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Mandatory Price Reporting, Market Efficiency, and Price Discovery in Livestock Markets

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Abstract

As the use of alternative marketing arrangements (AMAs) such as forward contracts and formula pricing has expanded in livestock markets since the early 1990s, and nego-tiated cash markets have become less commonly used to arrive at transaction prices, questions about price discovery and market efficiency have arisen. Congress passed the Livestock Mandatory Reporting Act (LMRA) in 1999 in response to concerns about a lack of public disclosure regarding AMAs, as well as concerns about concentra-tion in the meat packing industry. The LMRA introduced mandatory price reporting (LMR) of most livestock transactions to improve the flow of transaction information in the market place and enhance price discovery, and to replace the previous system (which had relied on voluntary reporting from cash market transactions). Renewed and amended in 2005 and 2010, the LMRA is up for renewal again in 2015. This report analyzes livestock market price behavior and price discovery before and after imple-mentation of LMRA, and finds that the increased flow of market information with LMR better informs the broader market. Analyses also indicate that futures and cash prices for hogs respond and adjust to new information (market efficiency) better in the LMR era, with an increased role for cash markets in price discovery.

Keywords: Beef, Cattle, Causality, Error Corrections Model, Futures Prices, Hogs, Livestock Mandatory Reporting, Livestock Mandatory Reporting Act, Livestock sellers, Meatpackers, Pork, Price Discovery, State-Space Model, Vector autoregression

Acknowledgments

Mandatory Price Reporting, Market Efficiency, and Price Discovery in Livestock Markets

Introduction

In 1999, the U.S. Congress passed the Livestock Mandatory Reporting Act (LMRA), which required mandatory reporting (LMR) of market transaction data, including price and quantity information. The LMRA was implemented in April 2001, renewed and amended in 2005 and 2010, and is set to expire on September 30, 2015. The LMRA was (U.S. Senate Report 106-168, 1999, p. 1):

> "…to establish a program of information regarding the marketing of cattle, swine, lambs, and products of such livestock that: provides information that can be readily understood by market participants; improves the U.S. Department of Agriculture's price and supply reporting services; and encourages competition in the marketplace for livestock and livestock products."

Since an earlier evaluation of the first version of the LMRA (Perry et al., 2005), significant data have accumulated on prices for cattle, hogs, beef, and, since 2013, pork. Perry et al. (2005) provided detail on the issues that drove the switch to mandatory reporting, focusing on cattle and beef, and showed that the same model could be used to forecast cattle and beef prices both before and during LMR, implying little change in how market prices were set before and during LMR.

LMR has now been in effect for more than 15 years. With the LMRA set to expire on September 30, 2015, a number of questions arise. What insights can be obtained from the current and prior economic literature regarding the flow of information in markets with LMR? What can data tell us about the effects of LMR on market efficiency during the last decade and a half, and what impacts has LMR had on price discovery? This report investigates the economic implications of LMR in the context of declining participation in cash markets in favor of alternative marketing arrangements (AMAs) for price discovery (what information and what mechanisms form market prices), market efficiency (how quickly and completely markets converge on a single price), and price behavior before and after passage of the LMRA (see box 1). While we do not explicitly address the issue of market power beyond the literature review, market power issues underlie both price discovery and market efficiency issues—i.e., the potential for control of the quality and quantity of information was one of the issues that motivated passage of the LMRA.

The goal of this report is to extend the analysis by Perry et al. (2005) in several ways. Following a brief description of the evolution of U.S. livestock and meat markets, we summarize studies completed since the LMRA renewals in 2005 and 2010 on the relative use of various AMAs compared with cash (spot) market activity in the cattle and hog markets. We review more recent economic literature on the effects of LMR on market performance (cash and futures markets), market power (price discovery and market efficiency), and market participants (livestock sellers, meatpackers, and futures traders). Finally, we conduct empirical analyses of pre-LMR and LMR market behavior that support the key findings of this report.

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U.S. Federal Government Intervention in Livestock Marketing

Since about 1946, the U.S. Department of Agriculture's Agricultural Marketing Service (AMS) used voluntarily reported prices for livestock and meat in its market news program (Perry et al. (2005) provides discussion of the voluntary system and related issues). Table 1 contains a history of the major livestock marketing policies and laws. There are two basic reasons that the Government has involved itself in livestock markets. The first is to improve the general functioning of these markets by providing them with better and more widely available information. Quality grades, standards, and market news can improve market performance by providing information to all meatpackers and live-stock sellers. For example, objective and verified grades make it possible to buy and sell livestock and meat sight unseen. General market news gives livestock sellers, meatpackers, policymakers, and the general public information on current conditions in the livestock and meat sectors.

Table 1

Landmarks and legislation affecting market transactions for livestock

Year	Landmark or legislation
1890	U.S. Senate Select Committee on the Transportation and Sale of Meat Products report
1914	Appropriation Act established the Livestock and Grain Market News Branch
1916	Quality grades for meat established
1917	Food Production Act authorized inspection and market news service on farm products during World War I
1917	Market news service on dairy and poultry products begins
1917	USDA began developing grade standards for market hogs and slaughter lambs and sheep
1918	First livestock market news reports issued for Chicago
1920	Packers' Consent Decree on the issue of concentration (and resultant manipulative pricing)
1921	Packers and Stockyards Act
1923	Grades and standards were first published in mimeographed form to facilitate beef grading for the U.S. Shipping Board and Veterans' Bureau Hospitals
1924	Agricultural Products Inspection and Grading Act authorized the Federal grading of livestock and meat
1926	Beef grades were promulgated by the Secretary of Agriculture as the Official United States Standards for Grades of Carcass Beef
1939	Agricultural Marketing Service (AMS) established
1946	Agricultural Marketing Act authorized Federal grading of agricultural products
1946	Livestock prices were reported through a voluntary livestock price reporting system developed by AMS
1985	Food Security Act, Section 1324, provides protection for purchasers of farm products against certain liens against these products
1999	Livestock Mandatory Reporting Act
2005	Livestock Mandatory Reporting Act reauthorized
2010	Livestock Mandatory Reporting Act reauthorized
2013	Livestock Mandatory Reporting began for wholesale pork

Source: USDA, Economic Research Service, based on Perry et al. (2005) with updates for 2005, 2010, and 2013.

Second, many of the laws and policies in table 1 were designed to protect livestock sellers from economic exploitation by meatpackers. Historically, there have been many livestock sellers and only a few major meatpackers. Many livestock sellers were and are concerned that meatpackers can use their market power to lower livestock prices. The *Packers' Consent Decree* and the *Packers and Stockyards Act* were intended to protect livestock sellers from market power and other abuses.

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Livestock Pricing Methods

In the late 19th and first half of the 20th century, the buying and selling of livestock was dominated by relatively large stockyard-terminal markets (auction markets at the terminals of rail lines). Livestock were shipped in rail cars by producers, sold in the market, and transported to meatpackers. Some meatpackers were located near the stockyards; others had the livestock again shipped to them via rail. The invention of refrigerated trucks in 1939 and the expansion of the highway system after World War II made it possible to locate packing plants closer to the animals, and trucks largely replaced rail for livestock and meat shipping.

The switch from rail to trucks led to the development of smaller auction markets closer to livestock producers, and price reporting for auction markets is straightforward. The winning bids were (are) public knowledge, and information about these bids was (is) distributed through both public and private channels. However, over time, direct marketing became more popular than auctions—livestock would go directly from the producer to the packer, saving on commissions, shipping, and other costs. One challenge with direct marketing is establishing a price for the livestock.

Box 1 discusses various pricing methods and terms. One way of determining the prices paid for livestock is negotiations between the meatpacker and the livestock seller. We refer to these cases as negotiated prices or negotiated markets, and there are three common types. Meatpackers and livestock sellers can agree to a specific price per pound of live animal. They may also price the animals based on their carcass-weight[1] production, or use carcass-weight pricing with premiums or discounts for specific attributes. Typically, the base price is negotiated; the premiums and discounts are specified by the meatpacker. The net price is the price after all the premiums and discounts.

Meatpackers and livestock sellers may also agree to use formula pricing, where the price the meatpacker pays is typically tied to some publicly reported price. Formula pricing is popular with both livestock sellers and meatpackers, and allows contracting for future delivery through AMAs.

With the evolution of AMAs, the shares of livestock sold in negotiated cash markets have declined. (Low-volume markets are sometimes called thin markets.) U.S. poultry markets (not included in this report) are an extreme example of the decline in negotiated cash markets. The growth of AMA, combined with consolidation and vertical integration, has led to the virtual disappearance of cash markets for poultry. Almost all poultry production is currently by contract growers under production contracts with about 20 major processors. Growers are paid for their services under the contracts, not for the value of their birds—consequently, there are few market transactions, either cash or contract, for live birds.

About one-third of hog production is under arrangements similar to those for poultry. Most remaining hog production is by contract growers under contracts with independent integrators, who then sell hogs to meatpackers under marketing contracts that specify quantities, delivery windows, and pricing formulas. Less than 5 percent of hog sales to meatpackers occur under cash sales.

Cattle production, on the other hand, occurs under a much more diverse set of arrangements, but more and more fed cattle are marketed to meatpackers under various types of AMAs, and fewer are marketed under straightforward cash sales.

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[1]Dressed or carcass weight is the weight of an animal after it has been slaughtered and processed, and it excludes the weight of the skin/hide in cattle (but not hogs) and internal organs, among other things.

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Box 1

Definitions for Alternative Marketing Arrangements for Cattle and Hogs

Alternative Marketing Arrangements (AMAs): AMAs refer to all possible alternatives to the cash or spot (directly negotiated) market. AMAs include forward contracts, marketing agreements, procurement or marketing contracts, production contracts, packer ownership, custom feeding, and custom slaughter.

Barrow: A male hog that has been castrated before reaching sexual maturity.

Base price: There are two definitions of base price. When livestock or meats are sold using formula pricing, the base price is the reported price that is used in the formula. It can be a plant average price, the Agricultural Marketing Service (AMS) regional price, a downstream price, a futures price, or some other mutually agreeable price source. This type of pricing often depends on a lagged price source—i.e., there is a time lag between the establishment of a base price and a transaction. A second definition applies in cases where livestock are priced after they are slaughtered and receive premiums and/or discounts for carcass quality. The price to which the premiums and discounts are applied is also called the base price. Livestock sold with premiums and discounts can use either a formula price or a negotiated price as the base price.

Cull: An animal removed from the herd or flock—usually undesirable and/or inefficient (unprofitable) breeding stock that will be sent to slaughter.

Dressed weight: The weight of a chilled animal carcass. Carcasses typically have the feet, head, hide, and internal organs removed, although there are some variations across species.

Fed cattle: Steers and heifers that have been finished (fattened) on a ration of roughage and feed concentrates (grains, protein meal, and other nutrient-rich feeds) prior to slaughter.

Formula price: A negotiated formula, which can include grid or non-grid prices, that uses a base price discovered elsewhere; there is no price discovery. For example, the price paid might be the average reported cash price plus $0.50/CWT (per hundredweight—equal to 100 pounds).

Forward contract: An agreement where fixed or base pricing occurs more than 14 days into the future. Many of the longer term contracts are tied to futures market prices.

Gilt: A female hog that has not produced a litter.

Grid price: A price adjusted by premiums or discounts from a base price for specific carcass-quality characteristics, such as grade and yield.

Heifer: A bovine female that has not given birth to a calf.

Negotiated cash price: Cash or spot market transactions that occur immediately (on the spot). These include auction barn sales; video or electronic auction sales; sales through order buyers, dealers, and brokers; and direct trades. The cash or spot market is a market in which prices are offered and received for a product (live or carcass) within a 3-week window (2-week window

for live animals), and which may include specified discounts or premiums. These transactions involve price discovery.

Negotiated grid price: A negotiated base price with specified premiums and discounts based on quality criteria with delivery to occur shortly.

Meatpacker owned: 100-percent meatpacker-owned livestock. This includes beef packers who raise their own cattle, typically buying feeder cattle and owning them through the feeding period, as well as pork packers who own and feed their own pigs and usually also own the breeding stock.

Spot market: Cash market; same as negotiated cash price.

Steer: A bovine male castrated before reaching sexual maturity.

Specialized hog/swine terms:

Hog/pig/swine: In U.S. English, the terms *pigs* and *swine* are generic to the species; *hog* generally refers to those animals large enough to be marketed for meat. In this report, these terms are used interchangeably.

Negotiated purchases: Cash or spot market purchases of swine by meatpackers from livestock sellers where there is an agreement on base price and a delivery day not more than 14 days after the date on which the livestock are committed to the meatpacker. Negotiated purchases include the same types of transactions described for cattle: Live-weight (or spot-market) transactions, carcass-weight transactions, and transactions using a base price with quality premiums and discounts.

Other market formula purchases: Purchase of swine by a meatpacker in which the pricing mechanism is a formula price based on any market other than the market for swine, pork, or a pork product. This includes formula purchases where the price formula is based on one or more futures or options contracts.

Swine or pork market-formula purchases: Purchase of swine by a meatpacker in which the pricing mechanism is a formula price based on a market for swine, pork, or a pork product, other than any formula purchase with a floor, window, or ceiling price, or a futures or options contract for swine, pork, or pork product.

Other purchase agreements: Purchase of swine by a meatpacker that is not a negotiated purchase, swine or pork market-formula purchase, or other market formula purchase; and does not involve meatpacker-owned swine. This would include long-term contract agreements, fixed price contracts, cost of production formulas, or formula purchases with a floor, window, or ceiling price.

Note: AMS defines these terms in the *Federal Register*, "Livestock Mandatory Reporting; Reestablishment and Revision of the Reporting Regulation for Swine, Cattle, Lamb, and Boxed Beef; Final Rule," Vol. 73, No. 96.

Source: USDA, Economic Research Service based on USDA, GIPSA, *Livestock and Meat Marketing Study Glossary Final Report*.

While the switch to trucks after World War II largely eliminated the railroad-based terminal markets, the popularity of formula pricing and direct sales led to the decline of the smaller auction markets for slaughter stock.[2] This decline in auction markets posed challenges for price reporting, and AMS developed its voluntary price reporting system in the 1970s and 1980s to reflect these new realities.[3] Under voluntary reporting, both the buyer and seller had to agree to share the price and volume of a specific transaction. If AMS had enough transactions for a commodity, it would then publish the low, high, and weighted-average price and the volume of sales.

However, there were concerns that the voluntary reports could be inaccurate if based on only some prices rather than all prices. Meatpackers also use the reported prices in their formula pricing, so they could potentially report only lower prices, which would lower the reported average and the prices they paid for their formula-priced livestock.

