Annual Review of Resource Economics

Price Transmission in Agricultural Markets

Stephan von Cramon-Taubadel[1]
and Barry K. Goodwin[2]

[1]Department of Agricultural Economics and Rural Development, University of Göttingen, 37073 Göttingen, Germany

[2]Department of Economics and Department of Agricultural and Resource Economics, North Carolina State University, Raleigh, North Carolina 27695, USA;
email: barry_goodwin@ncsu.edu

Annu. Rev. Resour. Econ. 2021. 13:65–84

First published as a Review in Advance on June 15, 2021

The *Annual Review of Resource Economics* is online at resource.annualreviews.org

https://doi.org/10.1146/annurev-resource-100518-093938

JEL codes: C580, F020

Keywords

law of one price, spatial market integration, vertical price transmission

Abstract

We review recent developments in the analysis of price transmission in agricultural markets. Markets may be separated in time, form, and space (as well as in combinations of such factors). Transactions and storage costs as well as production and marketing factors delineate these markets. We show that much of the research on spatial market linkages has reflected methodological advances that have led to increasingly nonlinear time-series models. Advances in the theoretical and empirical literature over the last few decades have demonstrated that price relationships in the food chain are highly context specific. Improvements in marketing, information, and transportation technology have strengthened the links between prices in the food system, but at the same time links in the food chain are increasingly subject to vertical coordination and, thus, less visible to outside observers, including researchers.

> In a single market, all of these price structures are interrelated and simultaneously determined through transfer costs, processing costs, and storage costs. Thus, there is not a single price for a particular commodity at the farm level but a complex structure of prices reflecting geographic differences, form differences, and time differences.
>
> —Bressler & King (1970, p. 84)

INTRODUCTION

An enormous literature has addressed the functioning of markets that are separated by space, form, and time. Commodity exchange across space, product form, and time serves to limit the potential for prices at different points along the market chain to drift arbitrarily far apart. In the case of markets that are spatially separated, trade over space is the key mechanism that links them. In the case of market form, issues relating to vertical integration, value added, and commodity processing are relevant. Finally, storage is the key mechanism for linking prices together and allowing temporal trade.

In all cases, arbitrage, or the pursuit of riskless profits, is the underlying economic mechanism that maintains linkages and disciplines departures from equilibrium. If prices in one dimension of the market (e.g., a regional market, farm-level markets, current and future spot prices) exceed arbitrage costs, rational agents will act to eliminate excessive price differences by buying in markets where prices are low and transferring or transforming the commodity to a market or form where prices are high. Price transmission refers to the extent to which localized or exogenous shocks in one market tend to generate effects in other markets. Our goal is to review recent developments in the study of price transmission. Our review is neither comprehensive nor nonrepetitive, since the relevant literature is immense and the concept of price transmission underlies the functioning of markets in nearly every consideration.

Spatial market integration involves linkages among markets separated by distance. This fundamental axiom is often stated as the law of one price (LOP). The LOP maintains that the actions of profit-seeking traders will lead to a long-run equilibrium whereby price differences should be no more than the costs of spatial arbitrage—typically comprising the transaction costs associated with spatial trade. Transport costs are an obvious component of spatial transaction costs. However, other factors such as risk premia, insurance, market research, contracting, loading and off-loading fees, and demurrage may be relevant to the overall costs of conducting spatial trade.

There is a fundamental and ultimately unresolvable tension between farmers' interest in high prices for the raw products that they sell and consumers' interest in low prices for the food that they consume. The relative weights that policy makers apply to these interests vary over time and space. The food price crisis of 2007–2008 focused attention on food price inflation and consumer interests (FAO 2009) as peaking food prices reduced food security in many countries, leading to unrest and even contributing to regime change in some (Bellemare 2015).

More recently, in contrast, some observers have claimed that intensive price competition in the food chain in Germany and other European countries has turned food into a discount product and that consumers no longer value food sufficiently. They allege that this shift encourages food waste and ultimately puts pressure on farmers upstream to produce in ways that are detrimental to the environment and animal welfare. This has led to calls for policy responses such as the recently adopted European Union directive on unfair trading practices in business-to-business relationships in the agricultural and food supply chain [Council Directive 633, 2019 (L 111/59)]. A ubiquitous issue, regardless of whether food prices are considered to be too high or too low, is the concern that farmers and/or consumers at their respective ends of the food chain may be disadvantaged by the exertion of market power by concentrated food processing and retailing industries.

At first glance, it may seem somewhat incongruous to also think about the LOP in a vertical context. The standard definition of the LOP (the prices for an identical good at different locations will differ by no more than the costs of trading the good between those locations; Fackler & Goodwin 2001) refers to equilibrium price relationships in space. In a vertical context, the goods being studied are rarely identical; as the product moves along the chain from farm to fork, there will invariably be an element of physical transformation, or at least the addition of services such as sorting, grading, traceability, and certification. Of course, the spatial equilibrium condition is only one manifestation of the fundamental principle that economic actors will take advantage of opportunities to generate profits. A generalization of the LOP that subsumes the spatial equilibrium condition is that all prices for a commodity are related over time, space, and product form (Blank & Schmiesing 1988, p. 35; see also the above formulation by Bressler & King 1970).

The spatial equilibrium condition is comparatively straightforward because spatial transformation involves the fixed-proportions combination of the product in question and a transportation input that is typically assumed to be in perfectly elastic supply. Identifying an opportunity for spatial arbitrage can be as simple as comparing product prices at two locations and freight rates between them; in principle, anyone with sufficient liquidity can take advantage of such an opportunity.

In the vertical dimension, the relationship between prices at different levels of the food chain will depend on often complex processing technologies, product differentiation, and the prices and market conditions for (multiple) other inputs. Arbitrage takes place when consumers compare prices across brands or in different stores, and when processors compare sources of supply for agricultural raw products. But identifying opportunities to arbitrage the value added in a link of the food chain will generally be more difficult. Such opportunities will often involve some degree of product transformation and hence require processing facilities, fixed costs, and specialized inputs with limited alternative uses.

The concept of spatial market integration plays a critical role in international trade. Border policies, international trade policies, language and customs differences, and many other factors may lead to situations where local prices diverge from international prices, thereby violating the LOP. When evaluated using aggregate prices, this law is often referred to as purchasing power parity (PPP). This principle plays an important role in the determination of exchange rates and the interactions among domestic monetary policies and the international market. A seminal contribution to the evaluation of spatial price transmission is that by Mundlak & Larson (1992), who found that world agricultural price shocks are generally transmitted to domestic markets. The economic phenomenon being empirically tested in international markets is exactly the same for evaluations in spatially distinct markets existing within an economy. Empirical studies of spatial market efficiency have generally used some form of correlation or regression of one price on another (see Fackler & Goodwin 2001 for a comprehensive overview of the methodology applied and markets examined in empirical evaluations of spatial market integration or the LOP).

In this article, we review recent developments in the study of price transmission. We focus mainly on two aspects of price transmission: spatial and vertical linkages. Temporal linkages involving storage are at least as important but involve a wider variety of issues than those typically covered within the context of simple price transmission (for a comprehensive review of models of commodity storage, see Williams & Wright 1991). Our review considers important foundational research but focuses on the most recent literature.

