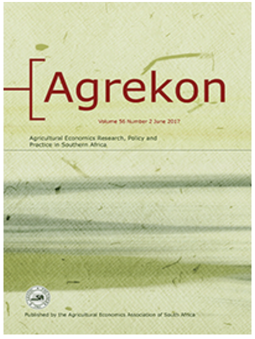

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SIMON BRAND MEMORIAL ADDRESS*

The analysis of market integration and price transmission – results and implications in an African context

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ABSTRACT
A vast literature on market integration and price transmission has accumulated over the last half century. This literature has received major impetus, first from the introduction of increasingly sophisticated co-integration methods since the late 1980s, and second from the so-called food price crisis of 2007–2008, which heightened interest in the transmission of food price spikes in space and along the supply chain. In this paper I review the literature on price transmission and market integration, highlighting applications in an African setting. I begin by reviewing the basic methods that are commonly used in price transmission analysis, as well as several extensions that have gained prevalence in recent years. I then discuss several important limitations and challenges that remain to be addressed in future research on price transmission and market integration.

KEYWORDS
Market integration; Price transmission; Africa

JEL CLASSIFICATION
C32; D40; Q11

1. Introduction

A vast literature on market integration and price transmission has accumulated over the last half century. Harriss (1979) cites dozens of studies from the 1960s and 1970s, many of which focus on markets on Africa. These include, for example, Jones (1968) who calculates 4836 correlation coefficients between regional prices for staple foods such as rice, sorghum and maize in Nigeria. More recently this literature has received major impetus, first from the introduction of increasingly sophisticated co-integration methods since the late 1980s, and second from the so-called food price crisis of 2007–2008, which heightened interest in the transmission of food price spikes in space and along the supply chain.

In this paper I will attempt to provide a review of the literature on price transmission and market integration. It goes without saying that this review is selective and subjective. As someone who has contributed to this literature I am very aware that it suffers from several important theoretical and methodological limitations. As a referee I am also aware that computer technology has made it relatively easy to churn out price transmission analyses of at best modest value. Indeed, I must admit to having done some churning of my own in the past. This combination of limitations and a substantial body of uninspired, mechanical applications has led to fatigue, exasperation and sometimes even hostility on the part of some editors and referees. The most trenchant referee report that I have ever received in response to a paper stated simply: "I think that this line of inquiry is largely a dead end and the methodology adopted in

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this paper (using co-integration and VECMs) is not capable of providing economically meaningful conclusions about market integration."

The existing limitations and such verdicts notwithstanding, I am convinced that research on price transmission and market integration is important and necessary. Many policy prescriptions (such as "get prices right", "invest in infrastructure") and their implications hinge on understanding how markets and prices interact horizontally in space and vertically along the supply chain. Competition policy (determining the extent of a market, detecting signs of price manipulation) can also benefit from a better understanding of price transmission and market integration. Parametrizations of price transmission are a crucial but often hidden ingredient in empirical policy simulation exercises based on partial and general equilibrium models. Finally, price behaviour is a fundamental part of economic theory, and there are many aspects of how prices behave in space and time that we do not understand. Peltzman (2000), for example, concludes that the economic theory of markets is "wrong" because it is incapable of explaining the observed prevalence of asymmetric price transmission. Hence, studying price transmission and market integration is interesting from a purely scientific perspective as well.

In the next section I will begin by reviewing the basic methods that are commonly used in price transmission analysis, as well as several extensions that have gained prevalence in recent years. In Section 3 I will discuss several important limitations and challenges that remain to be addressed in future research on price transmission and market integration. Section 4 concludes. Throughout I will endeavour to highlight African contributions to the market integration and price transmission literature as well as issues and implications that are specific to the African context.[1]

2. Methods

Fackler and Goodwin (2001: 978) define market integration as "a measure of the degree to which demand and supply shocks arising in one region are transmitted to another region". According to this definition, determining whether markets are integrated involves measuring price transmission. The literature on market integration and price transmission has been driven by the availability and refinement of empirical methods, and can be roughly divided into "pre-co-integration", "co-integration" and "other" strands. In the following I discuss each of these strands in turn.

2.1 Pre-co-integration methods

In the 1960s and 1970s price transmission was mainly measured using correlation coefficients and simple regression models. Harriss (1979) and Fackler and Goodwin (2001) discuss several weaknesses of correlation coefficients and simple regression analysis in the context of price transmission analysis. In particular, a variety of conditions or exogenous influences – such as weather patterns or pan-territorial pricing by a monopolist or public agency – can lead to high levels of correlation between prices that do not reflect integration in the sense of transmission of shocks among markets. This highlights the distinction between price co-movement, which can be due any number of factors, and price transmission due to flows of goods and/or information among markets that are caused by market participants such as traders and arbitrageurs.