Consequently, the LMRA requires major meatpackers to report all the prices they pay for sheep, cattle, and hogs, as well as their selling prices for lamb, beef, and (starting in 2013) pork. For beef, a major packer is any plant slaughtering at least 125,000 head per year. For pork, a major packer includes any plant slaughtering at least 100,000 head per year or a firm that slaughters 200,000 or more sows and boars. For lamb, firms are major packers if they import at least 2,500 metric tons or slaughter at least 75,000 head per year. Meatpackers have to report the volume of livestock that they buy and the (net) prices they pay under a range of AMAs. Under the LMRA, AMS captures information about more transactions than they could have under voluntary reporting and also captures information about the AMAs, which was not provided under the voluntary system.

Perry et al. (2005) provides more detail on the passage of the LMRA and its early implementation. As a result of the LMRA, AMS dropped some of its regional cattle reports, but Perry et al. (2005) found that, except for forward-priced cattle, the (net) prices for cattle under AMAs tended to be quite similar to those of directly negotiated cattle.

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[2]Auctions are still important for feeder calves and cull cows and bulls. Feeder calves are the young animals that are sold for further feeding; cull cows and bulls are breeding animals that are no longer being kept for breeding purposes.

[3]The USDA's Agricultural Marketing Service also became involved in wholesale meat price reporting, which is based on direct negotiations or formula pricing, due to concerns about the quality of privately reported wholesale meat prices.

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Highlights of the Mandatory Price Reporting Literature

Ward (2006, p. 1) observed that "[m]andatory price reporting for many–after a rocky start–has enhanced the transparency and accuracy of reported prices while increasing the amount and timeliness of information in some needed areas." Franken et al. (2011) found that linkages between hog prices at various locations changed after LMR was implemented, which they attributed to the declining volume of negotiated sales following the implementation of LMR rather than to LMR itself. Further, Koontz and Ward (2011) found mixed results regarding the costs and benefits of the legislation mandating LMR. They attributed increased spatial and vertical integration of the markets affected by LMR to the legislation, and found that LMR increased transparency and information for price discovery, especially in national markets. However, LMR also caused the loss of market news reporters' flexibility in discussing and reporting the market—a consequence of LMR computerization and programming of reporting rules and contingencies—as well as the onset of confidentiality issues that were largely absent in the voluntary system.

Parcell et al. (2009) considered the possibility of extending LMR to include wholesale pork prices. They argued that mandatory reporting could help reduce the number of missing daily product quotes that occurs with voluntary reporting. They also found some support within the industry for extending LMR to wholesale prices (though the support was not unanimous). They argued that the lack of trust in voluntary prices raised costs to firms since they must spend money to collect market intelligence regarding prices. In response to these concerns, LMR was extended to wholesale pork in 2013.

Ward et al. (2014) concluded that, while markets have gotten thinner since LMR implementation in 2001, the relationships between negotiated cash prices and AMA prices have changed little. For cattle, forward contracting—mainly through the use of futures market prices—showed the greatest variability, with other marketing arrangements generally lagging but more consistent with negotiated cash price discovery. For hogs, larger risk components in marketing agreements, especially those dependent on futures prices, led to greater divergence between forward contract prices and negotiated cash prices. For both cattle and hogs, the lag in AMA base prices relative to negotiated cash prices was not surprising since most AMAs are based on cash prices negotiated in a previous period (Ward et al., 2014). Based on time series analysis of regional fed cattle prices and earlier work by Pendell and Schroeder (2006), Sancewich (2014) concluded that LMR had increased the integration among regional fed cattle markets and had helped speed regional price adjustments.

Parcell and Schroeder (2014) investigated the prices paid for hogs that were sold for a negotiated base price with quality discounts and premiums. They found that meatpackers make quality adjustments in varying ways, so the reported base prices can vary depending on which meatpackers are more active on a given day. The authors explore the possibility of reporting prices net of quality adjustments and conclude that it is not possible to do so with the available information. LMR does not require the provision of information to match the purchase transactions with later slaughter transactions, but Parcell and Schroeder (2014) conclude that "while adding a unique identifier to the [LMR] requirement is appealing, we are unsure if the industry value will outweigh the cost to processors" (p. 1).

Livestock producers are also concerned that meatpackers have market power, because meatpacking is a highly concentrated industry. Meatpackers handle thousands of livestock transactions, while many livestock sellers only conduct a few transactions in a year, and the disparity in market experi-

ence potentially gives meatpackers an advantage in bargaining. While LMR was and is intended to level the playing field by providing information to all market participants, there are circumstances under which it could potentially benefit meatpackers more.

Most of the empirical work on the effects of LMR shows that its effects tend to be small compared with other factors driving livestock and meat prices, which makes it difficult to empirically determine instances of meatpackers exercising market power. The primary empirical work looking at market power before and after implementing LMR by Cai et al. (2011) found that meatpacker market power increased after the implementation of LMR. The study found that economic profit in periods after LMR implementation was $2.59 per head—i.e., oligopsony power[4] reduced fed cattle prices by 0.2 to 0.3 percent compared with 0.01 percent before LMR. However, the authors point out that there were numerous other changes occurring in the market (such as increased market concentration) that make it difficult to attribute changes solely to LMR.[5] Because of this problem, many authors rely on theoretical work to study the effects of LMR. While the theoretical work tends to support the hypothesis that livestock sellers benefit under LMR, there are alternate scenarios where LMR could increase meatpacker market power.

Though not applied directly to livestock markets, there is a set of literature showing that asymmetric information can lead to market power (Phlips, 1989; Ferraro, 2008). In the absence of LMR, meatpackers are expected to have better price information than livestock sellers do. To the extent that LMR reduces this asymmetric information, this theory suggests that LMR should benefit livestock sellers, which could also benefit consumers.

Wachenheim and DeVuyst (2001) also argue that the information provided by LMR could increase the ability of meatpackers to tacitly collude and exercise market power at the expense of livestock sellers. They follow Wilson et al. (1999), arguing that more information can facilitate cooperative bidding. Their arguments are not based on a formal model, but on empirical observations of industries, such as the railroad industry (Fuller et al., 1990) and long-distance telephone service (MacAvoy, 1995), that use posted prices. However, meatpackers already have excellent information about other firms' bids, so it is unclear whether LMR adds as much to meatpackers' information as it does to livestock sellers' information. Further, the livestock industry does not use a posted price system, so it is unclear if all of the arguments in these studies apply to livestock markets.

Additionally, in a series of papers using similar Cournot frameworks, Azzam (2003), Njoroge (2003), Azzam and Salvador (2004), and Njoroge et al. (2007) provided theoretical models of the effects of LMR and reach different conclusions. Azzam (2003) found that the AMS reports may be of little direct value to livestock sellers, but might increase competition among meatpackers, leading to an increase in the prices paid by meatpackers and a decrease in the variance of reported prices. Njoroge (2003) extended Azzam (2003) and, assuming that the prior distributions of meatpacker prices were asymmetric, found that LMR could promote collusion among meatpackers.

Koontz and Ward (2011) argued that the symmetric prior distributions assumed by Azzam (2003) for cattle markets were more likely than the asymmetric prior distributions assumed by Njoroge

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[4]Oligopsony refers to the greater negotiating strength caused by a small number of buyers.

[5]This is all maintained under the assumption that marginal processing costs depend only on wages and energy prices, and not on output—a strong assumption that favors a finding of market power if margins rise when meatpackers near full capacity (i.e., they assume that marginal costs don't rise when you near full capacity).

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(2003). Koontz and Ward (2011) also argued that large meatpackers had similar information about cattle prices. Njoroge et al. (2007) found that, even if LMR increased meatpacker market power, LMR still might benefit society by reducing the risk faced by meatpackers. Azzam and Salvador (2004) developed a theoretical model of risk-averse Cournot firms to measure the change in meatpackers' market power with LMR and found that LMR would not increase meatpackers' market power in all five regional markets.

In summary, the results from this set of theoretical models are mixed on the issue of market power. The relevance of the assumptions that lead to the negative implications regarding LMR is unclear, and there are doubts that livestock markets provide a situation where LMR would facilitate collusion.

The most recent theoretical work on LMR by Boyer and Brorsen (2013) argued that the Cournot assumption is unrealistic. Following Crespi and Sexton (2005), they used an auction-based model to study the effects of LMR, and found that it was unambiguously beneficial to livestock sellers, regardless of whether it increases information to feedlots or increases the information of meatpackers. Anderson et al. (1998) used experimental data from Oklahoma State University's Packer-Feeder game (which simulates the interactions between meatpackers and livestock sellers) and found that an increase in public information to meatpackers increased the market prices paid to livestock sellers.

An Overview of Recent Cattle and Hog Transaction and Market Data

As the agency charged with implementing LMR, AMS is the primary source of livestock and meat price data used in this report. Data on the number of market transactions include cash market transactions as well as AMAs. AMAs vary in important ways between livestock categories but generally include arrangements such as forward contracts, marketing agreements, procurement or marketing contracts, production contracts, packer ownership, custom feeding, and custom slaughter. All of the current cattle price and quantity data used (from 2005 through the third quarter of 2014) are from AMS's *Weekly Direct Steer and Heifer Slaughter Cattle Summary*. The hog data come from AMS's *Weekly National Direct Swine Report* beginning in 2007 (AMS made several changes in the hog reports starting in 2007 and the previous data definitions are incompatible with the current ones).

AMS reports daily, weekly, and (in some cases) monthly livestock prices. The data used in the analyses reported here are weekly because cattle are frequently priced on a weekly basis—it is common for formula-based cattle AMAs to use weekly data. Although the hog market is more of a daily market in practice, it is common for daily prices to be unreported for both cattle and hogs because they often do not trade in sufficient volumes to meet LMRA guidelines. Missing daily prices would complicate the statistical analysis conducted in this report, while weekly price data seldom has missing reports. The only missing data in our sample are from a 3-week period in October 2013, when the Federal Government was shut down. Additionally, our charts convert weekly into quarterly data.

Changes in Cattle Transactions and Marketing Data

Figure 1 shows volume-weighted average prices for five cattle series. The live or dressed heifer prices are not shown because they are similar to the live and dressed steer prices. To make the series more comparable, the direct live steer price is transformed to a carcass-weight basis using a 63-percent live-to-carcass yield.[6] The results indicate that the negotiated and formula prices (net of premiums and discounts) are similar. The forward contract prices differ slightly from that of the other series, but are neither consistently higher nor lower.[7] This type of relationship among the prices is consistent with the results found in Perry et al. (2005).

Figure 2 shows the shares of cattle marketed under the five broad classes of marketing arrangements: formula price, forward contract, negotiated cash price, negotiated grid price, and meat-packer owned. The equivalent figure in Perry et al. (2005) ended at 2005Q1 and showed that, while the share of negotiated cattle declined prior to the start of LMR in 2001, it increased between 2001 and 2005Q1. That report then discussed whether LMR had a role in increasing direct cattle marketing. However, more recent data shows that the negotiated volumes began to decline in late 2005 or early 2006 and, by 2014Q3, the share of cattle sold with negotiated pricing was less than 30 percent, down from more than 60 percent in 2004. Most of the shift in cattle
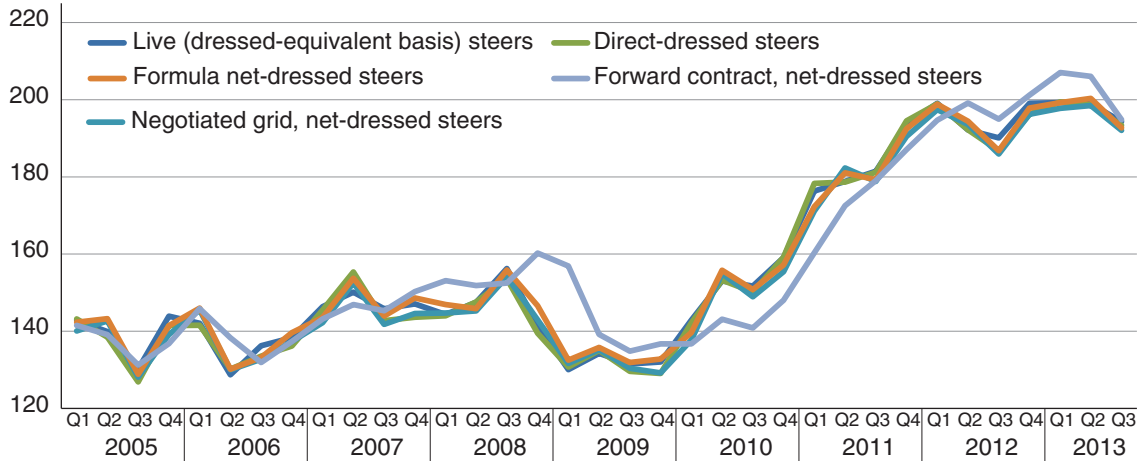
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[6]Carcass yields show some seasonal variation and trends over time. Our use of a fixed yield is a simplification. If the actual yield is over 63 percent, the carcass-equivalent price for the live steers will be too high and *vice versa*. The 63-percent yield is the standard yield used in the calculation of the beef price spreads data published by USDA, Economic Research Service.

[7]The prices of forward-contracted cattle are set in advance of delivery so it is not surprising that they track the other prices less closely. The other prices are set based on current market conditions.

