock increased the price of storage for corn, an effect that would have spilled over to other grains.[22] We find evidence of a break for all four contracts. Consistent with the findings of Carter, Rausser, and Smith, the post-break inventory coefficients tend to be larger than the full sample coefficients. This evidence reinforces our claim that the price of storage was the primary driver of the recent non-convergence episodes, and it implies that the supply of storage curve is not constant over time. Thus, our full-sample estimates reflect the average relationship between the wedge and inventories over our sample period. This relationship may differ from the average in some sub-periods. We correct the standard errors of our full-sample estimates for any autocorrelation that may be induced by these breaks, which allows correct inference about the average effect of inventory on the wedge.[23]

The econometric results highlight the key role of inventories and the price of physical storage in explaining non-convergence. The results are consistent with our theory, which predicts that, given a constant contract storage rate, the wedge and consequently the basis expands when grain inventory is plentiful and collapses when inventories are scarce. Specifically, non-convergence in theory will develop as cash prices drop after a temporary price shock. The temporary nature of the shock is important because only temporary shocks such as an exceptionally good harvest will cause inventories to run up sharply and convenience yield to fall.

Assessing the Alternative Explanations

Table 3 shows regression estimates with an expanded set of explanatory variables chosen

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[21] In the online appendix (table A1), we report the same regression except using the cheapest-to-deliver location to measure the wedge. The results are very similar.

[22] For corn and soybeans, the switch from a warehouse receipt to a shipping certificate delivery system in 2000 may also play a role in the larger coefficient in the latter part of the sample. Recent inventory at deliverable locations for these two commodities is much lower than before, perhaps because it is stored a little further away. Measured inventory thus understates effective inventory, thereby magnifying the coefficient on measured inventory.

[23] Our results are robust to the inclusion of a second lag in the Newey-West standard error estimator.

Table 2. Wedge Regressions for CBOT Corn, Soybeans, and Wheat and KCBOT Wheat with Inventory as the Explanatory Variable

		CBOT Corn		CBOT Soybeans		CBOT Wheat		KCBOT Wheat	
Coefficient Estimates		OLS	IV	OLS	IV	OLS	IV	OLS	IV
Inventory		5.47*	8.32*	15.68*	22.69*	4.26*	3.65*	3.03*	4.55*
		(1.91)	(2.03)	(3.82)	(6.47)	(1.05)	(1.43)	(0.99)	(1.82)
Constant		−58.95*	−85.42*	−155.96*	−217.55*	−46.09*	−40.08*	−33.01*	−46.93*
		(18.89)	(19.18)	(35.61)	(58.59)	(10.38)	(13.93)	(9.41)	(16.91)
Diagnostic Statistics									
F-test for Break in Oct 06	(c.v. = 5.99)	7.11*		7.29*		8.13*		7.94*	
Elliott-Muller Break Test	(c.v. = −14.38)	−24.92*		−17.15*		−10.36		−19.50*	
LM for AR(1)	(c.v. = 3.84)	7.87*		2.97		0.58		3.59	
1st Stage F-Stat	(c.v. = 10)		33.53*		49.11*		52.49*		46.61*
Hausman Test	(c.v. = 3.84)		4.31*		1.96		0.31		1.05
Residual Autocorrelation (AR(1))		0.28		0.20		0.09		0.19	
R-square		0.09		0.16		0.15		0.07	
Sample Size		138	138	195	195	138	138	117	117

Note: This table shows regressions of the wedge variable in equation (21) on the log of total inventory at deliverable locations. The wedge is measured in cents/bushel/month. Delivery location is Toledo for CBOT wheat and Kansas City for KCBOT wheat. For corn and soybeans, delivery location is Toledo before 2000 and Illinois River North after. The KCBOT sample begins in 1990, and the CBOT samples begin in 1986. Standard errors (in parentheses) are estimated using the Newey-West method with one lag. Critical values (c.v.) with nominal size of 5% are given in parentheses for diagnostic test statistics. The Elliott-Muller break test is developed in Elliott and Muller (2006).