In response to these criticisms, by the 1980s researchers were increasingly turning to dynamic regression methods such as Granger causality tests (Gupta & Mueller, 1982) and various forms of vector auto-regression (Ravallion, 1986; Timmer, 1987). In principle, dynamic regression with sufficiently high-frequency data can distinguish between the impulse-response behaviour which results when markets and prices react to one another, and other forces such as those mentioned in the previous paragraph that merely make prices co-move. Hence, dynamic regression represented an important improvement over earlier techniques.

2.2 Co-integration methods

Nevertheless, dynamic regression did not solve all of the problems confronting price transmission analysis. In the course of the 1980s it was increasingly acknowledged that many price series appear to be non-stationary. When standard regression analysis is applied to non-stationary data, the estimated coefficients are unbiased but their estimated standard errors are inconsistent. This can lead estimates of relationships between prices that appear to be statistically significant but are, in fact, spurious. Co-integration tests provide a means of distinguishing between spurious relationships and those that reflect true equilibrium relationships. Moreover, the core model in co-integration analysis, the vector error correction model (VECM), simultaneously captures both the long run equilibrium relationship between two prices, and the so-called error correction mechanism that describes how one or both of these prices react to restore equilibrium whenever it is disturbed by a shock. A standard VECM for two prices, p_t^A and p_t^B, takes the following form:

$$\begin{bmatrix} \Delta p_t^A \\ \Delta p_t^B \end{bmatrix} = \begin{bmatrix} \varphi_A \\ \varphi_B \end{bmatrix} + \begin{bmatrix} \alpha_A \\ \alpha_B \end{bmatrix} [p_{t-1}^A - \beta_0 - \beta_1 p_{t-1}^B] + \sum_{i=1}^{k} \begin{bmatrix} \delta_{Ai} & \rho_{Ai} \\ \delta_{Bi} & \rho_{Bi} \end{bmatrix} \begin{bmatrix} \Delta p_{t-i}^A \\ \Delta p_{t-i}^B \end{bmatrix} + \begin{bmatrix} \varepsilon_{At} \\ \varepsilon_{Bt} \end{bmatrix} \quad (1)$$

where Δ is the difference operator, φ, α, β, δ and ρ are parameters to be estimated, and the ε are error terms. Re-arranging the third term in brackets on the right hand side of Equation (1) reveals that it equals v_{t-1}, the lagged deviation from the long run equilibrium relationship between p_t^A and p_t^B:

$$p_t^A = \beta_0 + \beta_1 p_t^B + v_t. \quad (2)$$

Hence, the β can be interpreted as the coefficients of this long run equilibrium relationship: β_1 is the long run coefficient of price transmission between p_t^A and p_t^B, and β_0 measures the margin between them. The α are often referred to as the "adjustment parameters". They measure whether p_t^A, p_t^B or both react to correct deviations from the long run equilibrium relationship (i.e., values of $v_{t-1} \neq 0$, which are often referred to as "errors", whence the term "error correction model"). Johansen (1988) developed a maximum likelihood estimator for the VECM that is used in the great majority of applications. Zivot and Wang (2003) and Greb *et al*. (2013) discuss restrictions on the values of α_A and α_B that ensure the stability of the relationship in Equation (1), in other words that p_t^A and p_t^B overall will react to disequilibrium in a manner that restores the long run equilibrium.

Ardeni (1989) was the first study of price transmission in agricultural economics to employ co-integration methods. There are many examples of applications of basic co-integration methods in an African setting including Alderman (1993, maize in Ghana), Lutz *et al.* (1994, maize in Benin), Fafchamps and Gavian (1996, livestock in Niger), Rashid (2004, maize in Uganda) and Minot (2010, 62 staple food prices in nine sub-Saharan African countries). Over the last roughly 25 years, the market integration and price transmission literature has been dominated by co-integration methods and in particular by the estimation of VECMs. A recent search of the *AgEcon Search* website[2] using the keywords "price transmission" and "co-integration" or "error correction" produced 576 hits.

One important limitation of the standard VECM in Equation (1) that was soon recognised in the literature is its linearity, i.e., the assumption that the same error correction mechanism described by α_A and α_B is applied to all deviations from long run equilibrium, regardless of their sign, their magnitude, or when they occur. There are many situations in which this assumption of linearity can be challenged. For example, transport costs between two locations might vary seasonally. These variations might affect the speed with which price shocks are transmitted between the two locations, leading to different seasonal price transmission modes or, to use the term most common in the literature, "regimes". For example, if transport costs between two locations are lower in the dry season (when roads are passable) than in the rainy season (when they are not), then the speed of price transmission between these locations might vary accordingly (i.e., be higher in the dry than in the rainy season). This would lead to seasonal variations in the magnitudes of α_A and α_B.[3] Amikuzuno and von Cramon-Taubadel (2012) estimate a VECM with seasonally switching adjustment parameters to test for such variations in price transmission between tomato markets in Ghana.