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Figure 1
Five slaughter steer prices

$/CWT (carcass weight)

Notes: CWT = Hundred weight or 100 pounds. The live steer prices are negotiated between meatpackers and producers, and paid based on the live animal weights. These prices have been transformed to a carcass-weight basis using a carcass-to-live yield of 63 percent. Direct-dressed steers are those animals whose price is negotiated and based on the carcass weight of meat the cattle produce. Negotiated grid, net-dressed steers are like the direct-dressed steers except that the price is adjusted based on premiums and discounts for various factors. Formula net-dressed steers are like the negotiated grid, net-dressed steers except that the price is determined by a formula rather than by negotiation. Forward contract, net-dressed steers have a base price that is determined more than 2 weeks prior to delivery. Comparison with charts in Perry et al. (2005) is subject to some differences in data and definitions.
Source: USDA, Economic Research Service calculations based on USDA, Agricultural Marketing Service's (AMS), *Weekly Direct Steer and Heifer Slaughter Cattle Summary.*

Figure 2
Steer and heifer sales by marketing arrangement
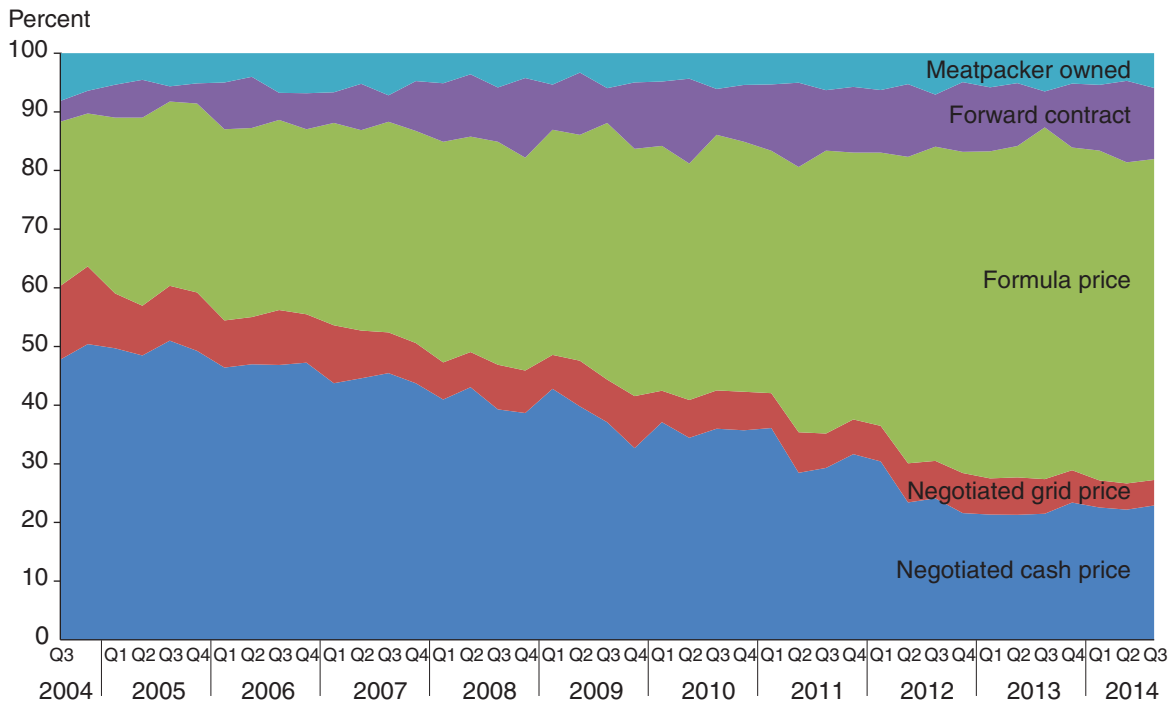
Percent

Note: Comparison with charts in Perry et al. (2005) is subject to some differences in data and definitions.
Source: USDA, Economic Research Service calculations based on USDA, Agricultural Marketing Service data.

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sales between 2004 and 2014 went to formula-priced cattle. There was also a modest increase in the share of cattle sold forward and a decline in the meatpacker-owned share of cattle. AMAs increase meatpackers' ability to ensure livestock deliveries and increase the likelihood that their plants will run closer to full capacity.

Changes in Hog Transactions and Marketing Data

Meatpacker-owned hogs are priced under several schemes. The negotiated live-weight hogs are priced based on their live weight. The negotiated carcass-weight class includes all hogs sold on a carcass-weight basis with a negotiated base price. Most of these negotiated carcass-weight hogs also receive premiums and discounts based on their muscling and fat thickness.

Figure 3 shows the quarterly values for the five types of hog prices: negotiated live hog price, negotiated carcass price, swine/pork market formula pricing, other market formula pricing, and other purchase agreement. The negotiated live price is transformed to a carcass-weight price using a 74-percent carcass yield.[8] The other market formula and other purchase agreement prices are only available starting in 2009Q1. The hog prices are less closely related than the cattle prices, with the exception of the negotiated carcass and swine/pork[9] market-formula prices (which are nearly identical). Negotiated live-weight hogs, the smallest of the slaughter classes, have the highest average prices on a carcass-weight basis.

Figure 3
Quarterly-weighted average hog prices
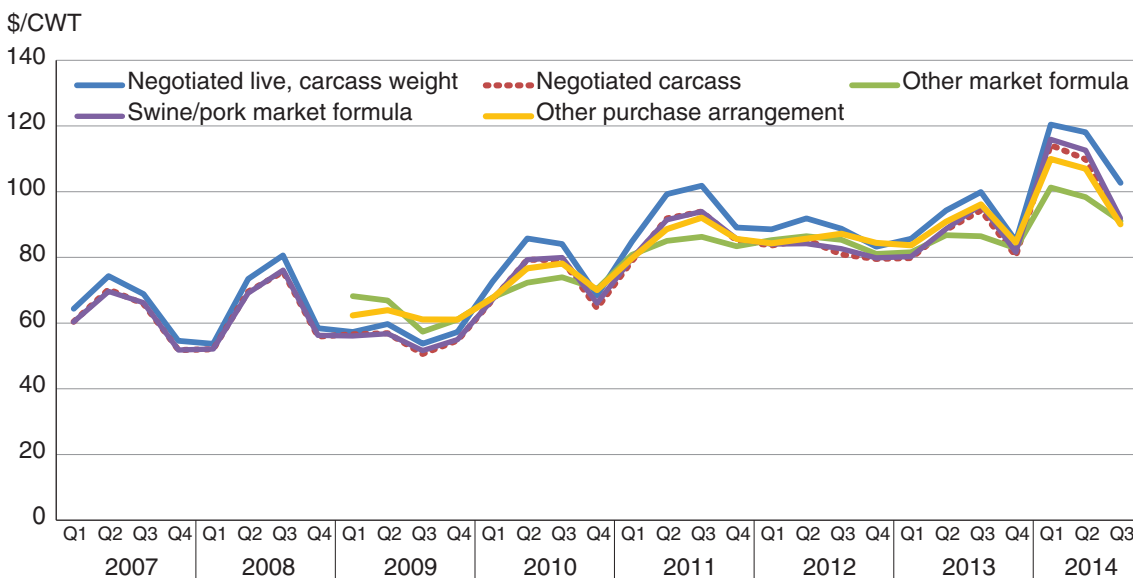
Notes: CWT = Hundred weight or 100 pounds. Negotiated-live hog prices are negotiated between the producer and meatpacker, and producers are paid based on the live weight of the hogs. Live-weight prices are converted to carcass-weight prices using a live-to-carcass yield of 74 percent. Negotiated carcass prices are also set by producer-meatpacker negotiations, but producers are paid based on the carcass weight of the slaughtered hog. Swine/pork market formula hogs are priced using formulas based on either hog prices or wholesale pork prices. Other market formulas use something other than hog or pork prices to set the price. Other marketing arrangements cover the rest of the hogs sold.
Source: USDA, Economic Research Service calculations based on USDA, Agricultural Marketing Service data.

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[8]USDA, Economic Research Service uses a 74-percent live-to-carcass yield in its calculations of the pork price spreads data.

[9]Swine/pork market formula uses formula based on some type of reported price to determine the price of a producer's hogs. Swine-based formulas use hog prices; pork formulas use prices for wholesale pork cuts.

The high average price for the negotiated-live hogs was unexpected. Producers often stated that the negotiated-live hogs were lower quality than those marketed via AMAs. If this were the case, our 74-percent carcass yield would be too high. The carcass-weight price in figure 3 was the live-weight price divided by the assumed yield. If the true yield were less than 74 percent, the carcass-equivalent price in figure 3 would be even higher—i.e., lower quality should be reflected in either a relatively low live price or a relatively low carcass yield. However, applying a lower carcass yield to the negotiated live-weight price data would result in an even higher carcass-equivalent price.

In figure 4, the five types of hog sales are collapsed into three groups: producer-negotiated sales, other sales by producers, and all meatpacker-raised hogs. The producer-negotiated hog sales are a small part of the entire market. In 2007 and 2008, these hogs were 8.5 to 9.0 percent of all hog slaughter. By 2012-13, producer-negotiated hogs were 2.3 to 2.6 percent of all slaughter. Meanwhile, formula-based sales by producers and meatpacker-raised hogs have both increased their shares of total hog slaughter.

Continued Trend of Thinning Markets

Negotiated cash markets have gotten thinner for all livestock species and categories. For poultry, this evolution, combined with vertical integration, has led to the virtual disappearance of cash markets. The hog sector is also becoming more concentrated and vertically integrated, which can lead to fewer transactions. For example, the largest pork packer owns 887,000 sows, implying that the operation accounts for about 20 million market hogs a year (*Successful Farming*, 2014), or roughly one-fifth of annual hog slaughter. The relatively low share of negotiated hog sales is also concerning. The average weekly sales of producer-negotiated hogs in the first 3 quarters of

Figure 4
Quarterly shares of barrow and gilt sales
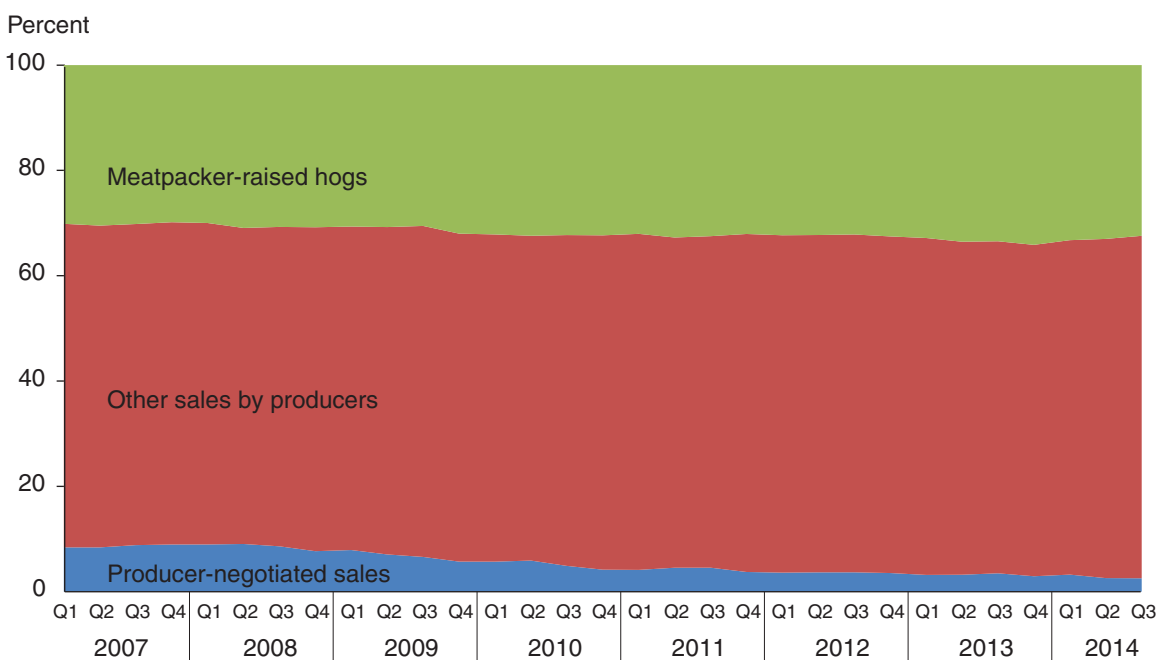
Notes: Barrow = A male hog that has been castrated before reaching sexual maturity.
Gilt = A female hog which has not produced a litter.
Source: USDA, Economic Research Service calculations based on USDA, Agricultural Marketing Service data.

2014 was 51,776 head, representing roughly 250 semi-trailer loads of hogs[10] or around 50 trailers a day—a relatively small share of hog sales, though still a large number of cash transactions.

There is no clear point at which cash markets become too thin to reliably provide representative market-clearing prices. The low relative volume of negotiated hog sales might lead one to suspect that the market is getting thinner, but are 50 transactions a day too thin to represent broader market conditions?

Researchers have attributed some hog market changes to the trend of thinning cash markets. Franken et al. (2011) looked at the interaction between direct and terminal (auction) market prices for hogs before and after implementation of LMR using the Iowa-Southern Minnesota market. Prior to LMR, Iowa-Southern Minnesota price changes followed the terminal market price changes. After LMR implementation, the Iowa-Southern Minnesota market leads the terminal markets, and Franken et al. attributed this switch to the declining volume of hogs moving through terminal markets.

The share of negotiated cash transactions is larger for cattle sales than for hog sales, and they have trended downward (fig. 2). However, this trend does not appear to have disturbed the relatively close price relationships between negotiated cash prices and base prices for AMAs during the period LMR has been in effect (Ward et al., 2014). Whether or not LMR has accelerated the trend toward AMAs in both hog and cattle markets, and whether LMR makes the reported negotiated prices more reliable, remain questions for future research.

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[10]A triple-decker semi-trailer holds around 200 head of hogs. Most large producers can sell in semi-trailer lots, while some small-to-medium producers will sell in smaller lots. A count of the semi-trailers sold in a week or day gives a rough estimate of the number of transactions.

The Impact of Mandatory Price Reporting on Cash and Futures Market Interactions

Has LMR influenced the interaction of the cash and futures markets for cattle and hogs? We look at two issues. First, has the relative importance of the cash and futures markets in the price-discovery process changed between the pre-LMR and LMR periods? Second, has mandatory price reporting made cash/futures market transactions more efficient (i.e., led to faster incorporation of new information)?

A large number of previous studies have looked at the lead-lag relationships between cash and futures prices (Garbade and Silber, 1983; Brorsen et al., 1984). These studies typically use causality tests and show that futures prices lead cash prices. Such results suggest that prices are predominantly established (being discovered) in the futures market. The lower transaction costs in futures markets (in the sense that it is easier to observe a futures price and understand its terms and conditions than to track a wide array of cash transactions that may also have varying and unknown terms) are the usual explanation. Many studies show a one-direction effect of futures markets leading cash markets—i.e., futures prices influence cash prices, not the other way around. However, livestock markets are one of the few markets that show a feedback relationship that suggests that the cash market is also an important part of price discovery (Oellermann and Farris, 1985; Oellermann et al., 1989; Koontz et al., 1990).

The emergence of the price-discovery literature in the past two decades has allowed economists and financial analysts to establish a nuanced relationship among market prices. Less effort is put into lead-lag structures than in past modeling techniques (Hasbrouck, 1995), and more effort is made to determine which market is primarily responsible for the generation of *new* price information. In other words, price-discovery tests assume that the markets being evaluated contain the market or group of markets in which new information originates.[11] Price-discovery studies focus on measuring the factor that drives the longrun trend among related prices. Using an Error Correction Model (ECM), the Gonzalo and Granger (1995) method weighs the contribution of each market in establishing the longrun trend.

There are two approaches to evaluate the relative importance of cash and futures markets. One approach is based on a version of the Gonzalo-Granger price-discovery test (Figuerola-Ferretti and Gonzalo, 2010) that focuses on how markets react to emerging information. In contrast to this approach, the second uses an ECM that allows estimation of the relative roles of cash and futures prices in price discovery in the form of price-discovery weights for each market. In addition, the ECM is used to determine the efficiency of markets by examining whether cash and futures prices adjust (converge), do not adjust (nonconvergence), and if they do adjust, how quickly. Appendix A describes these models and procedures in more detail, including tests used to ascertain statistical significance in the results. An earlier, more familiar approach is based on the Granger analysis (see appendix A), which is backward looking and evaluates how current prices react to a series of lagged prices.