to capture alternative hypotheses to explain non-convergence.[24] These variables are as follows:

- *a)* The log standard deviation of the difference between daily spot and nearby futures returns during the month prior to delivery to capture the option value in Aulerich, Fishe, and Harris (2011).
- *b)* The log of the ratio of inventories of materials and supplies held by food products manufacturing firms to sales of those firms. This variable captures the possibility that more efficient inventory management systems may have reduced the willingness of manufacturing firms to hold inventory, thereby reducing convenience yield and increasing the wedge.
- *c)* The spread between yield on 3-month non-financial commercial paper and 3-month Treasury Bills to approximate differences in the cost of capital between regular and financial firms that may have expanded the wedge.
- *d)* The change in futures positions held by commodity index traders to capture the index fund pressure hypothesis in USS/PSI (2009).

We report results with and without a linear trend and contract-month fixed effects. The purpose of the trend is to control for the possibility of spurious regression due to coincident trends.[25] The trend has a small and insignificant coefficient in each case. The fixed effects compete with the inventory variable because inventory varies seasonally; it is largest right after harvest and smallest just before the next harvest.

The results in table 3 show that the wedge is lowest late in the crop year when inventories are low, and highest around the harvest when inventories are plentiful. The corn and soybean harvest occurs around October. Corn and soybeans exhibit the lowest month effects in July and August, and the highest in September and November, respectively (November is the omitted category in the definition of the dummy variables for soybeans). The winter wheat harvest occurs in June and July, which is consistent with the basis being small in March and largest in September. For three of the four commodities, the inventory coefficient is smaller in the model that includes the fixed effects, which is consistent with the intra-season effects being positively correlated with inventory.

The coefficient on volatility is statistically insignificant in all cases, and is not consistent in sign. The coefficient is associated with a higher wedge for the soybean and wheat CBOT contracts, and a lower wedge for KCBOT wheat. This finding suggests that the option to convert delivery instruments into grain does not increase in value when volatility is high, which is the prediction of the exchange-option model in Aulerich, Fishe, and Harris (2011).

For the inventory-sales ratio, the estimated coefficients are negative in almost all cases. The corn model with month fixed effects and both KCBOT wheat models produce statistically significant coefficients at the 5% level. The log of the inventory-sales ratio declined by 0.16 between 2001 and 2013, which, for KCBOT wheat, represents a $30 * 0.16 = 4.8$c increase in the wedge. Taken together, these estimates suggest weakly that the convenience yield in food manufacturing may have declined over time, thereby increasing the wedge. The evidence is most consistent for hard red winter wheat, which is used to make bread and general purpose flour.

The coefficients on the remaining variables in the model are not statistically significant for the most part, although they often possess the expected signs. Next, we discuss these variables in the context of the hypotheses that they represent.

Fund Pressure

The coefficient on CIT positions is insignificant and varies in sign across the four contracts, so our regressions provide no evidence that CIT positions affected the basis. Moreover, the index fund pressure hypothesis makes no prediction about the connection between inventory and the basis. The fact that we find such a connection and that it is implied directly by our theory further reduces the plausibility of the index fund pressure hypothesis. Index fund positions grew rapidly in 2004–2006 before leveling off, whereas non-convergence was largest in

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[24] In the online appendix (table A2), we report the same regression except using the cheapest-to-deliver location to measure the wedge. The results are very similar.

[25] The episodes of non-convergence are concentrated at the end of the sample and average inventories tend to grow as the market grows. If we found that the correlation between the wedge and inventory disappeared when we controlled for a trend, then we would suspect that the wedge/inventory correlation is spurious.