A second example of non-linearity is so-called asymmetric price transmission. Processors and retailers are often suspected of transmitting price shocks asymmetrically along the marketing chain; for example, rapidly passing on to consumers increases in input costs, which squeeze their margins, but taking more time to pass on input cost reductions, which stretch their margins. If this is taking place, and if p_t^A and p_t^B in Equation (1) are an output and an input price, respectively, then a positive shock to p_t^B, which leads to a negative deviation from the long run equilibrium relationship between p_t^A and p_t^B (i.e., to $v_{t-1} < 0$), will lead to a more rapid reaction in p_t^A than a negative shock to p_t^B, which leads to a positive deviation from the long run equilibrium relationship between p_t^A and p_t^B (i.e., to $v_{t-1} > 0$). In either case, α_A will not be constant but rather will vary depending on the sign of v_{t-1}. The following model is a modified VECM that allows for asymmetric error correction:

$$\begin{bmatrix} \Delta p_t^A \\ \Delta p_t^B \end{bmatrix} = \begin{cases} \begin{bmatrix} \varphi_{A\oplus} \\ \varphi_{B\oplus} \end{bmatrix} + \begin{bmatrix} \alpha_{A\oplus} \\ \alpha_{B\oplus} \end{bmatrix} [p_{t-1}^A - \beta_0 - \beta_1 p_{t-1}^B] + \sum_{i=1}^{k} \begin{bmatrix} \delta_{Ai\oplus} & \rho_{Ai\oplus} \\ \delta_{Bi\oplus} & \rho_{Bi\oplus} \end{bmatrix} \begin{bmatrix} \Delta p_{t-i}^A \\ \Delta p_{t-i}^B \end{bmatrix} + \begin{bmatrix} \varepsilon_{At\oplus} \\ \varepsilon_{Bt\oplus} \end{bmatrix} & \text{if } v_{t-1} > 0 \\ \begin{bmatrix} \varphi_{A\ominus} \\ \varphi_{B\ominus} \end{bmatrix} + \begin{bmatrix} \alpha_{A\ominus} \\ \alpha_{B\ominus} \end{bmatrix} [p_{t-1}^A - \beta_0 - \beta_1 p_{t-1}^B] + \sum_{i=1}^{k} \begin{bmatrix} \delta_{Ai\ominus} & \rho_{Ai\ominus} \\ \delta_{Bi\ominus} & \rho_{Bi\ominus} \end{bmatrix} \begin{bmatrix} \Delta p_{t-i}^A \\ \Delta p_{t-i}^B \end{bmatrix} + \begin{bmatrix} \varepsilon_{At\ominus} \\ \varepsilon_{Bt\ominus} \end{bmatrix} & \text{if } v_{t-1} < 0 \end{cases} \tag{3}$$

where the subscripts $\oplus$ and $\ominus$ distinguish between price reactions when margins have been stretched ($v_{t-1} > 0$) and squeezed ($v_{t-1} < 0$), respectively. Frey and Manera (2007), Meyer and von Cramon-Taubadel (2004) and Vavra and Goodwin (2005) are reviews of the literature on the theory and estimation of asymmetric price transmission.[4] In an African context there have been numerous applications of tests for asymmetry based on the asymmetric VECM in Equation (3). These include, for example, Goletti and Babu (1994, who study the case of maize in Malawi), Cutts and Kirsten (2006, four foods in South Africa), Worako *et al.* (2008, coffee in Ethiopia), Amikuzuno and Ihle (2010, tomatoes in Ghana), Mkhabela and Nyhodo (2011, poultry in South Africa), Mofya-Mukuka and Abdulai (2013, coffee in Zambia and Tanzania) and Dillon and Barrett (2016, maize in East Africa).

A third example of non-linear price transmission that has received considerable attention in the literature is based on the concept of so-called "threshold error correction". Threshold models are most often used in the context of spatial price transmission. In spatial equilibrium, prices for a homogeneous good at two locations will differ by at most the costs of trading the good between these locations. If a shock disturbs this equilibrium so that the price difference exceeds the costs of trade, traders will engage in spatial arbitrage, driving up the price at the low-price location, and driving down the price at the high-price location until the equilibrium price difference is restored. If a shock does not lead to a price difference that exceeds the costs of trade, traders will have no incentive to engage in spatial arbitrage and the price difference will persist. Hence, whether a price shock at location A is transmitted to location B depends on whether the shock leads to a deviation from the long run equilibrium between p_t^A and p_t^B that exceeds a threshold value (τ) that equals the costs of trade between A and B.

