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Horizontal Price Transmission in Agricultural Markets: Fundamental Concepts and Open Empirical Issues

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Abstract. Following the dramatic changes experienced by the prices of agricultural commodities in 2007-2008, the analysis of horizontal price transmission mechanisms in agricultural markets has attracted renewed interest. In particular, this has led to the emergence of new challenges for the empirical analysis. How to model the increasing volatility and non linear behaviour of prices, to assess the impact of the policy responses to market turbulence, and how to account for the increasing interconnections between agricultural and non-agricultural commodity markets are amongst the most investigated issues. Building on a common analytical framework, this paper discusses and reviews the most recent methodological developments and empirical contributions in the field.

Keywords. Price transmission, cointegration, VECM, volatility, market policies

JEL Classification. Q110, C320

1. Introduction

In recent years, the empirical research on agricultural price transmission has gathered considerable attention. Interest in this topic unquestionably increased after the so-called «food crisis» of 2007-2008 in which international agricultural markets were shocked by increased volatility, i.e., a rapid rise and fall of the so-called price bubbles as well as a possible change in the long-term downward trend of agricultural prices (European Commission, 2008; Irwin and Good, 2009).

Such a dramatic change in the price behaviour clearly brought about a number of crucial research questions which are currently being investigated. In this work, we focus on horizontal price transmission, that is, the transmission of price shocks both across different places and commodities. The objective of this short note is to present some recent developments and open issues of the literature on this topic, all building upon a basic and well-established analytical framework, and to point out future possible research developments. Three aspects, in particular, are attracting increasing attention.

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The first key issue concerns the development of appropriate econometric models for the quantitative analysis of price transmission during periods of price exuberance and, more specifically, for the econometric treatment of non-linearities and volatility.

Secondly, agricultural markets are characterized by a high degree of policy intervention. During the food crisis, the dramatic rise in agricultural price volatility led many governments to adopt or strengthen specific policy measures (Tangermann, 2011). These interventions, however, raise serious doubts about their actual direct, indirect and unintended effects across agricultural markets, as the impression is that they boosted rather than mitigated market turbulence. Therefore, how to properly model the impact of policy intervention on price transmission, especially in the light of these recent developments, has become a major challenge for the empirical analysis.

A third major issue has emerged in recent years which concerns the increasing and complex interconnections between agricultural markets and other commodity and financial markets. A growing body of literature has been focusing on the relationship between food, feed and fuel prices; links between energy (e.g., oil) and agricultural prices; and interconnections between spot and future prices. Despite the different underlying theoretical motivations, this empirical literature converged toward a common econometric approach. Therefore, it is now possible to refer to horizontal price transmission in agricultural markets and to the related empirical literature, considering all these instances as a unique study.

This paper is structured as follows. The key concepts underlying price transmission analysis are described in section 2: the fundamental definitions (section 2.1), the time series properties of agricultural prices (section 2.2), the basic framework for price transmission analysis (section 2.3) with a focus on cointegration models (section 2.4) are presented. Then, the most recent literature on agricultural price transmission is reviewed in section 3 by focusing on the three crucial aspects characterizing the current scientific debate on this topic: non linearities (section 3.1), time-varying price volatility (section 3.2), and impact of policy measures (section 3.3). Some final considerations and a summary classification of this recent literature conclude our study in section 4.

2. Fundamental concepts and methods for the study of price transmission

While vertical price transmission refers to price linkages along a given supply chain, with horizontal price transmission we mean the linkage occurring among different markets at the same position in the supply chain. The notion of horizontal price transmission usually refers to price linkages across market places (*spatial price transmission*). *Lato sensu*, however, it can also concern the transmission across different agricultural commodities (*cross-commodity price transmission*) (Esposti and Listorti, 2011), from non-agricultural to agricultural commodities (notably, from energy/oil prices to agricultural prices) (Serra et al., 2008; Hassouneh et al., 2011), and across different purchase contracts for the same commodity (typically, from futures to spot markets and *vice versa*; Baldi et al., 2011).