Comprehensive but dated surveys of spatial market integration have been presented by Fackler & Goodwin (2001) and Frey & Manera (2007). Meyer & von Cramon-Taubadel (2004) review the literature on asymmetric vertical price adjustments. More recently, Lloyd (2017) has provided an

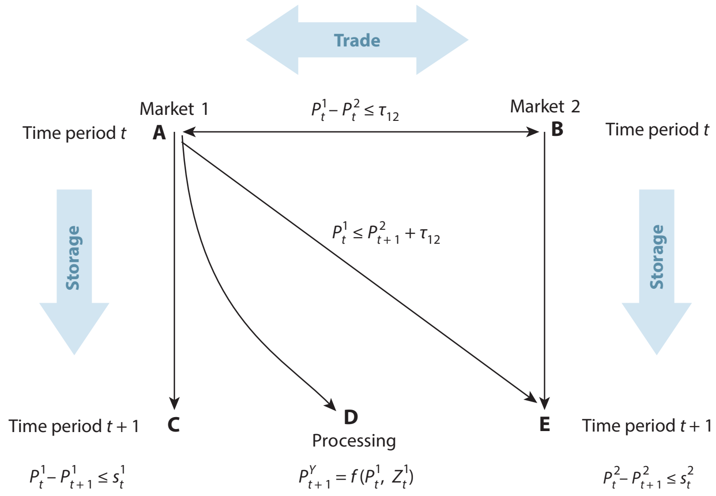

Figure 1

Modes of price transmission. Space is represented in the horizontal plane and time by vertical movement. Segment AB represents contemporaneous trade. Segments AC and BE represent temporal linkages between times t and $t + 1$. Segment AE represents spatial arbitrage conditions that involve noncontemporaneous price linkages. Curve AD represents the equilibrium condition implied by a transformation of a commodity. P_t^i represents the price of a commodity in market i in time period t. s_t^i represents the cost of storing the commodity for a single period. τ_{12} is the cost of transferring the commodity from market 1 to 2 (or vice versa). Z_t represents inputs used to modify the product form.

excellent overview of issues in vertical price transmission in the food industry. We hope to update and add to the insights presented in these studies.

CONCEPTUAL ISSUES

Most empirical evaluations of price transmission involve tests of some version of the following arbitrage condition:

$$P_t^1 - P_t^2 \leq \tau_{12}, \qquad 1.$$

where P_t^i represents the price of a commodity or product in market i at time t and τ_{12} represents the costs of transporting, transforming, or storing the commodity. A price transmission elasticity is usually expressed as $[(\partial P_t^i)/P_t^i]/[(\partial P_t^j)/P_t^j]$ (or $\partial p_t^i/\partial p_t^j$, where prices are in logarithmic terms, as is typically the case in empirical applications). **Figure 1** illustrates the nature of price linkages over space, time, and product form. In the figure, space is represented in the horizontal plane, while time is illustrated by vertical movement. Of course, time only moves forward. Segment AB represents contemporaneous trade, that is, trade that can be accomplished within the period of reference. This case represents the commonly tested price linkage in studies of spatial market integration. In this case, the relevant arbitrage condition binding markets is that given by Equation 1. The difference between contemporaneous prices at two different locations should be no more than the costs of arranging contemporaneous trade τ_{12}.

Segments AC and BE in **Figure 1** represent temporal linkages between times t and $t + 1$. In this case, prices should differ by no more than the costs of storing the commodity for a single time period s_t^i. In an environment of imperfect information, prices at a future date are unlikely to be known with certainty; thus, the actual arbitrage condition involves a conditional expectation of the price expected to be realized at time $t + 1$. This is a common arbitrage condition evaluated in a wide variety of studies of the efficiency of futures and forward markets. The exact arbitrage condition would be better written as $P_t^i - E(P_{t+1}^i|\Omega_t) \leq s_t^i$, where Ω_t represents the information set available to agents at time t. The difference between current and expected futures prices and storage costs should be orthogonal to all information available to agents at time t.

A few studies (Goodwin et al. 1990a,b) have noted that delivery lags that extend beyond a single time period may imply arbitrage conditions that involve noncontemporaneous price linkages, represented by segment AE in **Figure 1**. In this case, the relevant arbitrage condition has both spatial and temporal elements and becomes $P_t^i - E(P_{t+1}^i|\Omega_{ti}) \leq \tau_{12}$, which in turn, implies arbitrage conditions that involve comparisons of transaction costs and storage costs. In particular, arbitrage should ensure that, if markets are perfectly competitive, the costs of transporting a commodity between markets over the period t to $t+1$ should be bound to the costs of storing the commodity in a single market. This, in turn, implies arbitrage equilibrium conditions that link future prices in both markets: $E(P_{t+1}^1 - P_{t+1}^2)|\Omega_t) \leq \tau_{12}$.

Finally, curve AD in **Figure 1** represents the equilibrium condition implied by a transformation of a commodity, say, from the wholesale to the retail level. The equilibrium condition represents vertical price transmission, which may involve a production function that provides value added, represented by $f(P_t^1, Z_t)$, where Z_t represents other inputs used to modify the product form. Such inputs could include typical production and marketing inputs, such as labor and machinery, as well as aspects of transport and storage costs. In the case of vertical price transmission, the underlying arbitrage condition becomes much less clear, though by no means less interesting. To the extent that production and marketing margin inputs can be substituted for the commodity at one market level, the relationships among prices at different levels of the market become even less clear and may depend upon prices for the inputs used in the transformation process.

Empirical studies of price transmission have generally used some form of correlation or regression of one price on another. In recent years, the literature analyzing this phenomenon has focused on models capable of empirically representing regime change and mean-shifting behavior. This regime-changing and mean-shifting behavior is often thought to reflect the influences of unobserved transactions or processing costs, which have been represented through the application of various specifications and econometric techniques (e.g., Taylor 2001; Ng & Vogelsang 2002; Enders & Holt 2012, 2014; Teräsvirta & Holt 2012). The intent of such models has been to empirically account for the transactions, storage, and production costs associated with spatial, temporal, and vertical price arbitrage.

In its simplest form, the arbitrage condition represented in **Figure 1** may suggest one regime when the condition holds as an equality and another that pertains to the inequality representing a lack of profitable arbitrage. These models are often termed trade/no-trade or arbitrage/no-arbitrage models, where the two conditions suggest different regimes in price linkages. The idea of such regime change is not new. Heckscher (1916) noted the presence of "commodity points" that delineate the alternative regimes.[1] These commodity points are equivalent to transactions and storage costs.

SPATIAL MARKET INTEGRATION

The integration of markets across space has been the focus of a large body of research. Spatial integration is of interest not only in its own right (i.e., as a characteristic of market performance)

[1] For example, Heckscher (1916) observed the importance of commodity points, resulting from transportation costs, and their similarity to the gold points in species flow mechanisms (see Obstfeld & Taylor 1997 for a discussion of Heckscher's views on transaction costs and PPP).

but also as an ancillary measure of various characteristics of market infrastructure as well as an input into understanding deeper aspects of the impacts on markets of domestic and trade policies, imperfect competition, investment flows, income distribution, environmental externalities, and financial market linkages. Jensen & Miller (2018) note that a lack of integration limits firms' market size and therefore leaves consumers unaware of the prices and qualities of nonlocal firms.

Much of this research appears in the international development literature, where spatial integration is taken to be a measure of the overall functional aspects of market transactions over space. A weak infrastructure such as that involving roads, rail transport, and communication may inhibit the efficient transmission of information across markets delineated by space and/or national boundaries. For example, Donaldson (2018) demonstrates that the introduction of railroads in colonial India decreased trade costs, reduced interregional price differences, increased trade, and increased incomes and social welfare. At the most fundamental level, market integration is a critical factor determining the gains from trade and any concomitant social welfare losses that result from market inefficiencies (however efficiency is defined).

Perfect spatial integration is often taken to be an indicator of full efficiency of the marketplace. However, as Fackler & Goodwin (2001) have noted, a precise definition of efficiency in the price transmission literature is elusive, and the characterization of empirical results as confirming such efficiency has led to substantial confusion in the extensive literature measuring integration. Integration, or transmission of shocks across spatially distinct markets, is best considered in terms of the degree of adherence to fully efficient markets and not as a discrete, absolute concept. Likewise, as McCloskey (1985) has noted, a consideration of only the statistical properties of an empirical test of integration may lead to fallacious rejections of the theoretical properties of interest.