The asymmetric VECM displayed in Equation (3) above is a simple type of threshold model with a predetermined threshold $\tau = 0$ dividing two types of price response; one that occurs when $v_{t-1} > \tau = 0$, and one that occurs when $v_{t-1} < \tau = 0$. In applications to spatial price transmission, the size of the trade costs between A and B is generally not known, so the non-zero threshold τ must be estimated together with the parameters φ, α, β, δ and ρ. The result is a one-threshold VECM with error correction whenever $v_{t-1} > \tau$ (the difference between p_t^A and p_t^B is large enough to trigger trade) and no error correction whenever $v_{t-1} < \tau$ (the difference between p_t^A and p_t^B is not large enough to trigger trade). If trade reversals are possible, a two-threshold VECM results in which error correction takes place if $v_{t-1} > \tau_{B\to A}$ (the difference between p_t^A and p_t^B is large enough to trigger trade from B to A) or if $v_{t-1} < -\tau_{A\to B}$ (the difference between p_t^B and p_t^A is large enough to trigger trade from A to B). If $-\tau_{A\to B} < v_{t-1} < \tau_{B\to A}$, then p_t^A and p_t^B are said to be lying inside their "parity bounds", there are no incentives for trade in either direction, and therefore no error correction.[5]

At this point it is useful to discuss the relationship between market integration, market efficiency and the law of one price (LOP). As mentioned above, market integration is the extent to which price shocks at one location are transmitted to other locations (McNew & Fackler, 1997; Fackler & Goodwin, 2001). In the spatial equilibrium model outlined above, not all shocks will be transmitted; only those shocks that lead to a price difference between two locations that is larger than the trade costs between these locations will trigger trade and price adjustments. Smaller shocks will not be transmitted, but this does not imply that the markets in question are not integrated. However, we can conclude that two markets are not integrated if price differentials that exceed the costs of trade between them persist, i.e., are not error corrected.

In its strong form, the LOP states that a homogeneous good will sell for the same price at all locations. A weaker form of the LOP takes trade costs into account and is therefore equivalent to the spatial equilibrium condition mentioned above: in equilibrium the price differential between two locations will not exceed the costs of trade between these two locations. The LOP is an equilibrium condition that describes a state, whereas market integration refers to the processes that restore the LOP whenever it is violated. If price data of sufficient frequency are available, we will occasionally observe violations of the LOP even on markets that are integrated. However, on integrated markets these violations will not persist but rather trigger flows of goods or information that restore the LOP.

Finally, market efficiency refers to the speed with which the transmission of shocks and the restoration of the LOP takes place on integrated markets. Market efficiency, like efficiency in production economics, is a relative concept that can only be measured with respect to the existing institutional and infrastructural trade technology. Reducing trade costs can reduce the equilibrium threshold τ between two locations, thus narrowing the gap between the parity bounds for two markets and reducing the magnitude of the shock that is required to trigger disequilibrium and subsequent price adjustment. Trade cost reductions can also speed up the process of price adjustment (i.e., increase the magnitudes of one or both of the α in Equation (1)) so that a given violation of the LOP is takes less time to correct.[6]

Goodwin and Holt (1999) and Goodwin and Piggott (2001) were the first to apply the threshold VECM in agricultural economics. The simultaneous estimation of thresholds that delineate regimes and the parameters that describe price transmission within these regimes is not trivial. Greb *et al.* (2013) provide a detailed discussion of specification and estimation issues and propose a Bayesian estimator that performs better than the so-called "grid search" method that has been used most often to date. Applications of the threshold model in African settings include Abdulai (2000, maize in Ghana), Uchezuba (2005, apples in South Africa), Alemu and Biacuana (2006, maize in Mozambique), Van Campenhout (2007, maize in Tanzania), Alemu and Van Schalkwyk (2009, maize in Mozambique), Langyintuo (2010, cowpea in Ghana), and Kouyaté *et al.* (2016, rice in West Africa).[7]

All three of the examples of non-linear price transmission discussed in the preceding paragraphs are examples of what is referred to as "regime-dependent" price transmission. In each case the correction of deviations from the long run equilibrium relationship between prices switches between regimes according to some exogenous or endogenous trigger (the change of seasons, whether the deviation from equilibrium is negative or positive, whether the deviation from equilibrium is larger or smaller than a threshold value). Other examples of such regime-dependent price transmission applied in an African context are Stephens *et al.* (2012) and Traub *et al.* (2010). Both of these studies test whether the speed of price transmission differs in regimes with and without physical trade; the former for tomatoes in Zimbabwe, and the latter for maize trade between South Africa and Mozambique.