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[11]Past research has used the term *price discovery* when reporting on the results of a causality test.

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Cash and Futures Price Data

For cattle, the 1990 starting period of the cash model was determined by the availability of cash prices (as was the weekly frequency of data modeled). The analysis used the weekly, five-area, FOB (i.e., the price at the feedlot *free on board* here) with no transportation allowance in the price) All Grades Total fed steer direct price available from 1990 to 2014 from AMS. For one 4-week period in 1998 and one 3-week period in 2013, price data was missing because of Federal shutdowns. For these two periods, the relationships between available and unavailable cattle prices (of different grades) were used to fill in the missing data.[12]

Consistent data series for the cash price of hogs was available only for 1999 to 2014. The hog cash price data used is for 51- to 52-percent lean hog carcasses reported by AMS, converted to a live basis. Conversion to a live basis was done to be able to more directly compare cash prices for hogs with lean-hog futures prices. Missing hog price data were handled using a method similar to that used for missing cattle prices.

For Chicago Mercantile Exchange/Chicago Board Of Trade live cattle,[13] daily futures prices representing the nearby contract (the contract that will expire next) from 1990 through part of 2014 were obtained from Quandl, an online data platform.[14] These prices were aggregated (in a way that ensured that each daily futures price matched its cash equivalent) into weekly units to ensure the futures and cash price data represent exactly the same days of each week.

Traditionally, futures and cash prices have converged during the delivery month, which presents an issue with respect to rollover from one contract to a more distant (in time) contract for the relationship between cash and futures prices just prior to and during the delivery month—Quandl data include the rollover from one futures contract to another in the delivery month. Including the rollover can lead to large day-to-day differences in prices on days when the rollover occurs that result from the rollover rather than actual price changes, which can affect both price levels and intra-period price changes. To address this problem, analysts traditionally prefer to roll over to the next contract during the month prior to the delivery month. In the data set used here, we ensured that price differences always reflected the difference internal to the same contract. No data point represents the price difference occurring due to a rollover between two different contracts. Using data from the contract two periods ahead, we set up a futures price series that rolled over one month prior to the delivery month.

At the rollover date, the futures price jumps from current to new contract with a delivery date as far as 2 to 3 months distant. At this point, cash and futures price could diverge, particularly if one chose a poor rollover date. The fact that our cash and futures price series are so tightly integrated indicate that our choice of rollover date did not create an artificial divergence in prices.

The futures contract prices for hogs (lean hogs) for 1999 through part of 2014 are also from Quandl, and treated in a similar manner as those for cattle—i.e., we developed a futures price series that was rolled over 1 month prior to delivery. Unlike cattle, where no contract months are consecutive, delivery months dominate the futures market for hogs and 5 of the contract months are consecutive.

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[12]Statistical tests revealed that the use of filled-in data did not affect the results.

[13]Live cattle is the futures contract synonym for fed cattle.

[14]https://www.quandl.com/

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Box 2
Periods of Analysis

No formal tests were done to determine subperiods, but Arnade and Hoffman (2015) provide some justification for subperiods between low volatility and high volatility markets. For cattle, LMR was implemented in 2001. Longrun and shortrun models include a dummy variable, starting in 2002, to account for this. However, distinct dummy variables were used to distinguish three periods after 2002: 2002-06, 2006-08, and 2008-14. This allowed us to account for the fact that price variability increased significantly after 2006 and account for the financial crises of 2008. From 2002 to 2006, the standard deviation of cash price for cattle was $9.78 per CWT. From 2007 to 2014, the cash price standard deviation was $20.67.

A similar situation applies to futures prices for cattle. Since the level of price variability may influence the ability of the market to discover the true price and adjust to equilibrium, our model included dummy variables that allowed us to estimate distinct measures of adjustment speeds and calculate price-discovery weights between these two periods. Additionally, after 2006, the use of corn for ethanol rose significantly (Westcott, 2007) and drought hit the corn-producing and cattle-grazing regions of the United States. Since that period, price variability in cattle futures prices has been significantly high.

In the longrun model for cattle, all dummy variables were significant. Thus, a dummy variable for the LMR period, from 2002 to 2006, was included in the shortrun models. The second dummy variable represents the beginning of price variability and the rise of corn ethanol, and runs from 2006 and 2008. The third dummy variable represents the post-financial crisis period, a period also marked by high price variability. In the shortrun model, dummy variables for the 2002-06 and the 2006-08 periods were combined into a single 2002-08 dummy variable (since tests indicated no change in shortrun behavior until 2008).

For hogs, dummy variables were only included to represent the introduction of LMR for live hogs (2001) and for pork (2013)—i.e., dummy variables representing the beginning of price variability (2006) and the post-financial crisis (2008) were not significant and were dropped. A similar situation applies to futures prices for hogs.

Another dummy variable (called dmfil) was included in both the longrun and shortrun hog models to account for prices that were artificially created. Several prices were missing among the hundreds of price observations—by averaging the price before and after the missing price, artificial prices were created to fill in for missing prices. To ensure that these filled-in prices did not distort our econometric results, a dummy variable was included in the model to account for these observations.

Unlike the main models, the Granger tests were estimated for separate time periods in order to get a clean separation of time periods for cattle—pre-LMR and during LMR—and because dummy variables cannot be used. In addition, the year of transition to LMR was excluded from the Granger model. The same time separation was not used for hogs because of the limited degrees of freedom with the hog data. The same was true for cattle for the unit-root tests[1]—pre-LMR and during LMR—the year of transition to LMR was excluded.

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[1]A unit-root test is a statistical test for the behavior of time-series data.

Therefore, for 7 months of the year, our futures prices for hogs represent the price of the contract following the nearby contract.[15]

Price-Discovery Weights Before and With Mandatory Price Reporting

The next step in assessing the impact of the change from voluntary to mandatory price reporting on the relative importance of cash and futures markets for live cattle was to estimate measures of the relative importance of each market in price discovery. The price-discovery weights add to the lessons from the Granger tests by relying less on lagged price relationships and more on the contribution of each price to current price discovery. For this, we used an ECM framework applied to weekly cash and futures prices for cattle from 1990 to 2014. The cattle price series are the same as those described earlier, with dummy interaction variables included in the model to represent the weeks of missing data and fill-in data used for missing cash price information and then tested for their significance.[16] Consistent data series for the cash price of hogs prior to 1999 are unavailable, so the ECM for hogs was estimated from 1999 to 2014. Missing hog price data were handled using the same method used for missing cattle prices.

The Error Correction Model

The first step in evaluating both price discovery and efficiency is to estimate an ECM in prices. The resulting coefficients for each price equation can be used to assess the contribution to the discovery of the other price.

To evaluate efficiency, we start with McKenzie and Holt's (2002) hypothesis that, in an efficient market, both futures and cash prices instantly absorb new information and instantly adjust to their longrun equilibrium relationship. Instant adjustment to an equilibrium relationship is referred to as shortrun efficiency.[17] To determine whether markets are shortrun efficient, the adjustment rate coefficients in an ECM can be estimated and statistically tested to determine whether they are significantly different from 1.0. Failure to reject statistically the hypothesis of a coefficient of 1.0 implies instant adjustment. By estimating the extent to which behavior was different in the pre-LMR and LMR time periods, we can then also evaluate how the estimated adjustment rate may have changed after the introduction of LMR.

An equation representing the longrun equilibrium relationship between cash and future prices can be written as:

$$(1) \qquad P_{cs,t}^c = \beta_{fut} P_{fut,t}^c + C + u_t,$$

where C represents a constant term and u_t is the error term in the longrun relationship.

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[15]We also applied the analysis to a futures price that rolled over during the delivery month and thus includes the delivery month in the analysis. In this later approach, which is less commonly used by analysts, we account for this late rollover by including a dummy interaction variable to allow adjustment rates to be distinct in the delivery month.

[16]If tests revealed that this dummy variable was insignificant (indicating that the use of fill-in data did not affect the model), this dummy variable was dropped.

[17]Longrun efficiency is based on the coefficients of a longrun equilibrium equation.

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Ordinary Least Squares (OLS) is used to estimate equation (1) and obtain the estimated error term $\hat{\mu}_t$. The second step is to jointly estimate the two difference equations for cash and futures prices:

(2a) $\Delta P^c_{cs,t} = \gamma_{cs} * \hat{\mu}_{t-1} + \sum_{i=1}^{k} \eta_{11,i} \Delta P^c_{cs,t-i} + \sum_{i=1}^{k} \eta_{12,i} \Delta P^c_{fut,t-i} + \varepsilon_{cs,t}$,

(2b) $\Delta P^c_{fut,t} = \gamma_{fut} * \hat{\mu}_{t-1} + \sum_{i=1}^{k} \eta_{21,i} \Delta P^c_{cs,t-i} + \sum_{i=1}^{k} \eta_{22,i} \Delta P^c_{fut,t-i} + \varepsilon_{fu,t}$,

where $\hat{\mu}_{t-1}$ represents the lagged error from the longrun equation, and the variable γ_i represents the rate at which prices adjust to equilibrium. The term $\eta_{jk,i}$ represents the coefficient on the j price= j-1,2 in the k, equation $k==1,2$, at price difference lag i. The $\varepsilon_{cs,t}$ represents the error of the equation representing price differences in the cash market. A similar error is appended to the future equations.

While equation (1) represents a longrun equilibrium relationship between prices, equation (2) represents the relationship in prices when they are in disequilibrium and changing. Included in both equations is an adjustment rate coefficient, γ_i, that provides information on the speed to which prices are returning to their equilibrium relationship. The faster the rate of adjustment, the more efficient the market. Since the error term is unpredictable, it is often viewed as containing new information. Thus, adjustment rates can be viewed as representing each market's response to new information; a key factor in price discovery. Appendix A shows how each market's price-discovery weights can be calculated from the two estimated adjustment rates.

As a first step in estimating the price-discovery weights for cash and futures markets, it is necessary to establish the time series properties of data. Cointegration tests were conducted by regressing the cash price on the futures price and applying Dickey-Fuller unit-root tests to the error terms. Since price relationships in cattle markets change over time (Koontz et al., 1990), the tests were applied over three subperiods for both cattle and hogs by estimating the model over the entire period, with dummy variables used to delineate subperiods. All tests but one (cash price hogs 2001-12) indicated that both futures and cash prices followed a unit root process, but the error term from the regression did not, indicating that the cash and futures prices were cointegrated—that is, they tend to move together in the long run. Appendix table A1 summarizes the cointegration tests. With the time series properties of the data established and missing value issues addressed, weights were estimated for the impact of cash and futures market prices on the price-discovery process.

Results for Cattle

The ECM models were estimated using Engle and Granger's (1987) two-step method. The longrun equation (equation 1) was estimated first and the estimated error terms from this equation (u_t in equation 1) were used as an explanatory variable in the second ECM equations (equations 2a and 2b). The longrun equation for the cash and futures price of cattle was estimated for the entire period with interaction dummy variables on the lagged error term to obtain distinct adjustment rates for three periods: 1990-2001, 2002-08, and 2008-14 (box 2).

In each case, specification tests indicated that the fill-in dummy variable for the missing data was not significant. Therefore, the model was re-estimated without the fill-in dummy variable. The cattle

model was estimated using data from 1990 to 2014. Estimated parameters for the longrun model for cattle are:

Cattle: $\bar{R}^2 = .97$

$$(3) \qquad P_{csh} = -2.83 + 1.02P_{fut} + 0.519d_1P_{fut} - 3.067d_2P_{fut} - 1.03d_3P_{fut}$$

$$(\text{-}3.78)\ (132.1)\quad (2.04)\qquad (\text{-}7.31)\qquad (\text{-}2.58)$$

where $\bar{R}^2$ represents the percent of variation in the cash price that can be explained by the model, $d_1 = 1$ from January 2002 through 2006, $d_2 = 1$ from late 2006 to September 2008 (a period of increasing speculation in commodity markets), and $d_3 = 1$ after September 2008 (box 2).

Error terms from the longrun models above were used in the second stage of the ECM to obtain estimates of the longrun adjustment parameters (the γ_i in equations 2a and 2b). Estimates of the second-stage model parameters for each time period are presented in table A2 of appendix A.

The adjustment rate estimates of γ_{cs} and γ_{fut} in equations (2a) and (2b) obtained from the second-stage models were used to measure the Schwartz and Szakmary (1994) price-discovery weights (equations A.1a and A.1b in appendix A). Adjustment rate estimates and price-discovery weights for the three subperiods are reported in table 2.

While cash and futures market prices typically converge during the delivery month, the results reveal that, prior to LMR, the cash and futures markets did not converge during the period prior to the delivery month.[18] In other words, the cash market reacted to the deviations from the longrun

Table 2

Estimated adjustment and price-discovery rates for fed cattle, three periods from 1990-2014

	Adjustment rates	Adjustment half-life[1]	Price-discovery weights
1990-2001			
Cash	-0.11	6.64	NC
Futures	-0.007	99.36	NC
2002-08			
Cash	-0.102	7.13	0.02
Futures	0.002	346	0.979
2008-14			
Cash	-0.099	7.34	0.035
Futures	0.004	172.9	0.965

Notes: NC = Nonconvergence between cash and futures prices. During this period, futures prices dominated the price-discovery process and did not converge with cash prices.
[1]As the distance to equilibrium dwindles, the absolute adjustment speeds slow. Analysis often reports the half-life, the time it takes to adjust halfway to equilibrium.
Source: USDA, Economic Research Service.

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[18]Price-discovery weights were not calculated for delivery months since future prices are rolled over on the last day of the prior month. Thus, after the last day, the futures prices are represented by the following contract. Our method follows the standard method of rolling over contracts. This roll-over month could significantly distort results if other methods of rolling over prices are used.

relationship by returning to equilibrium, while the futures market remained disconnected from the cash market, so no price-discovery weights were calculated. The results reveal that, by bearing the complete burden of adjustment, the cash market played no role in the price-discovery process and prices were discovered in the futures market.

In the LMR periods, however, the situation may have changed. During the period prior to the delivery month, futures and cash prices slowly converged to their longrun equilibrium relationship. Over 2002-08, the estimated price-discovery weight in the futures market was 0.979 while the cash market weight was 0.02. The futures market still dominated the price-discovery process, with the long adjustment period for the futures price reflecting this dominance. The cash market did play a role in price discovery during the LMR periods, although futures prices adjusted very little to the longrun errors while cash prices bore the burden of adjustment.