Barrett & Li (2002) consider actual trade flows as an indicator of spatial market integration. They argue that empirical tests should distinguish the concept of spatial market integration from that of a competitive market equilibrium. The latter concept is reflected in market conditions whereby no trade occurs because arbitrage conditions do not permit profitable trade. The authors note that prices in two segmented markets may respond to exogenous drivers such as inflation or climatic conditions without actually representing a spatial equilibrium in markets. They augment the regime-switching methods of Baulch (1997), Spiller & Wood (1988), and Sexton et al. (1991) to distinguish trade/no-trade equilibria and to incorporate physical trade flow data. These arguments are persuasive but seem to take an excessively rigid view of market integration. For example, a discernible flow of commodity between two vendors selling fresh produce in the same farmers' market is unlikely to be observed, despite the fact that these traders are certainly, by any definition, part of a well-integrated market.

A recent World Bank overview outlines many of the factors that affect the spatial integration of markets (Rebello 2020). This overview notes that international market integration involves cooperation among policy makers on trade and investment policies, migration, transportation infrastructure, macroeconomic policy, natural resource policy, and other aspects of "shared sovereignty." It also notes that regional integration may be a critical component of policy reforms and as such may contribute to overall peace and security.

A somewhat dated survey of the methodological aspects of studies of spatial market integration is that by Rapsomanikis et al. (2003). They note that market integration studies, which they also term "price transmission" studies, assess a collection of factors thought to be relevant to linkages among prices in spatially distinct markets. The obvious factor is that of transport and transaction costs. They also note that market power may have important implications for linkages among markets over space. In particular, if large sellers or buyers are able to exercise spatial price discrimination, then spatial price linkages may be affected. An interesting footnote to this market power argument is that its exercise may result in prices being either held apart, through price discrimination, or forced together, because of illegal coordination in price fixing among competing sellers or buyers. This necessarily means that any interpretation of results depends on a deeper understanding of the particularities of the market in question.

Most empirical studies of spatial market integration utilize regression procedures to model the long-run relationship among prices given by Equation 1 (e.g., Richardson 1978):

$$p_t^1 = \alpha + \beta p_t^2 + \epsilon_t, \qquad 2.$$

where p_t^i represents prices (usually in logarithmic terms) in market i in time period t.[2] Perfect market integration holds if $\alpha = 0$ and $\beta = 1$. When prices are given in logarithmic terms, β represents the price transmission elasticity. In an allowance for transaction costs, which typically are empirically unobservable, α is often assumed to represent the additive or proportional (when in logarithms) transaction costs.[3]

Note the important difference in the theoretical arbitrage condition given by Equations 1 and 2. The former allows for the no-arbitrage condition that exists when Equation 1 holds as an inequality (i.e., when price differences are less than the costs of arbitrage). The existence of different regimes representing two different states of the market relationship, with one given by profitable trade and the other given by a lack of arbitrage opportunities, has given rise to more modern approaches that allow for regime switching and other nonlinear representations of integration.

Rapsomanikis et al. (2003) present an overview of the typical approach to the modern analysis of spatial market integration: the error correction model. If, as is typically the case, nominal prices are nonstationary but cointegrated (i.e., linked together in a long-run equilibrium), then the empirical relationship among a pair or group of prices can be evaluated using an error correction model of the form

$$\Delta p_t = \Pi p_{t-1} + \sum_{i=1}^{j} \Gamma_s \Delta p_{t-i} + \beta d_t + \epsilon_t, \qquad 3.$$

where p represents a vector of prices for a homogeneous good in spatially distinct markets; d is a set of deterministic variables; Π, Γ, and β are parameter matrices; and ϵ is a vector of random disturbance terms. Πp_{t-1} represents a linear (or nonlinear) combination of the prices that represents a long-run equilibrium relationship (i.e., cointegration).

The movement toward representing transaction costs and switching regimes using nonlinear models has largely reflected applications of the threshold modeling techniques of Balke & Fomby (1997) and the analogous smooth transition (STAR) models of Teräsvirta (1994). Such models appeal to the notion that transaction costs and other barriers to spatial trade may result in regime switching, with alternative regimes representing the trade/no-trade equilibria. Threshold models involve discrete changes among regimes, while STAR models allow the switching to be gradual.

A common approach to threshold modeling often involves a simple autoregressive model of the price differential. This model was applied by Goodwin & Piggott (2001) in an examination of grain prices at local markets. This specification is given by

$$\Delta y_t = (\lambda_0^1 + \lambda_1^1 y_{t-1}) I_A(y_{t-1} \le c_i) + [1 - I_A(y_{t-1} \le c_i)](\lambda_0^2 + \lambda_1^2 y_{t-1}) + \epsilon_t, \qquad 4.$$

---

[2]The distinction between tests of prices in levels versus logarithms is related to the nature of transaction costs and other impediments to trade. When prices are considered in logarithmic terms, these frictions are portrayed in proportional (to price) terms. When prices are in levels, the differentials are in absolute level terms. Proportional transport costs are often called iceberg costs, making the analogy of a certain proportion of the commodity "melting" in transit. Bosker & Buringh (2020) note that iceberg costs remain the standard in models of trade and economic geography.

[3]Even when shipping charges are observable (as in the case of Goodwin et al. 1990b), transaction costs will typically involve other unobservable factors, as noted above.

where Δy_t is the differenced value of the price differential for two spatially distinct prices ($y_t = p_t^1 - p_t^2$), $I_A(\cdot)$ is the indicator function, c_i is a threshold value, and (λ_i^j) is the ith parameter for regime j. A test for nonlinearity involves the null hypothesis that $\lambda_k^j = \lambda_k^l$ for $k = 1, \ldots, p$. The threshold parameter c_i is often taken as an indirect representation of the unobservable transaction costs. If the price differential exceeds transaction costs, spatial trade becomes profitable and arbitrage should lower the differential such that it no longer exceeds the costs of trade. In this framework, one typically expects to see different values of the parameter governing the adjustment process. When the differential falls within the transaction cost band (i.e., its absolute value is less than the threshold parameter c_i), the adjustment parameter λ_1^1 can assume any spurious value and is often fixed at zero, which implies a random walk for price differentials within the band. In contrast, outside the transaction cost band, the adjustment parameter λ_1^2 indicates the speed of adjustment of prices to eliminate differentials that exceed the transaction cost band. One expects to see a significant negative adjustment parameter. The greater is the magnitude of λ_1^2, the faster the price differentials are reduced.[4]

Following the same logic, a somewhat richer model expands the vector error correction model given by Equation 3 to include thresholds. Doing so allows for a more flexible evaluation of the dynamics of adjustment for individual prices. This approach was also applied by Goodwin & Piggott (2001). A threshold vector error correction representation of a collection of prices for spatially distinct markets can be written as

$$\Delta y_t = \begin{cases} \sum_{i=1}^{p} \gamma_i^{(1)} \Delta y_{t-i} + \theta^{(1)} \nu_{t-1} + \epsilon_t^{(1)} & \text{if} \quad |\nu_{t-1}| \leq c_i \\ \sum_{i=1}^{q} \gamma_i^{(2)} \Delta y_{t-i} + \theta^{(2)} \nu_{t-1} + \epsilon_t^{(2)} & \text{if} \quad |\nu_{t-1}| > c_i, \end{cases} \qquad 5.$$

where ϵ_t is a mean zero residual, ν_{t-1} is a lagged equilibrium error term that represents departures from equilibrium parity conditions, and c_i is again a threshold parameter that separates regimes.[5]

Threshold models can be expanded to consider multiple regimes, given that sufficient data are available to identify the multiple regimes. Again, STAR models may be used to allow for more gradual change, and a variety of nonlinear methods have permitted regime switching to be modeled in a more flexible form. These extensions to the basic threshold model again represent the transition in the literature from simple linear models to increasingly nonlinear models. When the regime switches are discrete (as opposed to gradual), the models are linear in parameters but represent a nonlinear path of price adjustment as the system switches among regimes throughout the time path of prices.