As detailed below, the key underlying theoretical explanation of spatial price transmission is the spatial arbitrage and the consequent Law of One Price (LOP). On the contrary, for cross-commodity price transmission, the co-movement of prices is mostly driven by the substitutability and complementarity relations among the products (Saadi, 2011), while transmission from non-agricultural to agricultural commodities is prevalently due to the underlying production technology and cost structure, but also due to the complex drivers (expectations, speculative behaviour, etc.) of financial markets which also underlies the linkage between spot and futures prices[1]. However, even though the background theory differs, the empirical framework and the econometric implications of these different cases of horizontal price transmission are the same. As our attention in the present paper is on the common methodological issues rather than on different theoretical explanations, we will review empirical applications in all these cases[2].

In the sections that follow, the general methodological framework for the analysis of horizontal price transmission is presented: the fundamental definitions (section 2.1), the time series properties of the prices (section 2.2), the basic model of price transmission (section 2.3) and, finally, the cointegration approach (section 2.4).

2.1 The basic definitions

If we limit the notion of horizontal price transmission to the co-movement of prices of a given product in different locations (spatial price transmission), the *spatial arbitrage condition* is the key theoretical concept. It implies that the difference between prices in different market places will never exceed transaction costs[3], otherwise the profiting opportunities would be immediately exploited by arbitrageurs. The consequence of spatial arbitrage is the *Law of One Price* (LOP), as already derived by Marshall (1890; see also Fackler and Goodwin, 2001): in markets linked by trade and arbitrage, homogeneous goods will have a unique price, when expressed in the same currency, net of transaction costs. Two other familiar theoretical concepts complement those of spatial arbitrage and the LOP. In this context, *market efficiency* indicates the capacity of markets to minimize costs when they match supply and demand. In a competitive market with perfect information, arbitrage will ensure that price differentials will reflect all marketing costs. The concept of *market integration* refers rather to the tradability of products between spatially distinct markets, irrespective of the presence or absence of spatial market equilibrium and efficiency (Barrett and Li, 2002; Thompson et al., 2002)[4].

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[1] Though there may be significantly different interpretations on the drivers of price interdependence, in our survey we will indifferently consider studies working with spot and futures prices.

[2] In fact, also in the case of vertical price transmission, the methodological issues and solutions are analogous to those of horizontal price transmission. However, theoretical and policy implications are much different. For instance, due to market power and supply contracts, the asymmetries in price transmission assume crucial importance. Therefore, given space limitations and with only few exceptions (Kuiper and Bunte, 2011; Rezitis et al., 2009; Rezitis and Stavropoulos, 2011), all the empirical literature on vertical price transmission is ignored in this paper.

[3] In this paper, in analogy with Marshall (1890, p. 325) (see also Fackler and Goodwin, 2001, p. 977), the term «transaction costs» refers to all costs necessary to transfer commodities between two different locations, thus including transportation costs.

[4] Though the concept of *market integration* finds its sound theoretical justification in the Takayama and Judge Price and Allocation Model (Barrett, 2001), it has been used in the literature quite loosely to generally indicate the degree of co-movement shown by prices across spatially separated markets (Goodwin and Piggott, 2001). Actually, other mechanisms, such as information flows, might indeed explain price transmission rather than physical trade flows. Therefore, price transmission might occur in the absence of trade (*segmented equilibrium*) as well as trade might take place in the absence of price transmission (*imperfect market integration*).

Most empirical works in this field essentially aim at assessing whether the LOP holds true. As a matter of fact, it is well recognized that the universal validity of this 'law' can be easily questioned, as its assumptions are quite restrictive and unlikely to hold in practice. The LOP is a static concept while, in reality, economic processes are dynamic and may show temporary deviations from equilibria. Assuming that prices are always in equilibrium is not realistic. Indeed, temporary arbitrage opportunities (disequilibrium) might co-exist with long-run equilibrium conditions. Moreover, it is clear that many factors can prevent or slow down price convergence (see Miljkovic, 1999; Conforti, 2004). Notably, *transaction costs* are relevant in agriculture if compared to the unit value of the commodities considered (Fackler and Goodwin, 2001; Barrett, 2001). Prices might still not move together if transaction costs are large and volatile or might move together only when their difference is high enough, with respect to transaction costs, to make arbitrage convenient[5]. In addition to conventional transaction costs, other factors may prevent the validity of the LOP: domestic and border regulation policies, market power, product heterogeneity and perishability, exchange rate risks, imperfect flow of information and expectations are some of the factors that interfere with spatial arbitrage, and then with price transmission (Miljkovic, 1999; Graubner et al., 2011; Rezitis and Stavropoulos, 2010; Santeramo and Cioffi, 2010).