Table 3. Wedge Regressions for CBOT Corn, Soybeans, and Wheat and KCBOT Wheat with Expanded Set of Explanatory Variables

		CBOT Corn		CBOT Soybeans		CBOT Wheat		KCBOT Wheat	
Coefficient Estimates		OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Inventory		7.42*	10.63*	14.34*	9.84*	3.74*	3.54*	3.33*	3.19*
		(2.54)	(3.10)	(4.48)	(4.76)	(1.28)	(1.42)	(0.92)	(1.01)
Volatility		2.47	−0.45	0.05	1.64	0.70	0.04	−1.07	−1.23
		(2.10)	(2.30)	(3.18)	(3.10)	(1.28)	(1.25)	(0.75)	(0.85)
Inventory/Sales		−29.52	−53.03*	−0.16	29.72	−6.70	−24.80	−21.95*	−30.76*
		(18.51)	(24.99)	(22.14)	(57.49)	(11.11)	(15.64)	(5.44)	(11.71)
Credit Spread		6.67	3.45	9.11	11.18	−0.26	−2.94	−3.57	−4.55
		(3.70)	(3.57)	(7.49)	(10.06)	(3.27)	(3.66)	(3.00)	(2.94)
CIT		0.11	0.04	−0.18	−0.22	0.00	0.07	−0.30	−0.13
		(0.10)	(0.09)	(0.92)	(0.78)	(0.17)	(0.18)	(0.51)	(0.53)
Trend			−0.18		0.20		−0.38		−0.20
			(0.36)		(0.96)		(0.34)		(0.26)
January					2.93				
					(8.53)				
March			−1.96		4.01		−6.16*		−2.66
			(2.25)		(8.40)		(2.15)		(1.79)
May			−3.52		−4.19		−2.80		1.81
			(2.64)		(8.50)		(2.51)		(1.90)
July			−8.81*		−18.58		−0.80		0.28
			(4.45)		(11.30)		(2.69)		(2.11)
August					−23.59				
					(8.66)				
September			11.42*		−8.32		2.44		2.61*
			(4.26)		(8.97)		(1.81)		(1.16)
Constant		25.50	78.86	−147.00*	−204.90	−16.61	50.93	41.31*	73.54
		(50.50)	(73.63)	(74.24)	(184.76)	(47.60)	(60.27)	(20.92)	(46.25)
Diagnostic Statistics									
F-test for Break in Oct 06	(c.v. = 5.99)	3.45	5.07	6.12*	8.16*	11.17*	11.27*	0.13	2.15
Elliott-Muller Break Test	(c.v. = −14.38)	−20.30*	−21.99*	−18.51*	−18.17*	−10.07	−10.24	−7.63	−8.10
LM for AR(1)	(c.v. = 3.84)	6.32*	8.00*	3.49	5.48*	0.80	0.82	0.08	0.45
Residual Autocorrelation (AR(1))		0.20	0.23	0.21	0.20	0.10	0.09	0.03	0.06
R-square		0.15	0.28	0.16	0.23	0.16	0.23	0.26	0.31
Sample Size		138	138	195	195	138	138	117	117

Note: This table shows regressions of the wedge variable in equation (21) on the log of total inventory at deliverable locations and other explanatory variables. The wedge is measured in cents/bushel/month. The delivery location is Toledo for CBOT wheat and Kansas City for KCBOT wheat. For corn and soybeans, the delivery location is Toledo before 2000 and Illinois River North after. The KCBOT sample begins in 1990, and the CBOT samples begin in 1986. Standard errors (in parentheses) estimated using the Newey-West method with one lag. Critical values (c.v.) with a nominal size of 5% are given in parentheses for diagnostic test statistics. The Elliott-Muller break test is developed in Elliott and Muller (2006).

2008–2010. Moreover, this theory suggests that non-convergence should be associated with increasing futures prices, whereas our theory implies that the largest basis typically occurs when prices are falling. Notably, and in support of our theory, figure 3 shows that the largest CBOT wheat basis occurred as prices declined from their 2008 peak.