Recent empirical research on spatial market integration has pushed the trend toward nonlinear models to the extreme by considering fully nonparametric models. For example, Guney et al. (2019) and Goodwin et al. (2021) apply the generalized additive models of Wood (2004) to empirical considerations of price transmission and spatial market integration. This approach utilizes a version of Equation 1 that includes parametric and nonparametric terms as regressors:

$$E(y) \equiv \mu, \qquad 6.$$

[4]Note that this speed of adjustment is often expressed in terms of the regression half-life, which corresponds to the time required for one-half of the deviation from parity conditions to dissipate. The half-life is given by $\ln(0.5)/\ln \lambda_1^2$.

[5]The error term ν_t is typically given by deviations from a long-run equilibrium, such as residuals from a cointegration regression, or some other variable representing deviations from parity, such as the price differential. The variable that defines alternative regimes is often termed the forcing variable, reflecting the fact that its values force the system to switch between the alternative regimes.

and

$$g(\mu) \equiv \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k + s_1(x_{k+1}) + \cdots + s_p(x_p) + \epsilon, \tag{7}$$

where ϵ is assumed to follow a specific parametric distribution, $g(\cdot)$ is a monotonic link function, and $s(\cdot)$ represents smoothed nonparametric functions of the covariates. Such additive models may contain the smoothed functions alone or may include combinations of linear and smoothed covariate terms. The smoothing functions are typically nonparametric and may be represented by local linear regressions, nonparametric kernel regressions, or nonlinear splines. Penalized regression or maximum likelihood estimation methods must be used in order to control the degree of smoothness in the nonparametric functions. Generalized or multifold cross-validation methods are typically used to select an optimal bandwidth or spline penalty function. The smoothing functions are defined by the data and lack any fixed structure outside of the extent of smoothing defined by bandwidth or regression penalty parameters. This lack of structure allows for a highly nonlinear representation of the relationships among prices and the implied patterns of adjustment to deviations from equilibrium parity conditions. Guney et al. (2019) and Goodwin et al. (2021) use linear link functions, such that $g(\mu) = \mu = E(y)$.

Nonlinear models may be difficult to interpret on the basis of parametric or nonparametric functions alone. An intuitive interpretation of the estimates can be obtained by shocking each price independently (or jointly) and tracing the dynamic paths of adjustments as the shock filters through the system. These dynamic patterns of adjustment in nonlinear models are typically described using some version of a generalized impulse response function (GIRF). With such nonlinear models, the nature of such responses may depend upon the timing, size, and direction of the shock. That is, different patterns of adjustment may result from alternatively sized and signed shocks. Likewise, the timing of the shock in the history of prices may also influence the resulting path of adjustment. In contrast, shocks in a linear model will result in the same path of adjustment, regardless of their size, direction, and timing.

A generalized impulse is given by

$$\mathrm{GIRF}(Y_{it+j}) = E(Y_{t+k}|Y_t + \eta, \ldots Y_{t-j}) - E(Y_{t+k}|Y_t, \ldots Y_{t-j}), \tag{8}$$

where η represents a random or deterministic shock to the dependent variable. As Koop et al. (1996) note, a variety of generalizations of standard impulse responses can be considered for nonlinear models. The most comprehensive approach involves sampling from the residuals or from a given distribution to generate random shocks and sampling from the estimation data over different time periods. This process is repeated and the resulting impulses are aggregated through averaging or consideration of given percentiles of the distribution. In the case of models that are costly to estimate, as is the case for generalized additive models, an abbreviated version of the sampling may be considered. In evaluations of market integration, GIRFs provide a representation of the dynamic patterns of adjustment over the period following localized market shocks.

Empirical studies of spatial market integration are typically conducted using daily, weekly, or monthly prices. In rare cases (e.g., Froot et al. 1995), annual price data may be used. The appropriateness of the time dimension of a particular set of price data essentially depends upon the time dimension of the associated spatial trade and arbitrage behavior thought to discipline markets so as to prevent persistent arbitrage possibilities. If spatial trade can be accomplished within the day, then contemporaneous daily prices should display the appropriate parity conditions and more finely sampled price data will be required to examine the dynamics of adjustment. The use of monthly prices in such a case would be less informative.

Most time-series analyses consider the persistence of price deviations over time. Aggregated prices, even within the day, will typically reflect numerous discrete trades, so a degree of aggregation is always likely. Because market price quotes typically involve timewise aggregation, any specific price quote is likely to embed trading behavior that persists across observations. The greater the degree of temporal aggregation and the shorter the time required for arbitrage, the less revealing such empirical tests are likely to be.

The fundamental point is that one should consider the underlying functioning of market linkages across space and time when evaluating the appropriateness of temporally aggregated price data in evaluating spatial market integration. An important consideration in this regard is the type of aggregation used: average-over-period or skip (e.g., end-of-period) sampling. Ghysels & Miller (2015) study how both types of aggregation affect the results of cointegration tests. Otherwise, this issue—despite its obvious implications for the estimation and interpretation of spatial (and vertical) price relationships—has received little attention, especially in the applied literature.

VERTICAL PRICE TRANSMISSION: THEORETICAL FRAMEWORK

At a sufficient level of abstraction, there is no fundamental difference between the spatial and vertical dimensions of the LOP, but the vertical dimension is inherently more complex. This is not meant to suggest that spatial price relationships are simple; spatial equilibrium conditions rapidly become complex when one moves beyond the simple two-location case (McNew & Fackler 1997). In addition, most instances of price transmission in the real world combine the spatial and vertical dimensions (**Figure 1**).

The theoretical foundation for the analysis of vertical price relations was laid by Muth (1964) and Gardner (1975), on the basis of earlier research by Bronfenbrenner (1961) and Marshall (1890). Their basic equilibrium displacement model assumes an industry consisting of a group of firms that process two inputs under constant returns to scale technology to produce a single, homogeneous industry output. The firms have identical production functions that allow for input substitution, and they are price takers in both the input and output markets. While Muth's (1964) discussion is general (with the exception of an application to housing and urban land economics toward the end of the paper), in Gardner's (1975) seminal paper the inputs are an agricultural raw product and a marketing input, and the industry output is a retail food product.[6]

Gardner (1975) uses his model to generate elasticities of transmission between the farm price of the agricultural raw product and the retail price of the food product, as well as to study the effects of shocks on the ratio of the retail food price to the agricultural input price. A key insight is that there is more than one elasticity of vertical price transmission, depending on whether the prices are reacting to a shift in the supply of the agricultural raw product, a shift in the supply of the marketing input, or a shift in demand for the retail food product.[7] In all three cases, the elasticity of the output price with respect to the price of the agricultural input is expected to be positive but less than one under normal conditions (i.e., a negative price elasticity of demand for the food output and positive price elasticities of supply for the agricultural and marketing inputs, with the former being smaller than the latter).

Kinnucan & Zhang (2015, p. 729) point out that "there appears to be some confusion in the literature" over this result, citing several authors who argue that the elasticity of price transmission

[6]Gardner (1975) points out that all of the results that he derives can also be derived graphically (as done in, e.g., chapter 6 of Tomek & Robinson 1981) under the assumption of fixed-proportions production technology in food processing.

[7]Miedema (1976) extends Muth's and Gardner's models to consider the effects of technical change in the processors' production function on the retail–farm price ratio, a point that is further developed by Kinnucan & Zhang (2015).

between farm and retail prices should equal exactly one under perfect competition. Kinnucan & Zhang (2015) present the (unlikely) conditions under which this will be the case, and they extend the model to explore the effects of shock on the absolute (as opposed to the relative) marketing margin. In addition, they discuss several implications for empirical analysis, including the point that failure to account for shifts in the supply of marketing inputs, or changes in processing technology, will lead to biased estimates of the elasticity of transmission between farm input and food product prices. Thus, one must be wary of empirical analyses that only consider bivariate relationships between input and output prices without accounting for simultaneous changes in other factors (see also Lloyd 2017). This is essentially analogous to the point that failure to account for changes in transport costs will lead to biased estimates of the elasticities of spatial price transmission; in terms of the Muth–Gardner model, spatial arbitrage involves combining an agricultural input at one location with a marketing input (transportation services) to produce an output at another location.