As these sources of deviations from the LOP are often unobservable, in many empirical models they are not explicitly considered and are therefore implicitly captured by disturbance terms. This leads to three major consequences for the empirical analysis. First of all, the assumptions on disturbances imply strong assumptions on how these drivers behave. Secondly, the estimated parameters sum up the combined effect of a whole set of factors affecting price transmission, not only the LOP. Thirdly, all the knowledge and information about these drivers are helpful in finding the appropriate empirical specification and interpretation of the estimation results (Fackler and Goodwin, 2001).

2.2 Time series properties of the prices

A fundamental characteristic of a price series is the persistence of its shocks as indicated by its autocorrelation coefficients. If equal to 1, shocks will never vanish over time and the series is said to contain a «unit root» (or integrated of order 1, I(1), since it needs to be differentiated to become stationary, I(0)). As a matter of fact, empirical tests often find evidence of unit roots, then non stationary price behaviour, in the time series of commodity prices[6].

It is well known, however, that the outcome of unit root tests can be influenced by a number of factors, like data frequency and alternative test specifications (Wang and Tomek, 2007). Furthermore, if not properly taken into account, the presence of structural breaks reduces the ability to reject a false unit root null hypothesis. Accordingly, vari-

[5] As transactions costs are usually associated to the real movement of commodities between markets, Myers and Jayne (2012) and Stephens et al. (2012) investigate the possibility that price transmission between spatially distinct markets might vary during periods with and without physical trade flows and might depend on the size of trade flows.

[6] For a recent contribution on the theoretical and empirical properties of the agricultural price series, see Stigler (2011).

ous unit root tests have been developed to allow for structural breaks in the time series (amongst others, Perron and Vogelsang, 1992; Clemente *et al.*, 1998; Zivot and Andrews, 1992; see Glynn et al. 2007 for a review).

Besides structural breaks, in some cases agricultural price series appear to be neither I(0) nor I(1) but rather I(d) processes with 0 < d < 1 (fractional integration). Originally proposed by Granger and Joyeux (1980), the idea of fractional integration implies that, although not behaving as random walks, the price series keep the memory of a given shock for a long period, and this may also generate non-linear patterns quite close to chaotic processes. As emphasized by Wei and Leuthold (1998) and Mohanty et al. (1998) (see also Stigler, 2011), this is often the case for agricultural prices (mostly, in fact, future prices). Conventional unit-root tests may fail in assessing whether price series are I(0) or I(1) while, in fact, they are I(d) with 0 < d < 1. Thus, the presence of such a long memory within the price series has to be tested following appropriate approaches, as that proposed by Geweke and Porter-Hudak (1983) and modified by Phillips (1999a,b).

Therefore, in a standard time series analysis, non-stationary variables are usually assumed to be either first-order integrated, I(1), or second-order integrated, I(2), or fractionally integrated (Engsted, 2006). However, the temporary explosive patterns of prices observed in recent years represent a true problem for the analysis. A price series showing explosive behavior is not necessarily an I(2) series. Indeed, I(2) series would imply a permanent exuberance of prices while, on the contrary, the observed patterns inflate and deflate within a relatively limited period of time («temporary collapsing bubbles») (Diba and Grossman, 1988). In other words, price bubbles induce a temporary explosive root in price series in addition to a unit root. If this additional root is not appropriately considered, conventional testing may fail to detect the real underlying stochastic process (Evans, 1991). Recent works by Phillips and Magdalinos (2009), Philips et al. (2009) and Phillips and Yu, 2009 (see also Gutierrez, 2010) have provided an appropriate framework for assessing the presence of an explosive root within processes that would be otherwise ruled as I(1)[7]. These sequential tests not only assess on a period-by-period basis the nonstationarity of the price series against an explosive alternative but they are also able to date the beginning and the end of price exuberance («the bubble»).