A related type of regime-dependent price transmission can be estimated using Markov-switching VECMs. Whereas in all of the regime-dependent models described above the transition from one regime to another is triggered by an observable variable (the sign or magnitude of the equilibrium error v_t, the change of seasons, or the presence/absence of physical trade), in a Markov-switching VECM regime shifts are triggered by an unobserved state variable (Brümmer *et al*., 2009). Ihle *et al.* (2009) apply a Markov-switching VECM to study the effects of trade restrictions on maize trade between Kenya and Tanzania.

All of the regime dependent models described so far only partly relax the assumption of linearity in price transmission. These models can be labelled "piecewise linear", because each specifies a finite number of individually linear price transmission regimes together with a mechanism that triggers transitions between these regimes. Some authors have proposed alternative models that further relax the assumption of non-linearity. One of these is the smooth transition VECM proposed by Teräsvirta (1994). In this model, the transition between two regimes is not hard or sudden when some trigger is reached, but rather smooth. Consider, for example the spatial equilibrium described above in connection with the threshold VECM. An implicit assumption in this model is that all potential arbitrageurs have identical trade costs τ, so that none engage in trade as long as $v_{t-1} \leq \tau$, and all engage in trade the moment this condition is violated. It is presumably more realistic to assume that there is a distribution of individual trade costs τ_i across a set of i = (1, …, n) traders, for example due to differences in their efficiency (Maindardi, 2001). Under these conditions, the larger the v_{t-1}that results from a price shock, the larger the number of traders for whom the condition $v_{t-1} \geq \tau_i$ will be violated and who will therefore engage in arbitrage. The result is a model which gradually switches from a no-trade and no-error-correction regime to a high-trade and rapid-error-correction regime as v_{t-1} increases. In empirical applications, a logistic function is often used to model an S-curve type of transition whereby one regime is increasingly diluted and ultimately replaced by another as v_{t-1} grows.[8] Ubilava and Holt (2013) use a smooth transition VECM to model the effects of the El Nino weather phenomenon on relationships between vegetable oils; I am not aware of any applications to specifically African settings.

Another way to relax the assumption of linearity in price transmission analysis is to use non-parametric VECM approaches. Serra *et al.* (2006a, 2006b) and Hassouneh *et al*. (2012) propose and demonstrate the use of local polynomial regression techniques to model non-parametric error response to the error term $p^A_{t-1} - \beta_0 - \beta_1 p^B_{t-1} = v_{t-1}$ in a VECM such as Equation (1). Van Campenhout (2012) uses a non-parametric extension of a threshold autoregressive model to study maize market integration in Mozambique. Rosales and von Cramon-Taubadel (2015) propose a model that also allows for a time-varying long run relationship and the use of penalized spline rather than local polynomial methods in non-parametric price transmission analysis.

In a related area referred to as the "price discovery" literature, co-integration methods are used to measure individual markets' contributions to an asset's fundamental value. When a homogeneous asset is traded on more than one market, price discovery methods are used to measure each market's share in the incorporation of new information that is transmitted via arbitrage to the other markets and ultimately determines the asset's fundamental price. Three main empirical price discovery metrics have been proposed: the information shares (IS) metric proposed by Hasbrouck (1995), the permanent-transitory (PT) decomposition proposed by Gonzalo and Granger (1995), and the information leadership shares (ILS) metric proposed by Putnins (2013). All of these metrics are based on co-integration techniques and the estimation of VECMs. To date, price discovery methods have been primarily applied to financial assets, for example to determine the relative contributions of the markets in Frankfurt and New York to price discovery for the stock of a particular company. Recently these methods have also been brought to bear on agricultural commodity markets, for example by Janzen and Adjemian (2016) and Pavlova and von Cramon-Taubadel (2016).

2.3 Other methods

While the linear, non-linear and, recently, non-parametric error correction approaches described above have dominated the market integration and price transmission literature in recent decades, several other approaches deserve mention. First, a large literature beginning with Engel and Rogers (1996) has looked at price dispersion as a measure of factors such as international borders that affect spatial market integration. In agriculture, Berkowitz and DeJong (2000) use price dispersion methods to study the spatial integration of food markets in Russia.