EXTENSIONS OF THE MUTH–GARDNER MODEL AND MARKET POWER IN THE FOOD CHAIN

Concentration is high and increasing in the food processing and retailing industries in industrialized and many emerging economies (OECD 2014, Sexton & Xia 2018). Consistent data for low-income countries are harder to come by, but concentration in food retail is increasing there as well (Reardon et al. 2003), and farther upstream farmers often transact with traders who have information advantages and local market power (e.g., Piyapromdee et al. 2014).

For this reason, many authors have extended the Muth–Gardner model to include imperfect competition by incorporating conjectural variations. Important studies in this literature include those by Holloway (1991) and McCorriston et al. (1998), who assume that the food processing firms are able to exert oligopoly power vis-à-vis food consumers, and Weldegebriel (2004), who assumes that they are also able to exert oligopsony power vis-à-vis the suppliers of the agricultural raw product. McCorriston et al. (2001) combine oligopoly power and nonconstant returns to scale in a Gardner-type model, and Wang et al. (2006) add nonconstant returns to scale to Weldegebriel's (2004) extension that allows the food processing firms to exert both oligopoly and oligopsony power.

The motivation for these studies is clear. Comprehensive investigations by competition authorities into the possible exertion of market power in the food chain are often time-consuming and costly. If the exertion of market power left a clear, unambiguous signature in price data, then comparatively simple tests could reduce the costs of these investigations or at least serve as a first-pass means of identifying cases that deserve closer scrutiny (Lloyd et al. 2009).

However, the main result of the studies outlined above is that market power alone and in combination with nonconstant returns to scale has complex effects on vertical price transmission. If food processing firms are able to exert both oligopoly and oligopsony power, then the elasticity of vertical price transmission can be both larger and smaller than in the perfectly competitive benchmark, depending on market parameters and the exact functional forms of retail demand and farm input supply. Nonconstant returns to scale can either enhance or counter the effects of market power.

This complexity makes it difficult to draw conclusions about the presence of market power from the results of time-series-based estimates of elasticities of vertical price transmission. Brümmer et al. (2009), for example, estimate the elasticity of price transmission between wheat and flour prices in the Ukraine to be 0.81, which is very close to the value of roughly 0.8 that is predicted by the Gardner model under conditions of perfect competition and given plausible estimates of market parameters for wheat and flour in Ukraine. However, this result cannot be interpreted as confirmation that the Ukrainian milling industry is perfectly competitive, because the estimated value of 0.81 could be the net result of market power (and possibly scale) effects and might just happen to be close to the perfectly competitive benchmark.[8] Furthermore, Brümmer et al. (2009) do not account for possible changes in marketing costs or processing technology in their empirical analysis.[9] As Weldegebriel (2004, p. 113) concludes, "it is not generally possible to attribute low (or high) values of the price transmission coefficient to market power."

Despite this overall pessimistic conclusion, several studies have used the Muth–Gardner framework to develop tests for market power. Kinnucan & Zhang (2015) propose a test based on the result that under perfect competition, and if the supply of marketing inputs is perfectly elastic, shifts in the supply of the farm input or the demand for the retail food product have no effect on the absolute marketing margin. Thus, the finding that farm supply and/or retail demand shifters have significant effects on the absolute marketing margin can be considered prima facie evidence of market power. Kinnucan & Tadjion (2014) apply this test to pork and beef markets in the USA, and Lloyd et al. (2009) apply a similar test to nine products in the United Kingdom.[10]

DYNAMIC RESPONSES: THE SPEED AND SYMMETRY OF VERTICAL PRICE TRANSMISSION

The literature discussed above focuses on long-run relationships between the levels of prices in the food chain—typically summarized in the form of elasticities of vertical price transmission. Following Vavra & Goodwin (2005, pp. 5–6), this long-run price transmission can be termed the magnitude of a price response at one level of the food chain to a shock at another level. Speed (how long it takes for a price response of a given magnitude to unfold) and especially symmetry (whether the magnitude or speed of a price response at one level depends on the direction of the shock that has occurred at another level) are two additional, dynamic dimensions of vertical price transmission that have attracted considerable attention in the literature.

In particular, the concept of rockets and feathers asymmetry, whereby increases in upstream prices are passed on more rapidly to consumers than decreases, has generated numerous empirical studies.[11] At first glance, it is plausible that actors in a chain who have market power might use it to pass on price increases for agricultural inputs (which squeeze their margins) more rapidly than price decreases (which stretch their margins), and many farmers and consumers are convinced that this is indeed taking place.

However, while it is conceivable that processing firms or retailers might collude to impose rockets and feathers asymmetry on price transmission in a food chain, we are aware of no formal model that predicts a specific pattern of asymmetric pricing as an optimal expression of market power. If firms are able to collude, then why should they not simply permanently stretch the margin rather than attempt to coordinate a complex and possibly difficult-to-monitor sequence

---

[8]According to Latifundist (2019), 10 firms produce 47% of the flour in Ukraine; concentration in regional markets is likely to be considerably higher.

[9]Changes in processing technology can perhaps be ruled out in this case, as Brümmer et al. (2009) analyze only 4 years of weekly price data.

[10]Unlike Kinnucan & Tadjion (2014) and Kinnucan & Zhang (2015), Lloyd et al. (2009) assume fixed-proportions production technology.

[11]Tappata (2009) attributes the first use of the term rockets and feathers to Bacon (1991).

of asymmetric price responses?[12] Furthermore, there are settings in which market power might be expected to lead to the opposite of rockets and feathers. For example, a dominant, financially sound firm in an oligopoly situation might pass on falling input prices more rapidly than rising input prices to restrict the margin and thus maintain pressure on weaker competitors with the objective of ultimately forcing them to exit the market.

Finally, as outlined by Meyer (2004), Vavra & Goodwin (2005), Frey & Manera (2007), and Loy et al. (2016), numerous explanations for asymmetric price transmission that do not depend on market power have been proposed in the literature. These include explanations based on the effects of menu costs in the presence of inflation (Ball & Mankiw 1994) and explanations based on asymmetries in consumers' search behavior depending on whether prices are increasing or decreasing (e.g., Tappata 2009). In addition, empirical findings of asymmetric price transmission can result from a failure to adequately account for the characteristics of price data rather than actual asymmetric pricing behavior by market participants: von Cramon-Taubadel & Meyer (2005) demonstrate that structural breaks in the long-run relationship between two prices can lead to overrejection of the null hypothesis of symmetric price adjustment between them. Tifaoui & von Cramon-Taubadel (2017) show that temporary sales prices in scanner data can have the same effect on tests for asymmetry, creating what appear to be rockets and feathers by virtue of the fact that they themselves (one-period price reductions that are immediately corrected in the next period) are asymmetric.

In summary, there are many possible causes of asymmetric vertical price transmission, but the literature provides few guidelines on how to link empirical findings to specific causes. As a result, many studies do not go beyond presenting empirical tests for asymmetric price transmission and make only general reference to possible causes, for example, citing concentration and market power in the market being studied as a motivation for testing for asymmetry.

In addition, many authors discuss only the statistical significance of the asymmetry that they find, and not its economic relevance, that is, how much slower price adjustment is in one direction than in the other, and what the magnitude of the resulting changes is in revenue/expenditure flows between sellers and buyers. If market power is hypothesized to cause asymmetric pricing in a particular setting, then a comparatively simple "is the game worth the candle" test would be to calculate how much economic benefit the asymmetry generates for those who are allegedly exerting that market power. Findings of asymmetry that are statistically significant but economically irrelevant would indicate that factors other than market power are at play.

A few authors have attempted to generate more general insights into the causes of asymmetric price transmission. Peltzman (2000) follows a two-step approach, first testing for asymmetric price transmission for more than 250 products or product categories (including 120 agricultural and food products) using US data and then relating the test results to proxies for market power, such as Herfindahl–Hirschman indices of concentration. He finds a negative association between retail concentration and asymmetry.