2.3 The basic empirical framework for price transmission analysis

Once the time series properties of the agricultural prices have been investigated, price interactions can be properly analysed. In this respect, and also concerning the econometric techniques put forward in empirical applications, Fackler and Goodwin (2001) identify *simple regression and correlation analysis* as the oldest approach. The basic representation of a price transmission equation is the following:

$$P_{1t} = \beta_0 + \beta_1 P_{2t} + \beta_2 T_t + \varepsilon_t \tag{1}$$

[7] Other modelling frameworks can actually admit transitory deviations from a regular I(0) or I(1) process. Koenker and Xiao (2006), for instance, show that quantile autoregression models (QAR) may allow temporary unit-root tendencies or even explosive behavior, while maintaining stationarity in the long run.

where P_{1t} and P_{2t} are the prices in locations 1 and 2 at time t, respectively. T represents transaction costs and ε_t is conventional disturbance. Markets 1 and 2 are taken to be perfectly integrated if $\beta_1 = \beta_2 = 1$ and $\beta_0 = 0$. These models can be also evaluated in logarithmic form, i.e.

$$p_{1t} = \beta_0 + \beta_1 p_{2t} + \beta_2 \tau_t + \varepsilon_t \tag{2}$$

the underlying equation in levels being

$$P_{1t} = e^{\beta_0} P_{2t}^{\beta_1} T_t^{\beta_2} e^{\varepsilon_t} \tag{3}$$

where $p = log\ P$, τ = log T and β_1 is the elasticity of price transmission. For spatial price transmission, β_1=1 reflects the validity of the LOP, while for transmission across commodities β_1 is expected to be close to 1/-1 under perfect substitutability/complementarity. As T (or τ) can be hardly observed, this term and the parameter β_2 are actually skipped, and $\beta_0 \neq 0$ roughly captures all factors contributing to price differentials[8].

Regression model (1), or (2), however, raises two major conceptual and practical concerns. First of all, markets 1 and 2 being interdependent, P_{2t} cannot be assumed exogenous with respect to P_{1t}. In other words, all prices are endogenous. Secondly, as mentioned before, any adjustment toward an equilibrium between markets and prices (as expressed by the LOP) takes time, and temporary deviations from this equilibrium can be observed. *Dynamic regression models* have thus gained increasing attention because they allow to represent both contemporaneous and lagged price linkages and take price endogeneity into account. The basic version of these dynamic specifications is the Vector Autoregression (VAR) model[9]:

$$\mathbf{p_t} = \sum_{i=1}^{k} \mathbf{C}_i \mathbf{p}_{\mathbf{t}-i} + \mathbf{D}\mathbf{X_t} + \boldsymbol{\varepsilon}_\mathbf{t} \tag{4}$$

where $\mathbf{p_t}$ is the (n×1; n is the number of price series considered in the analysis) vector of prices (either in levels or logarithms) at time t (thus, $\mathbf{p_{t-i}}$ indicates the vector of prices at time $t-i$, i being the generic time lag from 1 to k), $\boldsymbol{X_t}$ is a (m×1) vector of m possible exogenous factors with the associated (n×m) parameter matrix $\mathbf{D}$. The $\mathbf{C_k}$ are the (n×n) matrices of coefficients of the k-th lagged prices, and ε_t is a (n×1) vector of disturbances expressing the unobservable serially independent market shocks.

A common template embedding all dynamic regression models is provided by Fackler and Goodwin (2001). Granger causality, the so-called Ravallion (1986) market integration criteria (based on a radial structure with central and satellites markets) as well as the analyses of Impulse Response Functions (IRFs) and cointegration analysis (see next paragraph) can all be interpreted as empirical tools to analyse price transmission within this basic framework.

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[8] The strong underlying assumption is that all factors possibly contributing to price differentials, but not explicitly taken into account among regressors, are either constant (if a specification like (1) is used) or a constant proportion of prices (if a specification like (2) is used).

[9] The VAR model (4) actually represents the reduced-form specification of the linkages across prices. In order to make the structural relationships (that is, the contemporaneous linkages) explicit, the model has to be rewritten in a structural form (SVAR): $\mathbf{A_0 p_t} = \sum_{i=1}^{k} \mathbf{A}_i \mathbf{p}_{\mathbf{t}-i} + \mathbf{B}\mathbf{X_t} + \mathbf{u_t}$.