There are a number of possible reasons for the shift from nonconvergence to convergence in cash and futures markets after the implementation of LMR. The discontinuity of futures contracts due to shifting maturities may not be fully accounted for in the estimation. Alternately, after the economic slowdown in the late 1990s, market participants may have chosen to avoid information arising within the futures market as they attempted to pay more attention to market fundamentals.

The 2008-14 period was characterized by relatively high volatility, drought, increased trading by long-only index funds, and increased speculative activity. Price-discovery rates estimated over this period are similar to those estimated for 2002-08, with a large component of price discovery remaining in the futures market—with an estimated weight of 0.965—and a small but significant cash market weight of 0.035. The implication is that the futures market contributed 96.5 percent to the price-discovery process over this highly volatile period, very close to the results for the relatively less volatile 2002-08 period, and different from the results for the similarly volatile 1990-2001 period (when the cash markets played no role).

The estimates of the price-discovery weights for the 1990-2001 and 2008-14 periods indicate that, after LMR was introduced, cash and futures markets began to converge and the cash market began to play a small role in price discovery. It is important to note, however, that these results do not rule out the possibility that factors other than LMR were responsible for the growing role of the cash market in the price-discovery process. Further research is needed to eliminate other possible factors that may explain the results of the cattle model.

Results for Hogs

LMR was phased in for hogs in 2001 and for wholesale pork in March 2013. While we model hog prices, we account for the possibility that the introduction of LMR in the pork market could have spillover effects into the live hog market by breaking the LMR period into two subperiods. The period from March 2013 to the end of the data set in September 2014 did not provide enough observations (degrees of freedom) to estimate a credible model or to be able to apply credible unit-root tests. Like the cattle model, dummy variables were used to capture possible changes in the adjustment rates for live-hog prices over the different periods. The live-hog model was estimated over the entire 1999-2014 period for which data were available, with a dummy variable included to represent the period after March 2001 when LMR for hogs was implemented and another dummy variable after March 2013 when LMR for wholesale pork was implemented. An additional dummy variable was included to represent the few observations where missing prices were filled-in (with an average of the previous and following price) to ensure that our choice of the fill-in price did not distort the estimated equation.

Estimated parameters for the longrun model for hogs are:

Hogs: $\bar{R}^2 = 0.82$

(4) $\quad P_{hg} = 5.74 + .86P_{fut} + 2.66d_1P_{fut} + 6.27d_2P_{fut} + 3.05d_3P_{fil}$

$\qquad$ (4.33) (48.98) $\quad$ (4.92) $\quad$ (3.75) $\quad$ (2.14)

The estimated adjustment and price-discovery rates in table 3 reveal that, with the introduction of LMR for hogs, futures and cash market prices began to converge over the nondelivery months. In other words, prior to 2001, the futures market adjusted the wrong way (i.e., a negative sign for the adjustment rate, table 3), which was a sign that futures markets paid little attention to price movements in the cash market during the period prior to the delivery month. A negative adjustment rate for futures implies that the cash market is adjusting towards the equilibrium relationship during the period prior to the delivery month, while the futures market appears to ignore this relationship altogether. After the introduction of LMR for live hogs in 2001, both prices adjusted in the right direction, with the cash market carrying the burden of the adjustment. Price-discovery weights for the 2002-13 period indicate that although prices were primarily discovered in the futures market, which contributed 68 percent to the price-discovery process, cash prices also played an important role (contributing almost a third to the price-discovery process).

After LMR was implemented in 2001, the cash market adjustment rate slowed and the futures market prices began to converge toward the equilibrium relationship between cash and futures price during the period prior to the delivery month. After the implementation of LMR for wholesale pork in 2013, both markets again displayed nonconvergence during the period leading up to the delivery month, indicated by the negative adjustment rate in the futures market. However, factors other than the introduction of LMR, such as changing price volatility or the limited number of observations for the period including wholesale pork, may be responsible for the differences in adjustment rates across periods.

Table 3
Estimated adjustment and price-discovery rates for live hogs, three periods from 1999-2014

	Adjustment rates	Adjustment half-life[1]	Price-discovery weights
1999-2001			
Cash	-0.094	7.77	NC
Futures	-0.012	WS	NC
2002-13			
Cash	-0.089	8.12	0.32
Futures	0.041	16.56	0.68
2013-14			
Cash	-0.14	5.3	NC
Futures	-0.02	WS	NC

Notes: NC = Nonconvergence; WS = Wrong sign. Estimated adjustment and price-discovery rates do not represent delivery months. Unlike cattle, the adjustment rate of the futures price for hogs was the wrong sign in two periods.
[1]As the distance to equilibrium dwindles, the absolute adjustment speeds slow. Analysis often reports the half-life, the time it takes to adjust halfway to equilibrium.
Source: USDA, Economic Research Service.

The calculated half-life results in table 3 indicate that there was no period in which hog markets were shortrun efficient. However, the LMR period did correspond with markets that converged for at least one subperiod in the nondelivery months. The reasons for this nonconvergence are not obvious but may have to do with the numerous forms that contracting can take between the stages of hog and pork production.

The Impact of Livestock Mandatory Price Reporting on Cash Price Behavior in Cattle and Beef Markets

While we have examined how the relationship between cash and futures markets changed following the introduction of LMR, we now focus on how LMR may have influenced behavior in the cash market itself. In the futures market, some market participants may not be intimately familiar with real world events in the livestock/meat sectors—e.g., these participants may be spread across many markets and access to information internal to a particular livestock market may not be as readily available to them as to other participants. Participants in cash markets, however, are more likely to have closer ties to livestock because they may earn most of their income from it. As a result, the introduction of LMR may not have had as much influence on relationships within cash markets as it did on the relationships between the cash market and futures market.

The share of negotiated cash transactions in cattle and beef markets has declined significantly during the LMR period. Economic theory and logic provide little guidance to understanding the combined impact of LMR and thinning markets on pricing transactions. We examine transactions within the cash markets in an effort to determine if price behavior pre-LMR and during LMR has undergone a significant change. The analysis is designed to see if the shift from voluntary to mandatory pricing changed how livestock sellers and meatpackers reacted to reported cash prices/values for cattle, wholesale beef, and beef byproducts. AMS price information is available to the public and can be used by feedlots, beef packers, and beef-packers' customers.

Cattle and Beef Cash Market Price Data

We used prices for two wholesale beef composites, a measure of the price of the cattle byproducts sold by meatpackers (also called the drop credit), and a steer price. The four cash prices analyzed are:

1. *The Choice beef cutout:* A composite of the value of wholesale beef produced from a Choice (the 2nd highest grade of beef) steer carcass, measured on a carcass-weight basis.

2. *The Select beef cutout:* A composite of the value of the beef produced from a Select (the 3rd highest grade of beef) carcass, measured on a carcass-weight basis

3. *The steer drop value:* The drop includes the edible and inedible byproducts removed from an animal during slaughter. The drop is measured as the value of these products per hundred pounds (per CWT) of live steer. Unlike the other prices analyzed, this value is based on voluntarily reported data both pre-LMR and during LMR.

4. *The 5-area, Direct, FOB live steer prices:* The 35- to 65-percent Choice price measured in dollars per CWT of live steer.

The meat and byproduct prices are from the *Weekly National Carlot Meat Report*. Steer prices came from the *5-Area Weekly Weighted Average Direct Slaughter Cattle* report. The data span 819 weeks, from January 2, 1999 to September 6, 2014, with the first 118 weeks of data generated under voluntary price reporting. LMR was in effect for 701 weeks, from April 7, 2001 to September 26, 2014. The first 3 weeks of October 2013 are missing due to a Government shutdown, leaving 698 weeks of data in the LMR period.

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These four prices are especially important to beef packers. The steer price is what they pay for the cattle they process, and the composite meat (or cutout) and byproduct (or drop) prices represent what they receive for meat and byproducts.[19] Cattle are by far the largest part of beef packers' costs, and their meat and byproduct values represent the bulk of revenues. Most of the beef produced from steers and heifers in the United States grades either Choice or Select, with between 2 to 5 percent achieving the highest grade of Prime. These four prices are expected to interact with one another over time.

Analytical Approach

The statistical analysis in this section is an expansion of work done in Perry et al. (2005). Perry et al. included a state-space analysis of the same steer price series analyzed in this report. State space is a specific type of time series modeling framework. Here we expand the analysis to include the steer price, the two cutouts, and the drop credit. The initial model for this four-price analysis is a Vector AutoRegression (VAR) model,[20] in which prices for future weeks are based on prices for earlier weeks. These VAR models explain how the four price series interact over time.

We estimate two versions of the VAR model, one using the data for the pre-LMR period and the second using the data for the LMR period. The VAR model coefficients represent the underlying market fundamentals so, if market prices in the pre-LMR and LMR periods behave differently or have different impacts on the other prices, the VAR coefficients estimated for one period will be different from those estimated for the other. Once estimated, the models' coefficients are tested to see if they changed. If we find no significant changes in the coefficients, we will conclude that market insiders perceive voluntary and LMR data as the same—at least for these four prices.

The Price Forecasting Models

The basic, 1st-order VAR specification is:

$$(5) \qquad Y(t,i) = \sum_j VAR(i,j) * Y(t-1,j) + \sum_k \beta(i,k) X(t,k) + u(t,i), \forall i$$

In equation (5), the term $Y(t,i)$ stands for one of the four prices. The symbol t, $t=1,2,3,\ldots,819$ is used to number the weeks. The indices i and j are for the set of four prices (Choice, Select, steer, drop). The $VAR(i,j)$ term is a set of vector autoregressive coefficients that are multiplied against the previous week's prices, $Y(t1,j)$. These $VAR(i,j)$ coefficients make a VAR model in which a set of variables is related to their previous values. Mathematically, the sets of variables are treated as a vector. The fact that the current values of the vector depend on past values makes the model autoregressive. The X in equation (5) represents exogenous variables and the $\beta(i,k)$ their coefficients. The exogenous variables include an intercept, six terms that allow for seasonal movements in the prices, and four variables to pick up the impacts of the 2003 *Bovine spongiform encephalopathy* (BSE)

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[19]Beef grading is voluntary and the USDA, Agricultural Marketing Service charges meatpackers to grade their cattle. Most meatpackers request grading for cattle they expect will grade Select or higher. Non-graded carcasses are called no-roll because meat graders can use a roller stamp to mark carcass grades. Most beef carcasses are now marked with pop stamps. Pop stamps make one grade mark at a time; the meat grader pops the carcass in several places. Research shows that no-roll and Select prices are the same (Stone, 2004). A few steer and heifer carcasses get graded Standard; these are mostly animals that have been sold on the grid. Standard-graded carcasses have a substantial discount.

[20]Our most complicated model estimated a vector autoregression with the state-space features as in Perry et al., 2005. It turns out that we did not need the state-space features (see appendix B).

event in the United States and Canada.[21] The last term in equation (5) is $u(t,i)$, a random error term with a mean of 0. Equation (5) is the most constrained model we estimated: the $VAR(i,j)$ and $\beta(i,k)$ are the same for both the voluntary and mandatory periods.

Model Results for Cattle and Beef Markets

The first test in table 4 shows a composite test for making all the coefficients in the model (the $VAR(i,j)$ and $\beta(i,j)$) the same for both periods. The test statistic is 51.61. The next column is the degrees of freedom. The test statistic's distribution varies depending on how many coefficients you restrict. If we were testing whether a single term changed, we would have 1 degree of freedom. We have effectively 43 terms between the $VAR(i,j)$ and $\beta(i,j)$.[22] This set of 43 restrictions, if true, would follow the chi-square statistical distribution with 43 degrees of freedom.[23] The alpha level in the last column measures how often a test this size or larger would be observed if the hypothesis is true—in this case a little over 17 percent of the time. The test would be significant at the 5-percent level if the alpha were less than or equal to 5 percent. In this case, we can accept the hypothesis that the coefficients are the same in both periods. We also checked to see if the $VAR(i,j)$ changed by themselves or if the $\beta(i,k)$ changed, and found that neither of these tests is significant at the 5-percent level.

With the statistical tests finding no changes in the estimated model coefficients between the pre-LMR and LMR periods, the results indicate that we could use the same forecasting model for both periods. One interpretation is that either the pre-LMR and LMR prices are used the same way (i.e., deemed to provide the same information) by businesses in the livestock feeding/meatpacking segments of the economy, or that these businesses continue to make their decisions based on their own price information. Alternatively, there could be other differences between the two periods that are not captured in this analysis. While these results can be interpreted to mean that LMR has had no market impact, the analysis does not account for other market developments, such as the extent to which LMR may have helped mitigate the effects of a continued decline in the share of cash market transactions.

Table 4

Testing the VAR for shifts before and during mandatory price reporting (LMR)

Restriction	Test statistic	Degrees of freedom[1]	Chi-square alpha
None of the coefficients change	51.61	43	17.26%
Testing the lagged price coefficients for changes	18.00	15	26.25%
Testing the exogenous variables for changes	33.83	28	20.65%

[1] VAR = Vector autoregression. While $VAR(i,j)$ has 16 coefficients, it also has cointegration imposed on it, leaving 15 free terms in the VAR. There are seven exogenous variable coefficients across four equations that can change. The four *Bovine spongiform encephalopathy* (BSE) effects only matter in the mandatory period.
Source: USDA, Economic Research Service.

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[21]In the week of May 24, 2003, Canada announced its first *Bovine spongiform encephalopathy* (BSE) outbreak, leading to an immediate U.S. ban (later lifted) on imports of Canadian cattle. In the week of December 27, 2003, the United States announced its first case of BSE and immediately lost its beef export markets. The BSE outbreaks occurred during the livestock mandatory reporting period and had a major effect on U.S. cattle and beef markets.

[22]There are 16 *VAR()* coefficients and 28 β. However, as noted in appendix B, we imposed cointegration on the data, adding a side restriction on the 16 *VAR()* coefficients that leaves us with 15 net terms.

[23]Technically, the chi-square distribution is asymptotic. The distribution becomes more and more accurate as we add more and more time periods to our estimation routine. The chi-square is also a family of distributions whose values change with different degrees of freedom.

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Findings and Implications

Conceptual work hypothesizing LMR's effects has produced mixed results; nonetheless, most of the modeling frameworks show welfare gains to livestock sellers, meatpackers, and—ultimately—consumers, all of whom benefit from having more information on prices.

The trends toward thinning cash markets for cattle and hogs, and the increased use of AMAs observed prior to the enactment of LMRA in 1999, have continued in the LMR period. In the case of cattle, the share of negotiated cash transactions has declined from more than 60 percent in 2004 to under 30 percent in 2014. In the hog market, the already low share of cash transactions fell from 8.5 to 9.0 percent in 2007 to 2.3 to 2.6 percent in 2014. At the same time, the use of AMAs increased in both markets, with the implication that meatpackers continue to benefit from the reduced cost and improved ability to plan packing-plant operations afforded by AMAs. Additionally, market efficiency, measured as the speed at which markets absorb new information, has improved in the LMR period despite declining cash-market transactions.