Second, the so-called parity bounds model (PBM) has also been applied to study market integration. Introduced by Spiller and Wood (1988), the PBM builds on switching regression and stochastic frontier techniques to test for market integration. First applied in an agricultural context by Sexton *et al.* (1991), the PBM was modified by Baulch (1997) and later by Barrett and Li (2002). The main advantage of the PBM approach is that it explicitly takes spatial equilibrium conditions, trade costs, and – in Barrett and Li's (2002) specification – trade flows into account. Prior to the development of threshold co-integration methods, this represented a major improvement over standard linear VECM-based methods, which only use data on prices. However, the PBM method also suffers from several shortcomings (Van Campenhout 2007, 2012). It is sensitive to distributional assumptions (Fackler & Goodwin, 2001). Furthermore, PBM analysis is essentially static in nature, relating spatial price differentials, trade costs and trade flows in a given period to one another, but not considering the possibility that trade flows and price adjustments observed in one period may have been caused by price differentials in previous periods. Hence, while PBM results can tell us how often two markets are integrated, it does not generate many insights into the dynamic process of price transmission and response to price shocks. Finally, while data on trade costs and trade flows certainly add information that is not available in price data alone, trade cost and trade flow data are sometimes unreliable and generally unavailable at the higher frequencies (monthly, weekly and daily) that characterise price data. Perhaps for these reasons, the PBM has received less attention in the literature than co-integration-based methods in recent years. Nevertheless, there have been several applications of the PBM in African settings. These include Penzhorn and Arndt (2002), Tostao and Brorsen (2005) and Cirera and Arndt (2008, all analysing maize markets in Mozambique), as well as Negassa and Myers (2007, maize and wheat in Ethiopia), and Zant (2012, maize in Malawi), who also propose modifications to deal with some of the shortcomings mentioned above.

Third, a number of recent studies have proposed the use of time-varying copulas to study price transmission and market integration. A copula is a function that links or couples a multivariate distribution to its univariate marginal distribution functions. In the price transmission setting described in Equation (1) above, copulas provide a highly flexible means of analysing the joint distribution of $v_{t-1} = p^A_{t-1} - \beta_0 - \beta_1 p^B_{t-1}$, Δp^A_t and Δp^A_t. The first papers to explore the use of copulas to study spatial market integration and price transmission are Goodwin *et al.* (2011), who study spatial market linkages for manufactured lumber products, and Qiu and Goodwin (2012), who look for evidence of asymmetric vertical price transmission on US hog markets. Emmanouilides and Fousekis (2015) is an application of copulas to US beef markets. To my knowledge, no applications of copulas to price transmission and market integration in Africa have been published to date.

Finally, Miller and Hayenga (2001) test for asymmetric price transmission on US pork markets in different ranges of the frequency domain using band spectrum regression techniques. Ansah *et al.* (2014) propose the use of cluster analysis to study market integration when price data are incomplete, and apply this method to study the integration of Ethiopian and international wheat markets. Each of these studies is *sui generis* and it remains to be seen whether they will inspire future work.

3. Challenges

The vast and multi-facetted literature that I have surveyed above has addressed many important challenges, but resolved few of them. In the following I outline a number of the most important questions and challenges that face researchers in this field.

3.1 Co-integration and market integration

McNew (1996), Barrett (1996) and McNew and Fackler (1997) were the first to stress that the relationship between market integration and co-integration is complex. In Barrett's (1996: 827) words, "co-integration is neither necessary nor sufficient for market integration". Hence, failure to find co-integration between two markets does not mean that they are not integrated. The reasons for this discrepancy (e.g., trade cost thresholds in spatial price transmission settings, or asymmetry in vertical price transmission settings), and attempts to account for them by extending the standard VECM, have been discussed above. However, the underlying problem remains: failure to find co-integration between two markets might not reflect a lack of market integration but rather a failure to correctly specify a VECM that includes the appropriate regime shifts or other types of non-linearity.

Some argue that co-integration models are fundamentally flawed because they use only price data and therefore lack structure and theoretical foundation. Barrett (1996) distinguishes between level I studies that rely exclusively on price data, level II studies that use data on trade costs as well as prices, and level III studies that combine data on trade flows and prices.[9] He goes on to argue that no matter how sophisticated our econometric methods become, we will need more level II and level III studies to broaden our understanding of how markets function. The PBM literature that emerged in the second half of the 1990s can be interpreted as an answer to this call. Nevertheless, over the same period much more research has focused on increasingly sophisticated econometrics in level I studies. I do not believe that Barrett's message has been misunderstood or ignored; it is simply that the data required for level II and III studies are generally unavailable. Many components of trade costs are unobservable, and trade flow data are rarely available at a higher than annual frequency. However, most level I price transmission analysis works with at least monthly frequency price data, and on many markets the episodes of price transmission (shock followed by adjustment) that we wish to understand unfold in the course weeks, days or even shorter intervals. Hence, shifting from level I to level II or III studies can generate gains from the incorporation of trade cost or trade flow data, but also losses due to temporal aggregation that leads to the loss of information and the use of possibly inappropriate temporal resolutions. Moreover, we are often interested in the integration of domestic markets within a country, for which trade data are not available at any frequency. Level II and III studies hold great promise, but assembling the required datasets is a daunting task. Work with simulated data might offer a comparatively low cost, if imperfect substitute.