The validity of such basic framework lies on the fact that it analyzes price transmission without any available information but prices. Other empirical models have been proposed, as variants or alternatives with respect to (4), whenever more information on transaction costs, trade flows, and agents' expectations are made available (Barrett and Li, 2002). This is the case of the *switching regime models* (Sexton et al., 1991; Baulch, 1997) or of *rational expectations models* (Goodwin et al., 1990). However, the availability of long high-frequency (weekly or daily) price series, on the one hand, improves the capacity of capturing the dynamics of arbitrage processes; on the other hand, it prevents the use of variables other than observed market prices. For these practical reasons, reduced models like (4) have become the most prevalent framework for the empirical analysis of agricultural price transmission.

2.4 Cointegration models

Since the seminal work of Ardeni (1989), the concept of cointegration has demonstrated an intuitive appeal for the study of price transmission mechanisms within dynamic regression models. As price series are often nonstationary, as discussed before, cointegration models are ideal to represent how non-stationary variables are linked by a stationary long run relationship (which is, in fact, the main interest of price transmission analysis), though they can diverge from it in the short run. Cointegration models thus allow to disentangle short and long run dynamics in price interdependence. Their empirical specification takes the form of Vector Error Correction Models (VECM) that can be intended as the natural development of model specification (4) under such circumstances.

A standard Vector Error Correction Model (VECM) can be written as follows (Engle and Granger, 1987):

$$\Delta \mathbf{p_t} = \boldsymbol{\alpha\beta}' \mathbf{p_{t-1}} + \sum_{i=1}^{k-1} \Gamma_i \Delta \mathbf{p}_{\mathbf{t}-i} + \boldsymbol{\varepsilon}_\mathbf{t} \tag{5}$$

where $\mathbf{p}_t$ is the $(n\times 1)$ vector of prices at time t; $\boldsymbol{\alpha}$ $(n\times r)$ is the loading matrix which contains the adjustments parameters toward the equilibrium (the 'speed' of price transmission; Prakash 1999 cited in Conforti 2004); $\boldsymbol{\beta}$ $(n\times r)$ is the cointegration matrix containing the r long-run relationships (cointegrating vectors) expressing the 'degree' of price transmission (when prices $\mathbf{p}$ are expressed in logs, the coefficients of β can be read as price transmission elasticities); $\boldsymbol{\Gamma}_i$ $(n\times n)$ are matrixes containing coefficients expressing the short-run responses to price shocks; $\boldsymbol{\varepsilon}_t$ is a conventional $(n\times 1)$ vector of zero-mean, unit-variance, and independent and identically distributed disturbances.

The rank of $\boldsymbol{\Pi} = \boldsymbol{\alpha\beta}'$ allows to determine the presence of cointegration (i.e., of a long run relationship) amongst the variables: if rank($\boldsymbol{\Pi}$) = 0, the variables are not cointegrated, and the model becomes equivalent to a VAR in the first differences, $\boldsymbol{\Delta}\mathbf{p}$. In such case, the conclusion would be that there is no long run relationship among prices, and their interdependence is limited to short-run responses to shocks. If rank($\boldsymbol{\Pi}$) = n, the variables are stationary, and the model is equivalent to a VAR in levels like (4)[10]. If $0 <$ rank($\boldsymbol{\Pi}$) $= r < n$,

[10] Though not distinguishing between long-run and short-run price relationships, a VAR specification of the price transmission equations still admits all the modelling variants presented for the VECM case in section 3.

the variables are cointegrated[11]. Therefore, for nonstationary series, cointegration has been considered to be a sufficient condition for integrated markets. In a system with *n* prices, the number of cointegration relations (*r*) can be also considered as an index of the degree of integration of the respective markets.

In the empirical literature on agricultural price transmission of the last twenty years, the VECM approach has become dominant (Goodwin and Fackler 2001; Miljkovic, 1999; Listorti, 2009) also because several improvements of the basic specification (5) have been progressively introduced. For instance, *threshold cointegration models* (Balke and Fomby, 1997) and *asymmetric cointegration models* (Ghoshray, 2002; Meyer and von Craumon-Taubadel, 2004) allow for a more sophisticated representation of how prices respond to shocks in the short run and adjust to their long run equilibrium. These developments will be extensively discussed in the next section.