Our findings do not support the conclusion in the USS/PSI (2009) report that commodity index traders overpowered arbitrageurs and thereby expanded the basis. This result is consistent with Stoll and Whaley (2010), Irwin et al. (2011), Aulerich, Irwin, and Garcia (2013), and Hamilton and Wu (forthcoming), none of whom found evidence that CIT positions significantly expand term spreads in CBOT corn, soybeans, and wheat. Mou (2011) finds evidence that term spreads expand during the period when commodity index funds roll from one contract to another. However, such effects are concentrated in commodities such as energy and livestock, which exhibit much greater spread volatility than grains and oilseeds.

Firm Heterogeneity and Market Frictions

The credit spread coefficient is positive for 2 of the 4 contracts but is not statistically significant at the 5% level in any case; it is significant at 10% for corn. The point estimate for corn is 6.67, which implies that a one standard deviation (30 basis point) increase in the credit spread is associated with a 2-cent increase in the wedge. A 2-cent increase in the wedge that is expected to last for a year would raise the basis by about 24 cents, so this quantity is non-negligible. However, the imprecision of this estimate, along with the lack of evidence for similar effects in the other contracts, suggests that credit spreads are not a major driver of the wedge.

The version of our theory that allows for firm heterogeneity and market frictions predicts that making delivery more convenient would not reduce the basis. This prediction is quite relevant to changes made in the CBOT wheat contract. In July 2009, the CBOT more than doubled the contract's delivery capacity by adding new delivery locations in Northwest Ohio, on the Ohio River, and on the Mississippi River. This change gave greater flexibility to regular firms and thus lowered the inconvenience cost of making delivery. However, it had no effect on the basis because it was inconsequential for the price of storing wheat in the physical market and therefore had no effect on the wedge.[26]

Bubbles

On September 2, 2008, the cash price of soft red winter wheat in Toledo was \$5.49, which was \$1.95 below the price of the expiring futures contract and by far the widest basis in our sample. Cash prices had dropped almost 50% in the previous six months as plentiful harvests had replenished global inventories and relieved supply pressures. In our theoretical model, the basis expands when rising inventories cause an increase in the price of carrying physical grain. Was the increase in the price of physical grain storage large enough to justify a basis of \$1.95, or was this an example of a bubble?

To answer this question, and similar questions for the other commodities, we examine whether subsequent wedges were large enough to match the basis using the present value expression in equation (6). Figure 4 shows, for each delivery date, the implied basis if traders expected the current wedge to persist either until the next harvest or the harvest after next.[27] Thus, it provides a range of plausible estimates of the present value of future positive wedges. For September 2008, this calculation produces a range of \$1.20 to \$2.63 for the wheat basis in Toledo. This range includes the actual basis of \$1.95. The peak basis for the other three contracts also lies in the range implied by this calculation. If these peaks constituted bubbles, then the basis would have exceeded the rational expectation of future wedges. In contrast, we find that the peaks lie within the ex-post rational range we calculate.[28]

The slow declines from the peaks in the basis are also inconsistent with the bubble theory. Figures 3 and 4 show that periods of high basis typically begin with a spike

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[26] This is consistent with Aulerich, Fishe, and Harris's (2011) finding that cash market liquidity in CBOT corn, soybean, and wheat delivery territories was similar during delivery and non-delivery periods.

[27] To approximate the current wedge, we use the average of the dependent variable in equation (21) over the ensuing three contract deliveries.

[28] These calculations predict a zero basis for more than 99% of the contracts that expired with basis less than \$0.10. When convergence fails, the plausible range we calculate spans the basis in only 10–20% of expirations as can be seen in figure 4 (depending on the commodity). However, the purpose of these calculations is to show that the large basis observations are plausible in a rational expectations world. We do not claim to have a good forecast of future wedges in every delivery month.