3.2 Market pairs extracted from market networks

The great majority of the published market integration and price transmission studies analyse market pairs extracted from larger market networks. Sometimes attention is restricted to pairs because price data are only available at a high level of spatial aggregation. Hence, we study transmission between "the German" and "the French" prices of pork because EU statistical authorities publish national average data, even though pigs are traded at several locations in both Germany and France. Even where spatially disaggregated data are available, many researchers study price pairs, first because the results of bivariate analyses are comparatively easy to understand and interpret, and second because the number of parameters that must be estimated grows exponentially with the number of prices included in a VECM.

This raises two important questions. First, how does spatial aggregation affect the estimation and interpretation of price transmission processes? If pork trade between Germany and France takes place between individual regional markets, and perhaps even flows in different directions across different stretches of the Franco-German border, how do we interpret the results of a bivariate VECM such as Equation (1) estimated with average German and average French prices? A related aggregation issue, hinted at above, concerns the effects of temporal aggregation on estimates of price transmission. If it takes on average two weeks for prices on two integrated markets to adjust following a shock on one of them, how can we interpret the results of a price transmission estimation that is carried out with monthly price data for these markets? Von Cramon-Taubadel *et al.* (2006) study the effects of spatial aggregation on estimates of price transmission processes and Tifaoui and von Cramon-Taubadel (2016) review other studies that have also considered this issue. But these studies just scratch the surface of a complex issue, and the effects of temporal aggregation have received even less attention.

Second, the spatial threshold model discussed above is straightforward as long as A and B trade exclusively with one another. Between two markets A and B there are three possible trade patterns (no trade, A→B and B→A). Adding a third location C increases the number of possible trade patterns to 19, and adding a fourth location D increases this number to 189 (McNew & Fackler, 1997). This increases the complexity of the spatial arbitrage conditions considerably and with it the types of non-linear behaviour that prices can exhibit (McNew, 1996). For example, a small shock on market A that does not suffice to induce a violation of the spatial equilibrium condition between markets A and B might nevertheless cause a price adjustment on B via its effects on market C. As a result, econometric estimates of price transmission processes based on pairs of prices extracted from networks of interlinked markets will almost certainly be mis-specified. Fackler and Tastan (2008) derive measures of market integration from a generalised model of spatial price determination, but most applied work in the field continues to focus on price pairs.

3.3 The characteristics of price data

In addition to the issues of spatial and temporal data aggregation mentioned above, several other characteristics of price data can have an important influence on the results and interpretation of market integration and price transmission analysis. First, it is important to know how price data have been compiled. Whether monthly or weekly data are recorded beginning of period, end of period or average over period (and whether and how averages are weighted) will influence estimates of impulse–response relationships. Second, it is also important to know what share of a product's market volume is reflected in the price data that are analysed. As vertical integration in the food chain increases, spot market prices can become increasingly unrepresentative. A third issue concerns how to deal with missing values and especially seasonal gaps in price data for products such as fruits and vegetables that are not traded year-round, or for which old- and new-harvest produce differ significantly in quality.

An important issue in the analysis of vertical price transmission for many agricultural products is the processing that takes place between the farm gate and the retail level. Some products (such as eggs) can be traced entirely or largely unchanged from the farm gate to the retail level. In other cases, it is possible to trace most or all of a commodity's products and by-products at least part-way along the chain. For example, in Germany it is possible to obtain wholesale prices for most of the meat cuts in a slaughtered pig carcass, and therefore to calculate a wholesale equivalent carcass price that can be analysed together with the farm gate price for pork (von Cramon-Taubadel, 1998). In many cases, however, tracing a product along the chain, especially to the retail level (for example, reassembling a slaughtered pig or a litre of milk from the dozens of often highly processed, composite retail products that contain pork or milk) is not possible. This can make it difficult to draw conclusions from the results of vertical price transmission analysis. The empirical finding that price transmission from farm gate milk to retail butter is asymmetric might be evidence of market power in the dairy chain, but it might also simply reflect a failure to account for the other processed milk products and the complex technical and demand-side relationships between them in processing and at the retail level.

Finally, a number of issues related to the use of scanner retail price data in vertical price transmission analysis remain to be resolved. Scanner prices from individual stores display several characteristics that distinguish them from price data at the producer and wholesale levels. They are generally sticky (i.e., Δp_t is most often equal to zero); they tend to end in the digits 9 or 5 (psychological pricing); and they often include promotional effects such as temporary sales prices. While it is clearly of interest to study how price shocks at the producer or wholesale level are transmitted to individual retail chains and stores, the VECM, which models gradual adjustments rather than sporadic jumps, does not appear to be an appropriate model for this purpose. Tifaoui and von Cramon-Taubadel (2016) show that the presence of temporary sales prices in scanner price data can bias the results of vertical price transmission studies to findings of asymmetry, and they discuss filters that can be used to remove temporary sales from price data. But the question of finding a model that adequately accounts for stickiness and psychological pricing remains.