Bakucs et al.'s (2014) meta-analysis follows a similar procedure; however, the first-stage results that they analyze are not their own estimates but rather 101 estimates of vertical price transmission collected from 35 published studies. They regress a dummy variable that indicates whether vertical price transmission is asymmetric on a set of covariates that includes measures of concentration in

[12] Perhaps this would be because they believe that asymmetric pricing behavior is less likely to be noticed by competition authorities. To capture this belief, a formal model would have to account for risk aversion on the part of the oligopolists, the expected penalties associated with being convicted of collusion, and the probability of being convicted as a function of the precise form of the asymmetric pricing behavior.

the food chain and farm fragmentation. Their results confirm Peltzman's (2000) finding that retail concentration is associated with a lower probability of finding asymmetric price transmission. They also find that asymmetry is positively associated with the share of land operated by small farms and negatively associated with the share of land operated by large farms, a finding that the authors interpret as a possible indication of the role of countervailing power and "political clout" (Bakucs et al. 2014, p. 20).

Loy et al. (2016) analyze vertical price transmission for up to 90 brands of milk sold in 327 German retail stores. They find evidence of rockets and feathers asymmetry, the strength of which, however, is negatively related to market power. Since they also find that asymmetry is significantly more prevalent for fluid than for ultrahigh-temperature milk, they conclude that retailers' desire to avoid stock-outs for perishable products might be causing the asymmetry that they measure.

All three of the studies mentioned in the preceding paragraphs look for evidence that market power, search costs, and other factors are related to patterns of asymmetry in large sets of bivariate vertical price transmission regressions. As such, they suffer from the shortcomings of bivariate price transmission analysis mentioned above.

An alternative approach is to estimate structural econometric models for individual food chains in the tradition of the new industrial organization literature. Prominent examples include coffee in the USA (Nakamura & Zerom 2010), potatoes and fluid milk in the USA (Richards et al. 2012), breakfast cereals in the USA (Richards et al. 2014), and fluid milk and dairy desserts in France (Bonnet et al. 2015). These models essentially represent extensions and specific applications of the general framework exemplified by Weldegebriel (2004), augmented by detailed depictions both of consumer demand for the (differentiated) product in question and of processors' and retailers' strategic pricing behavior. The empirical findings of these studies are as varied as the products and modeling approaches used; the magnitude, speed, and symmetry of vertical price transmission depend on industry-specific demand conditions, structures and contractual relations in the chain, and many other factors, and they do not depart from the competitive benchmark in any generalizable manner.[13]

Ultimately, what is at issue in the literature reviewed above is whether the analysis of relationships between prices at different levels of the food chain—long-run elasticities of transmission between them but also dynamic measures of the speed and symmetry of their interactions—is able to generate insights into the performance of the chain. Of particular interest is whether the exercise of market power in concentrated food processing or retail industries leaves tell-tale traces in price transmission, signals that can be extracted by means of appropriate empirical methods. The main conclusion that can be drawn is sobering. Models of long-run vertical price transmission subject to market power generate complex, conditional predictions and empirical results. The available empirical studies suggest that the short-run dynamics of price transmission—despite the appeal of the standard "market power leads to rockets and feathers" narrative—are also complex and influenced by many factors in addition to market power.

---

[13] An extensive literature on asymmetric price transmission in the field of energy economics bears brief mention. Ogbuabor et al. (2019) review more than 40 papers that test for asymmetry in transmission from crude oil to gasoline prices in different countries. Some of these studies attribute asymmetry to market power (e.g., Borenstein et al. 1997). However, earlier than was the case in agricultural economics, this literature developed models of asymmetry based on search costs and differential consumer responses to price increases and decreases (e.g., Johnson 2002, Davis & Hamilton 2004). It is striking that although they employ similar econometric methods and appeal to the same economic theories, the agricultural and energy economic literatures on asymmetric price transmission make very little reference to one another.

Sexton (2013) and Swinnen & Vandeplas (2014) propose models of interactions between farmers and processors in concentrated food chains that account for long-run mutual dependencies due to factors such as sunk investments in specific processing assets, capacity constraints, and product differentiation, subject to different degrees of information asymmetry and the enforceability of contracts. An important implication of these models is that processors with substantial investments in processing capacities will have an incentive to pay farmers sufficiently high prices to ensure that they continue to be reliable suppliers; in other words, processors will not necessarily use their market power to depress prices to farmers below the competitive return (Saitone & Sexton 2017). In some cases of vertically coordinated supply chains, farmers might be even better off in situations in which price transmission is weaker than in the competitive benchmark (Swinnen & Vandeplas 2014).

The implications of these modern agricultural market models for the empirical analysis of vertical price transmission remain largely unexplored. Swinnen & Vandeplas (2014) demonstrate that price transmission is likely to display discontinuities/regime dependence within their framework. This finding suggests that estimation models commonly used in the spatial context, which include threshold and switching effects, could play an important role in future analysis. However, the model that Swinnen & Vandeplas (2014) develop requires detailed data on firm-specific investments and contracting costs that may be hard to obtain.

Furthermore, as vertical coordination in the chain becomes more prevalent, an increasingly large share of transactions will be governed by contracts, leading to residual or even nonexistent spot markets (Adjemian et al. 2016). This has implications for the availability and representativeness of the price data that are used in empirical price transmission analyses. The modern agricultural markets approach pioneered by Sexton (2013) alleviates some concerns about the negative welfare and distributional implications of market power in food chains, but it does not promise to make the analysis of vertical price transmission any simpler or more decisive.

ADDITIONAL ISSUES

There are several additional issues in vertical (and spatial) price transmission that we can mention briefly only in the available space. One of these concerns the implications of estimating price relationships with data that are aggregated over space, time, and/or product form. Wholesale or retail prices that are used in many price transmission analyses often display comovement and dynamic interactions. But the relationship between these interactions and the underlying arbitrage conditions at the individual transaction level are complex and largely unexplored.

Scanner data provide a temporally and spatially high-resolution window on retail food pricing and figure prominently in several recent studies (see discussion in Lloyd 2017). However, scanner data often display characteristics such as stickiness [the fact that many/most $\Delta(p_t) = 0$] and psychological pricing (the fact that most prices end in .99) that call for alternatives to standard cointegration models.

Another important issue that has only been touched upon in the literature on vertical price transmission is joint production. While the Gardner model assumes a single food output, in many cases processing an agricultural raw product leads to more than one marketable output. The transformation of soybeans into oil and meal is a comparatively simple case; the transformation of a slaughter animal into a variety of higher- and lower-quality cuts of meat as well as several by-products such as hide and bones, or the processing of fluid milk into dozens of dairy products, is more complex.

Standard practice in the literature has been to ignore this issue and relate the price of an upstream product to the price of only one of the downstream products into which is it processed.

For example, Kinnucan & Forker (1987) study price transmission from the farm gate price of milk to the prices of four individual retail dairy products in the USA; Serra (2006) does the same for raw milk prices and four retail dairy products in Spain; and von Cramon-Taubadel (1998) studies transmission from producer prices for slaughter pigs to a weighted average price for selected wholesale cuts of pork.

In all of these cases, the estimation equations may be misspecified because price transmission from an agricultural raw product to one of its outputs will likely depend on prices for the other outputs. Borenstein et al. (1997) consider the possibility that the prices of joint refined petroleum products such as heating oil may affect price transmission from crude oil to gasoline, and account for this in their empirical analysis. Houck (1964) and Piggott & Wohlgenant (2002) derive theoretical relationships between the price elasticity of demand for a raw product and the corresponding elasticities for the joint products into which it is processed. To our knowledge, the only attempt to incorporate joint production into a Muth–Gardner equilibrium displacement model and derive interrelated elasticities of vertical price transmission for joint products is that by Antonova (2013).