Inspection of the cash and forward contract price data for the cattle and hog markets found no observable differences in the patterns for reported cash and AMA prices in the cattle and hog markets compared with Perry et al. (2005). All of the cattle-market price series examined are closely related, with the forward market prices continuing to lag other price movements. Hog market cash and AMA prices are somewhat less closely related than in the case of cattle.

The analysis found small, but statistically significant, changes in the pre-LMR- and LMR-period relationships between cash and futures prices during the period prior to the delivery month. For both cash and futures markets for cattle and hogs, the pre-LMR period is characterized by nonconvergence in cash and futures prices while these markets tended to converge during the LMR period. Additionally, although the futures market is the center of price discovery both before and during LMR for cattle and hogs, cash markets played a small but significant role in the price-discovery process in the LMR period. The role of cash markets became more relevant during LMR, especially in hog markets where the cash market prices went from having virtually no weight in the price-discovery process to accounting for about a third of that weight. The increasing importance of the cash market occurred at the same time as the proportion of cash market transactions declined.

In an analysis focusing only on the cash markets for cattle, beef, and beef byproducts, this study found no significant differences in the behavior of prices in these markets between the pre-LMR and LMR periods. As a result, the same models can be used in both periods to forecast cash prices for fed cattle, Choice- and Select-quality beef cutout values, and byproduct values. In other words, despite the further decline in the role of cash transactions during the LMR period, the behavior of cash prices was similar in both periods and may imply that there was no deterioration of information with LMR.

One plausible explanation for finding evidence of little impact of LMR on the cash market in contrast to the findings for the cash/futures market relationship has to do with who participates in each market sector. Speculators, who participate in futures markets, are largely absent from cash markets, where most participants are involved in the cattle/beef sectors on a continuous basis and may have access to proprietary information. It may be that those cattle/beef cash market participants perceived no differences in quality or timing of information available to them between the pre-LMR and LMR periods. On the other hand, LMR did provide futures market participants with information to which they otherwise did not have access.

The analysis in this study did not explicitly account for other factors that may be affecting cash market performance, including the continued decline in the share of cash transactions during the LMR period. The finding of no change in cash-market price behavior may indicate that LMR likely supplemented the information available pre-LMR. The results of the analysis of cash/futures market interactions in this study do indicate an LMR increase in the flow of information and a speedier price-discovery process in all of the markets examined.

Further, one of the arguments behind LMR was that there was price discrimination, and that LMR would show that contracts yielded higher prices compared with cash prices for the same quality cattle. While the data and methodology used here are not detailed enough to test market power issues, there is sufficient detail to assess the changes in behavior of the interrelated prices studied, and evidence shows that any differences between pre-LMR- and LMR-period cash prices have been either nonexistent or very small.

In addition to the study of the economics of thinning markets, the volume and quality of price data obtained through LMR could facilitate USDA's ability to conduct additional research topics, including investigating the number and distribution of transactions within the reported data, the capacity for LMR regulatory responses to rapidly changing market conditions within each market, and the reassessment of information reported for each type of marketing arrangement. Further research could also isolate the role of LMR and other factors in changing market performance and price behavior.

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Appendix A—An Error Correction Model to Test Price Discovery

To evaluate the relative importance of cash and futures markets, we use the Thiessen (2002) version of the Gonzalo-Granger price-discovery test (Figuerola-Ferretti and Gonzalo, 2010). The advantage of this test over other methods of determining relative market performance is that it focuses on how markets react to emerging information. In contrast, causality tests are backward looking and evaluate current price reaction to a series of lagged prices. A second advantage is that numerical estimates of price-discovery weights, lying between zero and one, can be estimated for both futures and cash markets. In contrast, when both markets contribute to price discovery, causality tests can only claim causality is two way.

However, prior to using the Error Correction Model (ECM), time series checks on the data series were performed. Tests for unit roots indicated that the price and error series are nonstationary, or that correlations exist between time periods (table A1).

The Gonzalo Granger (GzGr) (Figuerola-Ferretti and Gonzalo, 2010) method begins by estimating an ECM in prices. ECMs have two components: a relationship specified with data in levels, which represents the longrun relationship between endogenous and exogenous variables; and a relationship specified with differenced data characterizing the disequilibrium relationship among variables. Estimated coefficients on lagged deviations (errors) from the longrun relationships are used to calculate the rate at which prices adjust to equilibrium. In contrast to a typical ECM, only one longrun relationship is specified in the GzGr model. Differences in adjustments rates to the *same error term* determine the role different prices play in the price-discovery process.

Table A1
Unit-root tests[1] applied to prices and longrun error terms

	Cash	Futures	Error
	Tau	Tau	Tau
Cattle			
1990-2000	-0.29	0.12	-6.85**
2002-08	-0.62	0.76	-4.79**
2008-14	1.70	1.42	-4.79**
Hogs			
1999-01	-2.052	-2.04	-2.35
2001-12	-2.92**	-2.44	-9.56**
2013-14	-2.27	-2.44	-2.31

[1]Unlike the main models, to get a clean separation of time periods for cattle—pre- and post-mandatory reporting period (LMR)—the unit-root tests were estimated for separate time periods; the year of transition to LMR was excluded. The same time separation was not done for hogs because of the limited degrees of freedom with the hog data. The ** marks indicates the test statistic, Tau, is significant at the 0.01 level. This means the Tau is less than the critical value of 2.58—i.e., we are 99-percent confident that the nonstationary null hypothesis can be rejected. If the Tau values for cash and futures prices means are not significant, we cannot reject the nonstationarity of the data. If, at the same time, the Tau values indicate we can reject nonstationarity for the error terms, then the cash and futures prices are cointegrated.
Source: USDA, Economic Research Service.

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When an ECM model consists of only two prices, discovery weights can be calculated from the estimated adjustment-rate coefficients of the ECM (Schwartz and Szakmary, 1994; Theissen, 2002). Models with more than two prices require a more complex method to determine price-discovery weights. [24, 25] In any case, Hasbrouck (1995), Gonzalo and Granger (1995), and Harris et al. (2002) have developed methods that allow one to establish a price-discovery weight for each market. In the GzGr technique, these weights represent the contribution each market makes towards establishing a longrun trend in prices (Gonzalo and Granger, 1995; Figuerola-Ferretti and Gonzalo, 2008).

Such a claim might be more indicative of how markets actually operate than typical causality tests, which only reveal the direction of price flows. Most price-discovery literature has concentrated on the relationship between futures and cash markets (Figureola-Ferretti and Gonzalo, 2008; Plato and Hoffman, 2011) and has found that futures strongly lead in the price-discovery process.

To illustrate how a two-price GzGr model works, consider the ECM model:

$$(A.1a) \quad \Delta P^c_{cs,t} = \gamma_{cs} \left(\beta_{cs} P^c_{cs,t-1} - \beta_{fut} P^c_{fut,t-1} - C \right) + \sum_{i=1}^{k} \eta_{11,i} \, \Delta P^c_{cs,t-i} + \sum_{i=1}^{k} \eta_{12,i} \, \Delta P^c_{fut,t-i} + \varepsilon_{cs,t}$$

$$(A.1b) \quad \Delta P^w_{fut,t} = \gamma_{fut} \left(\beta_{cs} P^c_{cs,t-1} - \beta_{fut} P^c_{fut,t-1} - C \right) + \sum_{i=1}^{k} \eta_{21,i} \, \Delta P^c_{cs,t-i} + \sum_{i=1}^{k} \eta_{22,i} \, \Delta P^c_{fut,t-i} + \varepsilon_{fut,t}$$

where $\Delta P^c_{cs,t}$ and $\Delta P^c_{fut,t}$ represent the change in the U.S. cash and futures prices for cattle, respectively, in time t (from t-1 to t).

The first term in parentheses in equations (A.1a) and (A.1b) contains a one-period lag of the long run (cointegrating relationship) between the cash and futures prices. The next two terms represent lag price differences, while the fourth term represents an equation error. What is notable in equations (A.1a) and (A.1b) is that both equations are specified with the same right-hand-side variables. Notice when the adjustment rate coefficients are zero, equations (A.1a) and (A.1b) reduce to a standard two-equation VAR model in price differences.

Key to the price-discovery measures is the relative size of the two adjustment rate coefficients: γ_{cs} and γ_{fut}. In a typical ECM model, adjustment rates are negative. Notice that the specification of the longrun price relationship in equations (A.1a) and (A.1b) (in parenthesis) includes one price with a negative sign in front of it (i.e., $-\beta_{fut}$). Therefore, the adjustment rate coefficients for each price in equations (A.1a) and (A.1b) are not expected to be the same sign. In the above example, if:

a) $0 < \gamma_{fut} < 1$ and $-1 < \gamma_{cs} < 0$, then both prices adjust and price is discovered in both markets.

b) $0 < \gamma_{fut} < 1$ and $\gamma_{cs} = 0$, then the futures price adjusts but the cash price does not. If only the futures price responds to deviations from the longrun equilibrium relationship, then prices are discovered in the cash market.

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[24]These weights also serve as a measure of a common factor underlying a cointegrating relationship. That is, Gonzalo and Granger (1995) showed that any common factor driving a cointegrating relationship, a factor that is often viewed as missing or unknown, could be approximated as a weighted average of a model's endogenous variables.

[25]Models with more than two prices require a more complex method for determining price-discovery weights, which is similar to the Johansen eigenvalue test for cointegration. However, this technique calculates minimum eigenvectors rather than maximum eigenvalues (Gonzalo and Granger, 1995; Plato and Hoffman, 2011).

c) $\gamma_{fut} = 0$ and $-1 < \gamma_{cs} < 0$, then only the cash price adjusts and prices are discovered in the futures market.

d) If $\gamma_{fut} = 0$ and $\gamma_{ss} = 0$, then the two markets are not integrated.

Price-Discovery Weights

Once adjustment rates are estimated, the next step is to obtain the price-discovery weights. Expanding on the work of Schwartz and Szakmary (1994), Theissen (2002) showed that in a two-variable model, it is possible to obtain price-discovery weights directly from the estimated error correction coefficients. In our example, the relationship between Schwartz and Szakmary weights and the estimated adjustment rate coefficients are:

(A.2a) $\quad Wg_{cs} = \hat{\gamma}_{fut} / (\hat{\gamma}_{fut} - \hat{\gamma}_{cs})$

(A.2b) $\quad Wg_{fut} = -\hat{\gamma}_{cs} / (\hat{\gamma}_{fut} - \hat{\gamma}_{cs})$

Price-discovery weights, which are calculated from estimated adjustment rates, represent each market's contribution to the common longrun trend in prices. Thus, a market's price-discovery weight represents the extent to which there is a longrun memory of a price change emanating from that market. When there are more than two prices, the method for calculating price-discovery weights follows a more complex procedure (Plato and Hoffman, 2011).

Estimation

Longrun cattle models were estimated using dummy variables. Equations (A.1a) and (A.1b) are nonlinear in parameters. To avoid the use of nonlinear estimating techniques, which can often lead to unstable parameter estimates (sensitivity to starting values and the chosen search algorithm), each ECM was estimated using Engle and Granger's (1987) two-step procedure.

With no loss of information, we set the parameter $\beta_{cs}=1$ so that the longrun cash and futures rela-tionship (the term in parenthesis in equations (A.1a) and (A.1b)) was specified as:

(A.3) $\quad P^c_{cs,t} = \beta_{fut} P^c_{fut,t} + +\beta_{dfl} Dmfl + C + u_t$

where *Dmfl* is a dummy variable=1 for the seven observations that used fill-in data.[26] Appropriate dummy variables for each subperiod were also included in equation (A.3) for cattle and hogs.

Equation (A.3), the longrun model, was estimated with OLS, and estimates of the error terms were obtained.

In the second step, the following two equations were estimated jointly:

(A.4a) $\quad \Delta P^c_{cs,t} = \gamma_{cs} * \hat{\mu}_{t-1} + \gamma_{cs} \left(\hat{\mu}_{t-1} * Df \right) + \gamma_{2cs} \left(\hat{\mu}_{t-1} * Dlv \right)$
$\quad\quad\quad + \sum_{i=1}^{k} \eta_{11,i} \Delta P^c_{cs,t-i} + \sum_{i=1}^{k} \eta_{12,i} \Delta P^c_{fut,t-i} + \varepsilon_{cs,t}$

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[26]Koontz et al. (1990) used causality tests to evaluate the flow of price information between major cattle markets, satellite markets, and the futures markets, and found that these relationships can change over time.

(A.4b) $\Delta P^c_{fut,t} = \gamma_{fut} * \hat{\mu}_{t-1} + \gamma_{1fut}\left(\hat{\mu}_{t-1} * Df\right) + \gamma_{2fut}\left(\hat{\mu}_{t-1} * Dlv\right)$

$\qquad + \sum_{i=1}^{k} \eta_{21,i}\Delta P^c_{cs,t-i} + \sum_{i=1}^{k} \eta_{22,i}\Delta P^c_{fut,t-i} + \varepsilon_{fu,t},$

where $\hat{\mu}_{t-1}$ represents the lagged error from the longrun equation. Notice both equations include dummy variables representing the delivery months (*Dlv* months when the futures price was represented by the contract following the nearby contract) and the 7 weeks that fill-in data were used (*Dfl*).[27] Thus the adjustment rates (and hence, price-discovery weights) were allowed to be distinct for periods in which the dummy variables were 1. Results of the estimation are in table A2.

Likelihood ratio tests indicated that three lags of the price differences belong in the model. Three lags were indicated by applying likelihood ratio tests to the second stage, which is a model linear in the parameters. By doing this, we avoided estimation issues associated with single-stage models that are nonlinear in parameters (which use an iterative search process that does not always converge). We also used the same starting values for both restricted and unrestricted models to calculate likelihood ratios. While it may be more likely to ensure that a maximum is truly maximum, searching through an array of starting values is a long, drawn-out process.

Dummy variables representing the three different time periods were significant, indicating that adjustment rates were different prior to and during LMR, and different again in the period of high price volatility after 2006.

The Relative Importance of Cash and Futures Markets in Price Discovery

There are two approaches to evaluate the relative importance of cash and futures markets. The older approach is based on a Granger analysis, which is backward looking and evaluates how current prices react to a series of lagged prices. The second approach is based on a version of the Gonzalo-Granger price-discovery test (Figuerola-Ferretti and Gonzalo, 2010) that focuses on how markets react to emerging information. In a Granger test, one wants to know if the futures price can be better predicted by lags of cash prices than by lags of past futures prices alone. If this occurs, it provides some evidence that the futures market follows the cash market. Conversely, a test of whether cash price can be better predicted by lags in futures prices would provide evidence that cash prices follow the futures market. The Granger causality approach allows one to test whether, for different pre-LMR and LMR periods, prices are determined by futures markets, cash markets, or both.