4. Conclusions

A great deal has been published on market integration and price transmission, but much remains to be done. The unresolved issues discussed in the previous section are cause for considerable caution when we interpret the results of price transmission analysis, but not for resignation. I derive some comfort from the results of two recent studies in which I participated. In a meta-analysis of 1189 estimates of spatial cereal price transmission in 57 published (not exclusively peer-review) studies, Kouyaté and von Cramon-Taubadel (2016) find that each 1000 km of distance between two markets reduces the likelihood that prices on these markets will be co-integrated by roughly 7 per cent, and that an international border between these two markets further reduces this likelihood by 23 per cent. Kouyaté et al. (2016) generate 351 own estimates of price transmission between rice markets in West Africa and find that 1000 km of distance reduces the likelihood of co-integration by between 6.4 and 9.9 per cent, while an international border reduces this likelihood by between 17 and 22%. This common thread running through a literature produced by many different authors using a wide range of methods and data suggests that, problems and unanswered questions notwithstanding, we are not entirely in the dark.

Looking forward, we need a methodological breakthrough that enables us to model multivariate price transmission in complex spatial networks more adequately. At the same time, we need to work harder to acquire generate datasets that enable us to move from Barrett's (1996) level I to levels II and III. Developments in information technology and big data may prove helpful in this regard. Finally, we need to make greater efforts to test new models and methods using existing as well as new datasets. Most peer-review journal papers that propose new econometric methods for analysing price transmission also employ new datasets to illustrate these methods. Also applying new methods to reference or benchmark datasets that have been used in previous studies would enable direct comparison of old and new methods and thus generate important additional insights.

Price transmission and market integration will continue to offer many fascinating opportunities for work by applied researchers who are concerned with the functioning and outcomes of agricultural markets. Work by African colleagues and applications in an African context will continue to be a vital component of this work. With its range of larger and smaller countries and its generally high trade costs due to often low levels of regional trade integration and poor trade infrastructure (Teravaninthorn and Raballand, 2009), Africa provides a rich and heterogeneous setting for applied work on price transmission and market integration. As African countries continue to develop, improvements in physical and institutional trade infrastructure can be expected to generate many exciting natural experiments that can be used to test hypotheses about the factors that shape market integration and price transmission and their implications for economic welfare and its distribution. The increasing integration of African agriculture into global high-value food chains will provide additional opportunities.

Notes

1. Rashid and Minot (2010) is a thought-provoking review of the evidence on staple food market integration in Africa.

2. See www.ageconsearch.org.
3. A similar effect could result if an important waterway between two locations freezes every winter. Such seasonal changes would not only cause the magnitudes of α_A and α_B to display seasonality; the magnitude of the equilibrium margin β_0 between p_t^A and p_t^B might then vary seasonally as well.
4. Gardner (1975), McCorriston *et al*. (2001), Weldegebriel (2004) and Kinnucan and Zhang (2015) provide theoretical underpinnings for the analysis of vertical price transmission in general.
5. Trade costs $\tau_{A\to B}$ and $\tau_{B\to A}$ need not be equal. For example, if trade in one direction moves upriver against the current, trade in the other moves downriver, leading to different transport costs of trade.
6. Rashid and Minot (2010) distinguish between exchange efficiency, which is the absence of unexploited arbitrage opportunities, and operational efficiency, which holds whenever it is not possible to reduce trade costs. Exchange efficiency is therefore the same as adherence to the LOP, while operational efficiency is akin to market efficiency as defined here.
7. Some authors, such as Abdulai (2000) and Van Campenhout (2007), estimate threshold autoregressive (TAR) models rather than threshold VECM models. The TAR model, which is related to the threshold VECM, was introduced by Enders and Granger (1998). VECM and TAR models are sometimes referred to as "threshold co-integration models" but Gonzalo and Pitarakis (2006) point out that this is misleading because these models assume that the underlying equilibrium or co-integration relationship is constant and not subject to threshold effects. VECM and TAR models are more accurately described as "threshold error correction models".
8. Another way to capture price responses that smoothly increase with the size of a price shock is to use polynomial adjustment terms for the error term $p_{t-1}^A - \beta_0 - \beta_1 p_{t-1}^B = v_{t-1}$ in the VECM in equation (1) (see von Cramon-Taubadel 1996 and Escribano 2004).
9. Barrett (1996) points out that even categorical trade flow data (i.e., a trade/no trade dummy variable) would help overcome some limitations of exclusively price-based analysis.

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