CONCLUDING REMARKS

The LOP is alive and well in the general sense conveyed in the quote from Bressler & King (1970) at the beginning of this review. However, with the exception of simple cases characterized by homogeneous goods, a high degree of competition, and very straightforward transformation in space, time, or form, its empirical expression remains elusive. Empirical considerations of spatial price transmission, often communicated in terms of the extent of spatial market integration, have been characterized by new methods, especially in a time-series context. These methods have largely involved a move toward nonlinear models, with a progression from discrete thresholds to increasingly flexible nonlinear models.

Recent research has taken this increased flexibility and diminished a priori structure to an extreme level with the application of nonparametric regression models. This increasing degree of nonlinearity is typically motivated as a means of accounting for the effects of unobserved transaction costs. Much of the new research in spatial price linkages addresses infrastructure limitations that often characterize developing markets.

Advances in the literature in recent decades have demonstrated that price relationships in the food chain are highly context specific. The trends toward increasing concentration and vertical coordination in modern food chains mean that spot markets are becoming increasingly thin, making it increasingly difficult to secure the data required to analyze horizontal and vertical price relations. Improvements in marketing, information, and transportation technology have strengthened the links between prices in the food system, but at the same time many parts of the system have been internalized and, thus, less visible to outside viewers, including researchers. The only notable exception to this trend results from the advent of scanner data, which, where they are available at reasonable cost, cast high-resolution light on the final link of the food chain. The literature provides increasingly sophisticated models and empirical methods that are able to generate context-specific estimates of price relationships, but these models and methods place considerable and often unmet demands on the available data.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

Adjemian MK, Saitone TL, Sexton RJ. 2016. A framework to analyze the performance of thinly traded agricultural commodity markets. *Am. J. Agric. Econ.* 98:581–96

Antonova M. 2013. *Theoretical analysis of price transmission: a case of joint production*. PhD Thesis, Univ. Kiel, Kiel, Ger.

Bacon RW. 1991. Rockets and feathers: the asymmetric speed of adjustment of UK retail gasoline prices to cost changes. *Energy Econ.* 13:211–18

Bakucs Z, Fałkowski J, Fertő I. 2014. Does market structure influence price transmission in the agro-food sector? A meta-analysis perspective. *J. Agric. Econ.* 65:1–25

Balke NS, Fomby TB. 1997. Threshold cointegration. *Int. Econ. Rev.* 38:627–45

Ball L, Mankiw NG. 1994. Asymmetric price adjustment and economic fluctuations. *Econ. J.* 104:247–61

Barrett CB, Li JR. 2002. Distinguishing between equilibrium and integration in spatial price analysis. *Am. J. Agric. Econ.* 84:292–307

Baulch B. 1997. Transfer costs, spatial arbitrage, and testing for food market integration. *Am. J. Agric. Econ.* 79:477–87

Bellemare MF. 2015. Rising food prices, food price volatility, and social unrest. *Am. J. Agric. Econ.* 97:1–21

Blank SC, Schmiesing BH. 1988. Modeling of agricultural markets and prices using causality and path analysis. *North Cent. J. Agric. Econ.* 10:35–48

Bonnet C, Corre T, Réquillart V. 2015. Price transmission in food chains: the case of the dairy industry. In *Food Price Dynamics and Price Adjustment in the EU*, ed. S McCorriston. Oxford, UK: Oxford Scholarsh. Online

Borenstein S, Cameron A, Gilbert R. 1997. Do gasoline prices respond asymmetrically to crude oil price changes? *Q. J. Econ.* 112:305–39

Bosker M, Buringh E. 2020. Ice(berg) transport costs. *Econ. J.* 130:1262–87

Bressler RG, King RA. 1970. *Markets, Prices and Interregional Trade*. New York: Wiley

Bronfenbrenner M. 1961. Notes on the elasticity of derived demand. *Oxford Econ. Pap.* 13:254–61

Brümmer B, von Cramon-Taubadel S, Zorya S. 2009. The impact of market and policy instability on price transmission between wheat and flour in Ukraine. *Eur. Rev. Agric. Econ.* 36:203–30

Davis M, Hamilton J. 2004. Why are prices sticky? The dynamics of wholesale gasoline prices. *J. Money Credit Bank.* 36:17–37

Donaldson D. 2018. Railroads of the Raj: estimating the impact of transportation infrastructure. *Am. Econ. Rev.* 108:899–934

Enders W, Holt MT. 2012. Sharp breaks or smooth shifts? An investigation of the evolution of primary commodity prices. *Am. J. Agric. Econ.* 94:659–73

Enders W, Holt MT. 2014. The evolving relationships between agricultural and energy commodity prices: a shifting-mean vector autoregressive analysis. In *The Economics of Food Price Volatility*, ed. J-P Chavas, D Hummels, BD Wright, pp. 135–87. Chicago: Univ. Chicago Press

Fackler PL, Goodwin BK. 2001. Spatial price analysis. In *Handbook of Agricultural Economics*, ed. G Rausser, BL Gardner, pp. 971–1024. Waltham, MA: Elsevier

FAO (Food Agric. Organ.). 2009. *The state of agricultural commodity markets 2009. High food prices and the food crisis: experiences and lessons learned.* Rep., FAO, Rome. **http://www.fao.org/3/i0854e/i0854e00.htm**

Frey G, Manera M. 2007. Econometric models of asymmetric price transmission. *J. Econ. Surv.* 21:349–415

Froot KA, Kim M, Rogoff K. 1995. *The law of one price over 700 years*. NBER Work. Pap. 5132

Gardner BL. 1975. The farm-retail price spread in a competitive food industry. *Am. J. Agric. Econ.* 57:399–409

Ghysels E, Miller JI. 2015. Testing for cointegration with temporally aggregated and mixed-frequency time series. *J. Time Ser. Anal.* 36:797–816

Goodwin BK, Grennes TJ, Wohlgenant MK. 1990a. A revised test of the law of one price using rational price expectations. *Am. J. Agric. Econ.* 72:682–93

Goodwin BK, Grennes T, Wohlgenant MK. 1990b. Testing the law of one price when trade takes time. *J. Int. Money Finance* 9:21–40

Goodwin BK, Holt MT, Prestemon J. 2021. Semi-parametric models of spatial market integration. *Empir. Econ.* **https://doi.org/10.1007/s00181-020-01985-2**

Goodwin BK, Piggott NE. 2001. Spatial market integration in the presence of threshold effects. *Am. J. Agric. Econ.* 83:302–17

Guney S, Goodwin BK, Riquelme A. 2019. Semi-parametric generalized additive vector autoregressive models of spatial basis dynamics. *Am. J. Agric. Econ.* 101:541–62

Heckscher E. 1916. Vaxelkursens grundval vid pappersmyntfot. *Ekon. Tidskr.* 18:309–12

Holloway GJ. 1991. The farm-retail price spread in an imperfectly competitive food industry. *Am. J. Agric. Econ.* 73:979–89

Houck JP. 1964. Price elasticities and joint products. *Am. J. Agric. Econ.* 46:652–56

Jensen R, Miller NH. 2018. Market integration, demand, and the growth of firms: evidence from a natural experiment in India. *Am. Econ. Rev.* 108:3583–625

Johnson RN. 2002. Search costs, lags and prices at the pump. *Rev. Ind. Organ.* 20:33–50

Kinnucan HW, Forker OD. 1987. Asymmetry in farm-retail price transmission for major dairy products. *Am. J. Agric. Econ.* 69:285–92

Kinnucan HW, Tadjion O. 2014. Theoretical restrictions on farm-retail price transmission elasticities: a note. *Agribusiness* 30:278–89

Kinnucan HW, Zhang D. 2015. Notes on farm-retail price transmission and marketing margin behavior. *Agric. Econ.* 46:729–37

Koop G, Pesaran M, Potter SM. 1996. Impulse response analysis in nonlinear multivariate models. *J. Econom.* 74:119–47

Latifundist. 2019. Flour production 2019: Ukraine's market leaders. *Latifundist News*, Febr. 24. **https://latifundist.com/en/novosti/48774-nazvany-top-10-proizvoditelej-muki-v-ukraine-v-2019-g**