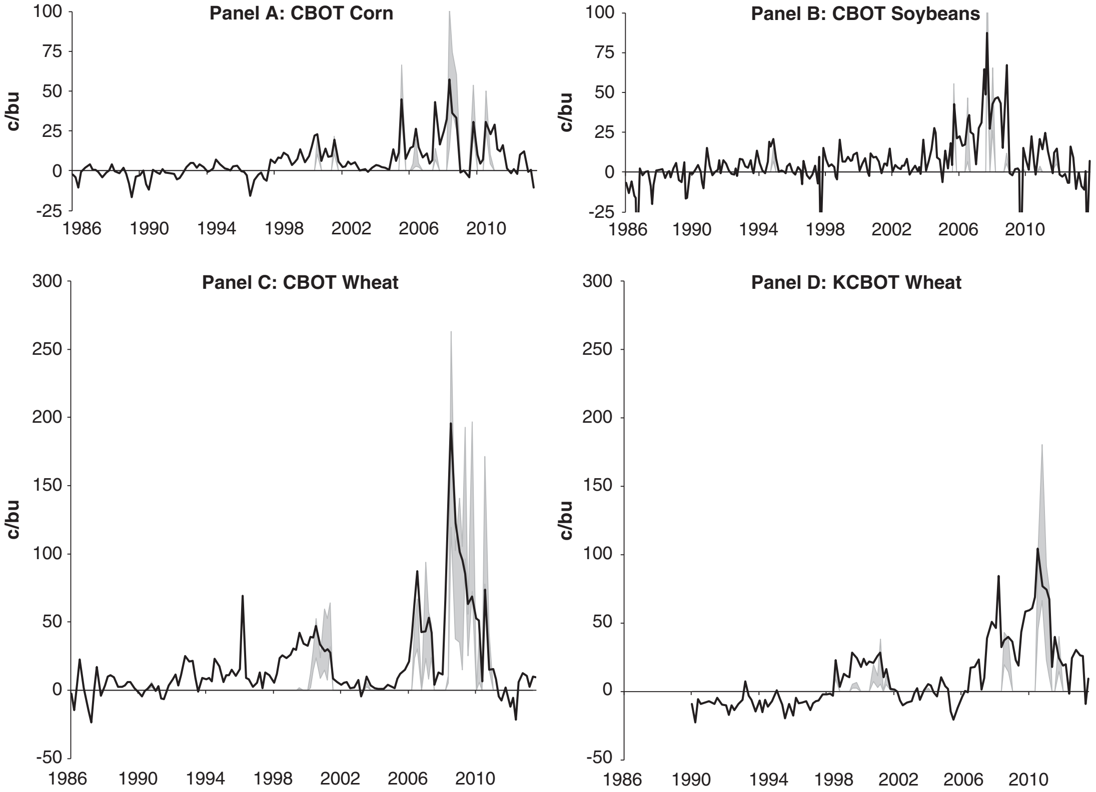

Figure 4. Predicted basis at expiration using expected future wedges in fixed locations, 1986–2013

Note: The shaded region represents the basis implied by our model if traders expected the current wedge to persist at least until the next harvest, and at most until the harvest after next. Thus, it provides a range of plausible estimates of the present value of future positive wedges. The fixed delivery location is Toledo for CBOT Wheat, and Kansas City for KCBOT wheat. For corn and soybeans, the fixed delivery location is Toledo before 2000 and IL River North after. The KCBOT sample begins in 1990, the CBOT samples begin in 1986, and all samples end in September 2013.

at harvest, which then slowly declines during the crop year. The period beginning in September 2008 in CBOT wheat provides the starkest example of this pattern. In contrast, models of bubbles imply that traders expect the price to increase over time. This expectation does not imply that actual prices should increase over time; spikes and crashes may generate a bubble price path that differs from the ex ante expectation. Nonetheless, a steady decline in the basis is incongruous with a model in which traders expect an increasing basis.

Conclusion

In this article we develop a dynamic rational expectations model of commodity storage that explains recent convergence failures in grain futures markets. When delivery occurs on a grain futures contract, the firm on the short side of the market issues a delivery instrument (a warehouse receipt or shipping certificate) to the firm on the long side of the market. The delivery instrument is a security that can be exchanged for grain at any time. The long firm may hold the delivery instrument indefinitely, although it must pay an exchange-determined daily storage rate while it holds the instrument. We show that non-convergence arises in equilibrium when the market price of physical grain storage exceeds the cost of holding delivery instruments. We call the difference between the price of carrying physical grain and the cost of carrying delivery instruments the *wedge*, and show theoretically that the magnitude of the non-convergence equals the expected present discounted value of a function of future wedges.