Granger Causality

The Granger tests emphasize the influence of past lags on current prices (Spreen and Shonkwiler, 1981) and, while not measuring the effects of the discovery of new information, they have proven to be an effective tool in analyzing price relationships. Granger tests give some indication of which market is the price leader and which is the price follower in the pre-LMR and LMR periods. However, it does not pick up on the smaller, more subtle shifts that can be detected by a price-discovery test.

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[27]Tests indicated the dummy variables representing the four or five observations with filled-in data were not significant, indicating that the use of constructed data to fill in for four or five missing prices did not significantly distort model coefficients.

Table A2

Shortrun model parameters for the mandatory reporting period (LMR)

	Cash P		Futures P	
	Coefficient	T-stat	Coefficient	T-stat
Cattle				
Var				
Lag Err	-0.117	-4.15	-0.072	-3.01
DP2*Err	0.007	0.19	0.073	2.21
DP3*Err	0.019	0.32	0.077	2.27
Dpcsh-1[1]	0.150	4.24	0.280	8.73
Dpcsh-2	0.263	-7.96	-0.150	-6.02
Dpcsh-3	0.01	0.29	-0.033	-1.02
Dfput-1	0.057	0.14	-0.082	-2.27
Dfput-2	0.016	0.531	0.0007	-1.19
Dfput-3	0.063	1.63	0.104	2.97
Ddv	0.04	0.59	0.29	0.38
LLF	-1629			
Hogs				
Var				
Lag Err	-0.094	-4.01	-0.122	-2.44
DP1*err	0.01	0.37	0.163	2.92
Dp2*err	-0.058	-1.63	-0.309	-4.08
Dpcsh-1	0.506	14.26	0.151	1.99
Dpcsh-2	-0.159	-4.05	0.021	0.25
Dpcsh-3	0.01	0.29	-0.051	-0.70
Dfput-1	0.072	3.66	-0.289	-6.92
Dfput-2	0.037	1.86	-0.115	-2.71
Dfput-3	0.055	3.02	-0.048	-1.24
Ddmfl	0.346	0.76	1.38	1.43
Dmfl2	-0.217	-0.77	-1.50	-2.51
LLF	-4097			

[1]Exogenous variables in the shortrun model include a one-period lag of the longrun model error, and this error interacted with time period dummy variables. The model also included three lags of cash prices (Dpcsh$_{-i}$ where i=1,2,3…) and three lags of future price differences (Dpfut$_{-i}$ where i=1,2,3…). Longer price-differences lags were not significant.
Source: USDA, Economic Research Service.

The results of the Granger analysis are provided in appendix table A3 for fed cattle and table A4 for hogs, and tend to indicate a growing influence of the cash market in the price-discovery process during the LMR period.

For fed cattle, the results in table A3 indicate that futures prices played a significant role in deter-mining cash prices (second column) in the pre-LMR period (1990-2001), while the role of cash prices in determining futures prices was insignificant at the 1-percent level of significance (first column). In the LMR period, the results reverse and indicate that cash prices influenced futures prices.

Table A3

Granger causality test statistics[1] for fed cattle prices

	Cash-causes-futures equation		Futures-causes-cash equation
1990-2000 (Pre-LMR)			
F-Stat	7.59	F-stat	6.59
P-Value[2]	0.00005	P-Value	0.00025
2002-08 (LMR)			
F-Stat	11.93	F-Stat	0.027
P-Value	0.01	P-value	0.841
2008-14 (LMR)			
F-Stat	26.28	F-Stat	1.62
P-Value	0.00001	P-Value	0.18

[1]Unlike the main models, to get a clean separation of time periods for cattle—pre- and post-mandatory reporting period (LMR)—and because dummy variables cannot be used, the Granger tests were estimated for separate time periods; the year of transition to LMR was excluded from the Granger model. The same time separation was not done for hogs because of constrained degrees of freedom with the hog data. Lagged cash prices are tested in the futures price equation and lagged futures prices are tested in the cash price equation.
[2]F-statistics test if lagged cash (futures) prices contribute significantly to the fit of the futures (cash) price equations. If the F-statistic is significant, then the cash (futures) price is said to cause the futures (cash) price. P-values smaller than 0.05 imply significant effects in more than 95 percent of samples and establish that we can be 95-percent confident that one price causes the other.
Source: USDA, Economic Research Service.

Table A4

Granger test statistics[1] for hog prices

	Cash-causes-futures equation		Futures-causes-cash equation
1990-2001 (Pre-LMR)			
F-Stat	1.47	F-stat	1.5
P-Value[2]	0.23	P-Value	0.22
2002-12 (LMR)			
F-Stat	2.6	F-Stat	24.86
P-Value	0.056	P-value	0.000
2013-14 (LMR)			
F-Stat	0.77	F-Stat	11.54
P-Value	0.51	P-Value	0.000

[1]Lagged cash prices are tested in the futures price equation and lagged futures prices are tested in the cash price equation.
[2]F-statistics test if lagged cash (futures) prices contribute significantly to the fit of the futures (cash) price equations. If the F-statistic is significant, then the cash (futures) price is said to cause the futures (cash) price. P-values smaller than 0.05 imply significant effects in more than 95 percent of samples and establish that we can be 95-percent confident that one price causes the other.
Source: USDA, Economic Research Service.

When applied to hog prices, the causality tests in table A4 indicate that futures prices tended to determine cash prices during LMR but not before. The results suggest that cash markets only cause futures prices, at a borderline significance level, in the LMR period from 2001-13. In other words, there was two-way causality during this period, but in the latter part of the LMR period (2013-14), causality reverts to futures causing cash prices.

The information provided by the causality tests is more general than the information contained in the GzGr price-discovery tests. Despite being more general, the results are informative and, overall, consistent with each other in indicating a slightly increased role for the cash market with LMR.

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Appendix B—The VAR Forecasting Model

Our basic approach is vector autoregression (VAR). We organized the price data into tables: the rows are the weeks, the columns are the prices for the week. We can treat each week's prices as an array or vector of numbers;[28] the V part of VAR. Regression is a general statistical technique for using one set of variables to explain, relate, or predict another set of variables. The A in VAR, auto (meaning self), refers to using the previous week's prices to help forecast this week's prices.

We rescaled the Choice and Select cutouts, and the steer prices and drop credit are both in dollars per hundred pounds of live animal. The two cutouts are measured in dollars per hundred pounds of carcass. We transformed the cutouts so that they were also in dollars per hundred pounds of live animal. We multiplied the cutouts by carcass yields—the pounds of carcass per pound of steer. Our carcass yield for Choice is 63 percent and for Select is 62 percent. Choice cattle tend to yield slightly better than Select cattle. This transformation will not change our statistical tests but it does simplify some of our later analysis and interpretation of the results.

We start with a basic, 1st order VAR specification:

$$(B.1) \quad S(t,i) = \sum_j VAR(m,i,j) * \delta(t,m) * S(t-1,j) + \sum_k \beta_{m,i,k} * \delta(t,m) X(t,k) + u(t,i)$$

Equation (B.1) differs from equation (5) in the body of the report in two important ways. First we have replaced the $Y(t,i)$ with an $S(t,i)$. The S variable is a state variable. The state definition is helpful when we allow for price measurement errors. We have also added an additional subscript to the VAR and β coefficients and a $\delta(t,m)$.

The m index allows the model to vary between the voluntary and mandatory periods. The $\delta(t,m)$ is a dummy variable that made the regression select the correct set of coefficients for the time period. Both the $VAR(m,i,j)$ and $\beta(m,i,j)$ coefficients could vary between the voluntary and mandatory periods.

The exogenous variables were based on an intercept and three cosine and three sine terms. The cosine and sine terms come in pairs: one pair made one rotation per year, the next pair two rotations per year, and the last pair three rotations per year. The sine and cosine terms are an alternative to using seasonal dummy variables. These exogenous variables were multiplied by a price index to account for inflation; our price index was the Bureau of Economic Analysis's Personal Consumption Deflator. This deflator comes monthly so we interpolated and smoothed its values over the weeks.

In addition to the intercept and seasonal dummy variables, we also included four additional dummy variables. In the week of May 24, 2003, Canada reported its first case of *Bovine spongiform enceph-alopathy* (BSE). We included a dummy variable for that week and another one for the following week. The Canadian BSE event led to a temporary cessation of imports of Canadian cattle and beef into the United States. Prior to May 2003, Canada was the leading U.S. supplier of cattle and an important source of beef. In the week of December 27, 2003, the United States reported its first BSE case—we included a dummy variable for that week and the following week. The U.S. BSE outbreak largely eliminated U.S. beef and cattle exports in 2004.

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[28]None of the equations in the body of the text or in this appendix are written using vector notation, however.

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Replacing the *Y()* variable in equation (5) with the *S()* in equation (B.1) allows us to deal with potential measurement errors. What do we mean by that and why does a state variable help with measurement errors? Let us start with the concept of measurement error. Under voluntary price reporting, only some of the prices were collected and used to make the average price estimate. Statistical theory shows us that the average of a sample is going to be an inaccurate measure of the true average of the underlying the data. Let *S()* be the true average and *Y()* be the one that is reported—the best-case scenario for the relationship between the true and reported average would be:

(B.2) $Y(t,i) = S(t,i) + e(t,i)$

In equation (B.2) the term *e(t,i)* is a random measurement error with a mean of 0 and some variance. Our most general model has two different variances for each price. There is a variance in the voluntary period and a different one (potentially) in the LMR period.

In the LMR period, all the prices have to be reported—statistical theory suggests that the reported average ought to match the true average. The drop-credit value is based entirely on voluntarily reported prices so that term could have measurement errors. However, the two cutouts and steer prices are mandatorily reported, so why would they have measurement errors with LMR? This is because AMS reports a sales-weighted average price. While the general assumption is that the average price is the best measure of the market price, a different weighting scheme could be ideal and the sales-weighted average could have measurement errors relative to the ideal average.

Another reason that we may have *e()*- errors both before and with LMR is that these errors need not be entirely or even partially due to measurement errors. Hahn et al. (2009) used similar analysis to compare two sources of retail price data. They noted that these *e()*- errors could be the result of transient effects—in this case, random things that affect prices this period but do not affect them in future periods. In this case, the *S()* can be interpreted as the part of the current price that drives the future price evolution. Temporary effects, to the extent one can identify them, provide useful information to the market. A positive, temporary increase in the steer price would encourage livestock sellers to sell cattle this week rather than waiting for next.

We implicitly assume that the *S()* terms are what is driving the market's evolution over time. Market participants know the prices for their livestock, meat, and byproducts; consequently, they would be better able to react to the ideal prices. They are also likely to follow the AMS reports; they could add this information to their own to get an idea of what is happening elsewhere in the market. Better or just different information could change how the market operates leading to changes in the coefficients equation (B.1).

Suppose that *e()*-errors are 0 for each price in each time period. In that case, equation (B.2) becomes:

(B.3) $Y(t,i) = S(t,i)$

If equation (B.3) holds for all time periods and all prices, then we can replace *S()* in equation (B.1) with *Y()*, giving us:

(B.4) $Y(t,i) = \sum_j VAR(m,i,j) * \delta(t,m) * Y(t-1,j) + \sum_k \beta_{m,i,k} * \delta(t,m) X(t,k) + u(t,i)$

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Equation (B.4) is now the same as equation (5) except that it has two sets of coefficients, one for each time period.

Our most complicated model combined equation (B.1) and equation (B.4) to build a state-space model. The $S(t,i)$ were then the state variables and equation (B.1) was the transition equation. In the most general types of state-space models, the state variables are not directly observed. We made estimates of the state variables using their effects on the observed variables, the Y. Equation (B.4) is called the observation equation in state-space analysis.

If an $e(t,i)$ has 0 variance in one or both periods, then that error is always 0 and equation (B.2) implies that the state variable and the endogenous variable were the same. If all of the errors in both periods have 0 variances, we could estimate a straight VAR.

Special estimation issues—steady state covariances and filters

This discussion of general state-space techniques is superficial. If all the $e(t,i)$ had non-zero variances, then we would not observe any of the state variables under either type of price reporting regime. In these cases, we used estimated state variables. We used the estimated states from the week before to forecast a given week's states, then used these forecast states to predict this week's prices. We could then use a given week's forecast errors to improve our estimates of that week's states (a process called filtering) and start it all over again next week. State-space techniques allowed us to calculate the covariances between the actual states and the estimated state (before and after seeing the endogenous variables), the covariances of our forecast errors, and the filter matrices that allowed us to turn the forecast errors into improved state estimates.

These covariance matrices and filters varied from one period to the next. However, the specific forms we have are such that, as we add more and more weeks to the routine, these matrices converged to a set of steady-state matrices. The model had to keep track of all these estimated states, covariance, and filter matrices. Durbin and Koopman (2001) noted that you could speed up the estimation routine by switching to the steady state matrices at some point in the routine. We used the steady-state matrices for nearly all the weeks.[29] The sequester weeks occurred during LMR; in those weeks when there were no reports, we turned off the filtering step.

While we forecast prices for the whole sample, we used a smaller set of forecast errors in the likelihood function. In the voluntary period, we used the 12th through 118th weeks in the likelihood. LMR started in the 119th week, but we used the 129th through 770th weeks and 784th through 819th weeks of mandatory forecast errors in the likelihood. The sequester ran from week 771 to 773—we dropped these weeks in theory and in practice because the forecasts early in the sample (immediately after the start of LMR) and immediately after sequestration can be much worse than those later in the sample.

Testing the variances of the measurement errors

All our models were estimated using maximum likelihood estimation (MLE), and we used likelihood-ratio testing. Imposing constraints on the model generally lowers its objective. Our tests of a restriction are (twice) the decrease in the likelihood.[30]

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[29]Hahn et al. (2009) also used steady-state matrices.

[30]We set up the model so that its objective is actually twice the likelihood given normally distributed error terms.

We tested our model in two phases. First, we tested for the significance of the measurement error's variances. If all of these were zero, then we could estimate and test a conventional VAR. Statistical theory requires all variances to be greater than or equal to zero. The fact that the variances have to be positive complicates statistical testing. Most statistical tests are designed to test parameters that do not have bounds, so we built our own customized approach to these tests.

We wanted to test if some or all of the measurement-error variances were zero. There were eight of these in our most complicated model—seven of these estimates actually were zero. Had all eight of these estimates been zero, we would have accepted the null hypothesis that all eight of them should be zero. The one that was not zero was the steer's LMR term. This result was consistent with the results in Perry et al. (2005), which showed that the steer-price volatility increased with LMR. However, in our results, the steer-price volatility was not significantly different from zero.