Lloyd T. 2017. Forty years of price transmission research in the food industry: insights, challenges and prospects. *J. Agric. Econ.* 68:3–21

Lloyd T, McCorriston S, Morgan W, Rayner A, Weldegebriel H. 2009. Buyer power in U.K. food retailing: a 'first-pass' test. *J. Agric. Food Ind. Organ.* 7:5

Loy JP, Weiss CR, Glauben T. 2016. Asymmetric cost pass-through? Empirical evidence on the role of market power, search and menu costs. *J. Econ. Behav. Organ.* 123:184–92

Marshall AC. 1890. *Principles of Economics*. London: Macmillan

McCloskey D. 1985. The loss function has been mislaid: the rhetoric of significance tests. *Am. Econ. Rev.* 75:201–5

McCorriston S, Morgan CW, Rayner AJ. 1998. Processing technology, market power and price transmission. *J. Agric. Econ.* 49:185–201

McCorriston S, Morgan W, Rayner J. 2001. Price transmission, market power, marketing chain, returns to scale, food industry. *Eur. Rev. Agric. Econ.* 28:143–59

McNew K, Fackler PL. 1997. Testing market equilibrium: Is cointegration informative? *J. Agric. Resour. Econ.* 22:191–207

Meyer J. 2004. Measuring market integration in the presence of transaction costs—a threshold vector error correction approach. *Agric. Econ.* 31:327–34

Meyer J, von Cramon-Taubadel S. 2004. Asymmetric price transmission: a survey. *J. Agric. Econ.* 55:581–611

Miedema AK. 1976. The retail-farm price ratio, the farmer's share, and technical change. *Am. J. Agric. Econ.* 58:750–56

Mundlak Y, Larson D. 1992. On the transmission of world agricultural prices. *World Bank Econ. Rev.* 6:399–422

Muth RF. 1964. The derived demand curve for a productive factor and the industry supply curve. *Oxford Econ. Pap.* 16:221–34

Nakamura E, Zerom D. 2010. Accounting for incomplete pass-through. *Rev. Econ. Stud.* 77:1192–230

Ng S, Vogelsang T. 2002. Forecasting autoregressive time series in the presence of deterministic components. *Econom. J.* 5:196–224

Obstfeld M, Taylor AM. 1997. Nonlinear aspects of goods-market arbitrage and adjustment: Heckscher's commodity points revisited. *J. Jpn. Int. Econ.* 11:441–79

OECD. 2014. *Policy roundtables: competition issues in the food chain industry, 2013*. Publ. DAF/COMP(2014)16, OECD, Paris. **https://www.oecd.org/daf/competition/CompetitionIssuesintheFoodChainIndustry.pdf**

Ogbuabor JE, Orji A, Aneke GC, Charles MO. 2019. Did the global financial crisis alter the oil–gasoline price relationship? *Empir. Econ.* 57:1171–200

Peltzman S. 2000. Prices rise faster than they fall. *J. Political Econ.* 108:466–502

Piggott NE, Wohlgenant MK. 2002. Price elasticities, joint products, and international trade. *Aust. J. Agric. Resour. Econ.* 46:487–500

Piyapromdee S, Hillberry R, MacLaren D. 2014. 'Fair trade' coffee and the mitigation of local oligopsony power. *Eur. Rev. Agric. Econ.* 41:537–59

Rapsomanikis G, Hallam D, Conforti P. 2003. Market integration and price transmission in selected food and cash crop markets of developing countries: review and applications. In *Commodity Market Review 2003–2004*, pp. 51–75. Rome: FAO. **http://www.fao.org/3/y5117e/y5117e.pdf**

Reardon T, Timmer CP, Barrett CB, Berdegué J. 2003. The rise of supermarkets in Africa, Asia, and Latin America. *Am. J. Agric. Econ.* 85:1140–46

Rebello J. 2020. *Regional integration: overview*. Topic Overv., World Bank, Washington, DC. **https://www.worldbank.org/en/topic/regional-integration/overview**

Richards TJ, Allender WJ, Hamilton S. 2012. Commodity price inflation, retail pass-through and market power. *Int. J. Ind. Organ.* 30:50–57

Richards TJ, Gómez MI, Lee J. 2014. Pass-through and consumer search: an empirical analysis. *Am. J. Agric. Econ.* 96:1049–69

Richardson JD. 1978. Some empirical evidence on commodity arbitrage and the law of one price. *J. Int. Econ.* 8:341–51

Saitone TL, Sexton RJ. 2017. Concentration and consolidation in the U.S. food supply chain: the latest evidence and implications for consumers, farmers, and policymakers. *Econ. Rev.* 102(Spec. Issue):25–60. **https://www.kansascityfed.org/documents/764/Concentration_and_Consolidation_in_the_U.S._Food_Supply_Chain_The_Latest_Evidence_and_.pdf**

Serra T. 2006. Local polynomial fitting and spatial price relationships: price transmission in EU pork markets. *Eur. Rev. Agric. Econ.* 33:415–36

Sexton RJ. 2013. Market power, misconceptions, and modern agricultural markets. *Am. J. Agric. Econ.* 95:209–19

Sexton RJ, Kling CL, Carman HF. 1991. Market integration, efficiency of arbitrage, and imperfect competition: methodology and application to U.S. celery. *Am. J. Agric. Econ.* 73:568–80

Sexton RJ, Xia T. 2018. Increasing concentration in the agricultural supply chain: implications for market power and sector performance. *Annu. Rev. Resour. Econ.* 10:229–51

Spiller PT, Wood RO. 1988. The estimation of transaction costs in arbitrage models. *J. Econom.* 39:309–26

Swinnen JFM, Vandeplas A. 2014. Price transmission and market power in modern agricultural value chains: some conceptual issues. In *Food Price Dynamics and Price Adjustment in the EU*, ed. S McCorriston. Oxford, UK: Oxford Scholarsh. Online

Tappata M. 2009. Rockets and feathers: understanding asymmetric pricing. *RAND J. Econ.* 40:673–87

Taylor AM. 2001. Potential pitfalls for the purchasing-power-parity puzzle? Sampling and specification biases in mean-reversion tests of the law of one price. *Econometrica* 69:473–98

Teräsvirta T. 1994. Specification, estimation, and evaluation of smooth transition autoregressive models. *J. Am. Stat. Assoc.* 89:208–18

Teräsvirta T, Holt MT. 2012. *Global hemispheric temperature trends and co–shifting: a shifting mean vector autoregressive analysis*. CREATES Res. Pap. 2012-54, Aarhus Univ., Aarhus, Den.

Tifaoui S, von Cramon-Taubadel S. 2017. Temporary sales prices and asymmetric price transmission. *Agribusiness* 33:85–97

Tomek WG, Robinson KL. 1981. *Agricultural Product Prices*. Ithaca, NY: Cornell Univ. Press

Vavra P, Goodwin BK. 2005. *Analysis of price transmission along the food chain*. Food Agric. Fish. Pap. 3, OECD, Paris. **https://doi.org/10.1787/752335872456**

von Cramon-Taubadel S. 1998. Estimating asymmetric price transmission with the error correction representation: an application to the German pork market. *Eur. Rev. Agric. Econ.* 25:1–18

von Cramon-Taubadel S, Meyer J. 2005. La robustesse des tests de transmission asymétrique des prix en présence de changements structurels. *Écon. Rurale* 283:10–26

Wang X, Tadesse H, Rayner T. 2006. *Transmission, market power and returns to scale: a note*. Discuss. Pap. Econ., Univ. Nottingham, Nottingham, UK

Weldegebriel HT. 2004. Imperfect price transmission: Is market power really to blame? *J. Agric. Econ.* 55:101–14

Williams JC, Wright BD. 1991. *Storage and Commodity Markets*. Cambridge, UK: Cambridge Univ. Press

Wood SN. 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. *J. Am. Stat. Assoc.* 99:673–86