Empirical findings support our theoretical model, and provide evidence of the importance of inventories at the deliverable locations as the key factor in explaining the wedge and basis behavior over time. As anticipated from the theory, inventories have a pervasive effect on the basis in all the markets, and the expected present discounted value of future wedges closely maps the magnitude of non-convergence. Theoretical predictions are also consistent with the relative effectiveness of CME's actions to bring about convergence in CBOT wheat. Increasing the number of delivery locations to reduce costs had little effect, but introducing the variable rate storage rule (VSR), which adjusts the maximum storage rate, facilitated convergence. In contrast, systematic evidence for alternative explanations of basis behavior is limited or fails to emerge. Empirical findings fail to support the arguments that trading by commodity index funds, credit differentials favoring speculative financial firms, or irrational bubbles contributed in any measureable way to the non-convergence problem.

Futures markets exist to facilitate effective risk-shifting and efficient price discovery (e.g., Telser and Higinbotham 1977; Pirrong, Haddock, and Kormendi 1993). Our model shows that if futures prices are driven by expectations of future wedges, then they fail to price cash grain. However, non-convergence does not induce any welfare losses in our model because market participants have full information and understand the equilibrium. Moreover, firms that wanted to hedge cash price risk could design derivative contracts to, for example, price the option to load-out from delivery instruments (Aulerich, Fishe, and Harris 2011).

In reality, many firms may have been made worse off by the lack of convergence. The vigorous public debate surrounding the causes of non-convergence suggests that many market participants may not have fully understood the source of non-convergence and therefore may have misinterpreted the price signals received from futures prices. Specifically, our model shows there is a breakdown in Working's (1949) famous argument about the role of a futures market in the temporal allocation of stocks. The term spread provides a downward-biased estimate of the expected returns from storage when the price of storing the physical commodity exceeds the exchange-determined storage rate on the delivery instrument. If this bias is not recognized and understood, market participants may underestimate the returns to storage and store less than is optimal. Even fully-informed traders, who could theoretically enter into derivative contracts to achieve a desired hedge, would incur additional transactions costs in the presence of non-convergence.

Nonetheless, grain and oilseed markets have so far taken non-convergence in stride. Volume and open interest for CBOT corn and wheat increased significantly though the non-convergence period, and these quantities increased at similar rates to other important commodity futures markets, such as NYMEX crude oil, which had no convergence problems. In contrast, numerous prominent futures contracts have undergone dramatic declines in trading when structural problems undermined their facility as hedging and price discovery tools. In agricultural markets, the most recent example is pork bellies, which ceased trading in 2011 because it was no longer useful as a hedging tool. In an earlier example, Working (1954) documents a dramatic decline in volume and open interest in Kansas City wheat futures in 1953, when a change in the value of delivery options caused the futures market to price soft rather than hard red winter wheat. The Kansas City contract lost about 70% of its trading volume in a two-month period, and wheat trading in Kansas City only recovered when the exchange introduced a new futures contract that allowed only hard wheat to be delivered.

Chicago Board of Trade wheat has been the poster child for non-convergence. Consistent with our theory, the institution of a variable rate storage rule (VSR) appears to have resolved the immediate convergence problems in that market, but significant obstacles remain. The VSR is complicated and potentially prone to manipulation, and significant structural problems exist because wheat production has moved away from Toledo, which remains the cheapest-to-deliver location (Irwin et al. 2011). More broadly, the physical price of grain storage has increased significantly in recent years, and in wheat markets it has increased by more than would be expected for observed inventory levels, even with spill-overs from other grains caused by competition for bin space. The source of this rise remains a topic for future research.

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