The likelihood-ratio test statistic for forcing all eight of the variances to be zero was 6.50. To determine whether or not this is statistically significant, we used Monte-Carlo analysis or parametric bootstrapping. We used the coefficients from our most constrained model and normally distributed errors from a covariance matrix that was the same as our estimated covariance matrix to generate a new set of prices; we then used those prices to test forcing all eight variances to be zero. We saved that test, had the model create another set of prices, and tested those. We programmed a loop, and had the model update a file with the test results to date. Though we set up the model to do 5,000 iterations, we actually stopped it sooner. When we checked after 113 iterations, we found that 32 of the tests were larger than 6.50, the actual value. We were using the typical 5-percent critical value. If 6.50 were a 5-percent value, we would typically see between 4 and 7 tests at or over 6.50 in 113 iterations. If values at or above 6.50 happen only 5 percent of the time, having 32 of 113 over 6.50 is virtually impossible. We concluded that 6.5 is not significant at the 5-percent level. Incidentally, 13 of these 113 tests were 0, implying that in 13 cases, all 8 estimated variances are 0 (the value the model simulations were based on).

Accepting that the data have no measurement errors in either reporting regime allows us to use the conventional VAR specification. We do not need filters for the VAR approach and were able to use more of the observations. At this point, we tested the other parameter estimates to see if they changed between the voluntary and mandatory pricing periods. As shown in table 4, the two sets of coefficients are not statistically significantly different.

Unit roots and cointegration

Nearly all versions of the models were estimated under the assumption that the four prices share a root equal to one. We did some runs with and without cointegration imposed, testing cointegration using Johansen's (1988, 1991) likelihood ratio test. Forcing the estimates to have a unit root imposes a restriction on the model; the decrease in likelihood can be used as a test of this restriction. Johansen derived the distribution of this test. Our test values were all insignificant, indicating a failure to reject the null hypothesis of cointegration.

Typically, unit roots are imposed on error-correction versions of the VAR. This is the approach used in the analysis of futures/cash price interactions. We used an alternative approach based on the use of Eigen vectors; Taha and Hahn (2014) used this approach. Sims et al. (1990) used Eigen vectors and values to demonstrate that VAR with unit roots are consistently estimated by least squares even if the unit root is not imposed. (Johansen also demonstrated the generic consistency of least-squares estimates of cointegrated VAR.)

We estimated a vector of parameters that described the ways the prices were cointegrated or related across each other and from one week to the next. Shorthand technical terms for this vector are characteristic or Eigen vector. We used this characteristic or Eigen vector to impose the unit root on the VAR as a way to impose our estimates of the four prices as the ideal or true prices for the model. Recall that this week's forecast is determined by last week's prices. If there is a unit root, then we can find a set of last week's prices that makes this week's forecast exactly the same as last week's prices. Technically, that forecast is a homogenous forecast. We only count the effects of the lagged prices. The homogenous forecast is:

(B.5) $\quad \overline{Y}(t,i) = \sum_j VAR(i,j) * Y(t-1,j)$

In equation (B.5), $\overline{Y}(t,i)$ is the homogenous forecast. Equation (B.5) is equation (5) with the exogenous variables effects and error terms dropped. Eigen vectors are associated with Eigen values. The typical symbol for an Eigen value is λ. One way to define Eigen vectors and values is that there will exist a non-0 vector, call it $V(i)$, such that:

(B.6) $\quad \lambda V(i) = \sum_j VAR(i,j) * V(j), \forall i$

A 1st-order VAR with four lagged dependent variables will have four Eigen values. When we have a unit root, one of the λ is 1. We will subscript the V, calling the unit-root's Eigen vector's elements, $V_1(i)$. The version of equation (B.6) with an Eigen vector equal to 1 is written:

(B.7) $\quad V_1(i) = \sum_j VAR(i,j) * V_1(j), \forall i$

You will note that, unlike equation (B.6), equation (B.7) has no λ in it. Implicitly, we require that the λ_1 is exactly 1. One of the problems with equation (B.7) is that it holds when we make all the $V_1(i)$s = 0 for each i, which is neither interesting nor useful. Eigen vectors are defined as non-0 vectors, and we made the model solvable (identified) by making the steer term = 1 in the Eigen vector $V_1(i)$. Table B1 shows the Eigen vector estimates for the unit root.

The unit root in table B1 implies that the four prices we have been analyzing are fundamentally unstable. When they increase, they have a tendency to stay high. When they decrease, they have a tendency to stay low. The four prices do tend to stick together. Something that would change the steer price by $X over the long run would change the Choice cutout by $0.8516X, the Select cutout by $0.8410X, and the drop credit by $0.1537X.

Table B1
Eigen vector estimates for the unit root

Endogenous variable	Unit-root Eigen vector		
	Estimate	Standard deviation	Z ratio
Choice	0.8516	0.0414	20.55
Select	0.8410	0.0281	29.93
Steer	1		
Drop	0.1537	0.0212	7.27

Source: USDA, Economic Research Service.

More Eigen vectors and gross margins

The unit root tends to keep the four prices lined up over longer periods. We also tested the model for another longrun relationship among the prices. Meatpackers buy cattle and then sell their meat and their byproducts, resulting in a gross margin. We estimated a simplified gross-margin relationship assuming that cattle were either Choice or Select. Our gross-margin equation was:

(B.8)   Actual Gross Margin = x percent Choice *Choice cutout value+ (100-x) percent Select * Select cutout value + drop value – steer price

The gross margin in equation (B.8) is in dollars per hundred pounds of live animal. Recall we had transformed the cutouts values from dollars per hundred pounds of carcass weight to dollars per hundred pounds of steer weight. We created a gross-margin vector, $W_2(i)$ based on equation (B.8):

$W_2(Choice) = x$, $W_2(Select) = 1-x$,

$W_2(steer) = -1$, and $W_2(drop) = 1$.

The vector form of equation (B.8) for a specific week is:

(B.9) $\sum_i W_2(i) Y(t,i)$

Combining the VAR equation, equation (5) from the body of the text, and equation (B.9) gives us:

(B.10) $\sum_i W_2(i) Y(t,i) = \sum_{i,j} W_2(i) VAR(i,j) * Y(t-1,j)$
$$+ \sum_{i,k} W_2(i)\beta(i,k)X(t,k) + \sum_i W_2(i)u(t,i)$$

Suppose that following restriction holds on the lagged endogenous-variable coefficients:

(B.11) $\sum_{i,j} W_2(i) VAR(i,j) = 0, \forall j$

In that case, equation (B.10) implies:

(B.12) $Gross\,margin(t) = \sum_{i,k} W_2(i)\beta(i,k)X(t,k) + \sum_i W_2(i)u(t,i)$

Equation (B.12) has the gross margin on the left-hand-side of the equation and the functions of the exogenous variables and error terms on the right-hand side. If equation (B.12) actually holds, then the gross margin for the steer price is a function of the inflation rate and seasonal factors.

Equation (B.11) defines $W_2(i)$ as a different type of Eigen vector; its Eigen value is 0. When we defined the unit-root Eigen vector, we multiplied the $VAR(i,j)$ coefficients from the right-hand-side. If there is a W_2 consistent with equation (B.11), there is also a $V_2(i)$ that multiplies the lagged-endogenous variable coefficients from the right and has a λ_2 that is 0. (There is also a left-hand-side Eigen vector for the unit root.)

We could generalize equation (B.11) so that it, like equation (B.7), has a non-0 λ_2. In this case, we can interpret the gross-margin relationship as if it states:

(B.13)   This week's gross margin = λ_2*(last week's gross margin) + (1-λ_2)*long-run equilibrium margin

We then tested the VAR to see if equation (B.12) or equation (B.13) held. Forcing $\lambda_2 = 0$ was rejected by our statistical tests. A model with an estimated non-zero λ was not rejected by our tests.

We started our W_2 values with the Choice and Select terms both at 0.5. Our steer price is the 35 to 65 percent Choice steer, and 50 percent is the midpoint of 35 to 65 percent. The estimated W_2 did not change much from its starting values of 0.5. Our model in which the W_2 were fixed (so that the steers were half Choice and half Select) was not statistically significantly different from a model that estimated values for Choice and Select.

When we calculated the V_2 vector associated with the fixed W_2 vector of coefficients, we found that the Choice and Select terms were similar and the steer and drop terms were small. We made the Choice and Select terms in $V_2(i)$ 1 and the drop and steer terms 0, and tested this against a model where all the $V_2(i)$ terms were estimated. This set of restrictions was also insignificant. Table B2 below shows the fixed values for the W_2 and V_2 and the estimate for λ_2.

The estimate for λ_2 implies that the current gross margin on the steer is around 69 percent of last week's margin and $(1-\lambda_2)$ 31 percent of the full-adjustment margin. In theory, high costs of cattle processing will lead to combination of higher output prices (the two cutouts and the drop) and lower input prices (steers). The V2 values imply that when the current gross margin is above its longrun equilibrium (full adjustment) level, we get higher cutouts, not lower cattle prices.

Lead-lag relationships

Further analysis of the VAR showed that the lagged cutouts' coefficients did not have a significant effect on the current steer prices and drop values. We dropped these insignificant terms from the final version of the VAR. The steer price and drop value drove the two cutouts but were not affected by their lagged values. Steer prices and the drop values led the two cutouts. Table B3 shows the final estimates of the lagged endogenous variable coefficients while table B4 has the estimates for the exogenous variable coefficients.

Table B2

Fixed Eigen-vector terms for the gross margins and the λ-estimate statistics

	W_2, left-hand-side vector	V_2, right-hand-side vector
Choice	0.5	1
Select	0.5	1
Steer	-1	0
Drop	1	0
	Estimate	Standard deviation[1]	*Z ratio*
λ_2 estimate	0.6868	0.0220	*31.23*

[1]Standard deviations and *Z-ratios* are based on 5,000 Monte Carlo iterations of the model. *Z-ratios* greater than 1.96 imply statistical significance.
Source: USDA, Economic Research Service.

Table B3
The VAR estimates for lagged prices and values and associated statistics[1]

Equation	statistic	Lagged endogenous variable coefficients			
		Choice	Select	Steer	Drop
Choice	Estimate	0.8241	-0.1373	0.2901	-0.1618
	Standard deviation[2]	0.0121	0.0110	0.0223	0.0533
	Z ratio	*67.99*	*-12.42*	*13.01*	*-3.03*
Select	Estimate	-0.1373	0.8241	0.2853	-0.1329
	Standard deviation	0.0110	0.0121	0.0221	0.0520
	Z ratio	*-12.42*	*67.99*	*12.90*	*-2.55*
Steer	Estimate			0.9769	0.1502
	Standard deviation			0.0074	0.0490
	Z ratio			*131.72*	*3.06*
Drop	Estimate			0.0024	0.9844
	Standard deviation			0.0007	0.0049
	Z ratio			*3.69*	*201.88*

Note: VAR = Vector autoregression.
[1]Blank cells in the table are fixed to 0, have standard deviations equal to 0, and no *Z ratios*.
[2]Standard deviations and *Z-ratios* based on 5,000 Monte Carlo iterations of the model. *Z-ratios* greater than 1.96 or less than -1.96 imply statistical significance.
Source: USDA, Economic Research Service.

Table B4
Exogenous variable coefficient estimates

		Intercept and seasonal terms							BSE dummies			
		X0	COS1	COS2	COS3	SIN1	SIN2	SIN3	CAN1	CAN2	USA1	USA2
Choice	Estimate	3.721	-0.449	-0.045	0.253	0.321	0.046	-0.059	1.672	4.155	-1.683	-3.300
	Standard deviation[1]	0.453	0.116	0.106	0.103	0.107	0.106	0.104	2.114	2.120	2.099	2.113
	Z ratio[1]	*8.21*	*-3.88*	*-0.42*	*2.45*	*3.00*	*0.43*	*-0.57*	*0.79*	*1.96*	*-0.80*	*-1.56*
Select	Estimate	3.612	-0.291	0.368	0.058	0.370	0.213	0.003	1.973	3.930	-0.843	-3.299
	Standard deviation	0.428	0.113	0.103	0.099	0.105	0.102	0.100	2.029	2.042	2.011	2.039
	Z ratio	*8.44*	*-2.59*	*3.59*	*0.58*	*3.52*	*2.10*	*0.03*	*0.97*	*1.92*	*-0.42*	*-1.62*
Steer	Estimate	0.780	0.211	-0.082	-0.009	-0.111	0.332	-0.029	-0.811	2.087	-5.772	-11.893
	Standard deviation	0.349	0.101	0.099	0.098	0.099	0.098	0.098	2.001	2.032	1.977	2.022
	Z ratio	*2.24*	*2.09*	*-0.83*	*-0.10*	*-1.13*	*3.40*	*-0.29*	*-0.41*	*1.03*	*-2.92*	*-5.88*
Drop	Estimate	-0.058	-0.016	0.001	-0.006	0.010	0.019	-0.016	0.009	0.099	0.085	-0.129
	Standard deviation	0.027	0.007	0.007	0.007	0.007	0.007	0.007	0.144	0.143	0.144	0.144
	Z ratio	*-2.15*	*-2.24*	*0.17*	*-0.93*	*1.38*	*2.72*	*-2.24*	*0.06*	*0.70*	*0.59*	*-0.90*

Note: BSE = *Bovine spongiform encephalopathy*.
[1]Standard deviations and *Z-ratios* based on 5,000 Monte Carlo iterations of the model. *Z-ratios* greater than 1.96 or less than -1.96 imply statistical significance.
Source: USDA, Economic Research Service.

Model adjustment speed

We have written about the longrun relationship among the four prices implied by the unit roots and the gross-margin equation. The longrun relationships are theoretical concepts. Each week, the exogenous variables changed, as did the *u* errors; these changes changed the longrun values of the four prices. One way to figure out what the longrun values of the prices were for a given week was to simulate their values for the future assuming that the exogenous variables do not change and that the future error terms are 0. We simulated by using this week's prices to forecast next week's prices with the same exogenous variables and no errors; we then used that forecast to forecast two weeks out, and so on. There are also ways to directly calculate the full-adjustment values, although the math is more difficult.

One of the advantages of using the simulation method is that you can see how quickly prices adjust to their longrun relationships. In general, adjustment is quite slow. Even after 64 weeks (a year is 52 weeks and a day or two), prices are only 84-percent adjusted. The gross-margin relationship adjusts more quickly. In 14 weeks, gross-margin adjustment will be over 99 percent completed. The gross-margin relationship is more powerful than the unit-root effect in keeping the four prices aligned with one another.