Despite this intuitive appeal and its success in price transmission and market integration analysis, the use of cointegration techniques also presents some shortcomings (Barrett, 1996; Miljkovic, 1999). In particular, given that the long run relation expresses the LOP, the fundamental assumption underlying the VECM (5) is that price spreads $\boldsymbol{\beta}'\mathbf{p}_{t-1}$ (therefore, all components which account for these spreads) are constant, if prices are in levels (or, in the case of prices expressed in logarithms, are a constant proportion of prices). More generally, cointegration is not a necessary condition for markets to be efficiently integrated, since transaction costs (as well as other elements contributing to price spreads) could vary over time and may themselves be nonstationary processes. Also in this respect, some possible developments will be discussed in the next section. Nonetheless, cointegration analyses should always be accompanied by a careful exploration of the economic characteristics of the markets under study.

3. Recent literature and open issues

In all variants discussed in the previous section (VAR models in case of I(0) price series, VECM models when the series are cointegrated, and d-differences VAR models whenever the I(d) series are not cointegrated), the dynamic regression models constitute the predominant framework for the empirical analysis of agricultural price transmission. However, in its conventional specifications, this modelling approach may fail in providing an adequate representation of the often complex price co-movements. To better capture the observed behaviour of prices, recent research on horizontal price transmission expanded this framework in three major directions: price transmission and non-linearities; price transmission and changing volatility; price transmission and policy intervention. Table 1 displays a selection of the most recent contributions with regard to the three directions of research[12].

For instance, Santeramo and Cioffi (2010, 2012) and Cioffi et al. (2011) present several applications to agricultural markets of the Threshold VAR (TVAR) model.

[11] Hassouneh et al. (2012: 22) review the proper specifications of the price transmission equations depending on the outcome of the unit-root and cointegration testing procedures.

[12] Stigler (2011) provides a good survey on the main empirical issues raised by the recent price rally on agricultural markets. Many of these issues are related to those under discussion here, although our attention is more on the methodological developments put forward by the recent literature rather than on the actual identification of the drivers of the market turmoil in the past few years.

Table 1. Tentative mapping of the recent contributions on horizontal agricultural price transmission

Primary focus Secondary focus	Non-linearities	Volatility	Policies
Non-linearities	Goodwin and Piggott (2001) Mainardi (2001) Sephton (2003) Balcombe et al. (2007) Balcombe and Rapsomanikis (2008) Götz et al. (2008) Serra et al. (2008) Ihle and Amikuzuno (2009) Ihle et al. (2009) Ubilava and Holt (2009) Amikuzuno (2010) Santeramo and Cioffi (2010) Baldi et al. (2011) Brosig et al. (2011) Greb et al. (2011) Hassouneh et al. (2011) Liu (2011) Myers and Jayne (2011) Natanelov et al., (2011) Stephens et al. (2012)		Listorti (2007, 2009) Götz et al. (2010) Cioffi et al. (2011) Djuric et al. (2011) Ihle et al. (2011) Santeramo and Cioffi (2012)
Volatility	Rezitis and Stavropoulos (2011)	Busse et al. (2010) Hernandez et al. (2011) Serra (2011) Rapsomanikis (2011) Rapsomanikis and Mugera (2011)	Serra et al. (2011)
Policies	Dawson et al. (2006) Dawson and Sanjuan (2006) Serra et al. (2006) Barassi and Ghoshray (2007) Esposti and Listorti (2011) Hernández-Villafuerte (2011)	Rezitis and Stavropoulos (2010)	Thompson et al. (2002) Mohanty and Langley (2003) Verga and Zuppiroli (2003) Barassi and Ghoshray (2007)

3.1 Price transmission and non-linearities

The general framework of price transmission presented in section 2 is based on the assumption that the prices under study can be represented as linear I(d)[13] (mostly I(1)) Autoregressive Integrated Moving Average (ARIMA) processes. Under such circumstance, a preliminary condition for price transmission analysis is assessing whether these prices show the same order of integration. The knowledge of this common order of integration allows analyzing price transmission by identifying linear short-term and/or long-term relationships. However, actual price movements may seriously question this assumption.

[13] d indicates the order of integration.

In other words, real observations may suggest that the data generating process is rather a non-linear function of the lagged prices (Harvey and Leybourne, 2007). In such cases, differentiation does not restore stationarity, and price transmission cannot be analysed as a linear stationary combination of prices.

In agricultural markets, such deviations from the conventional linear cointegration framework should not come as a surprise. The price «bubble» observed in 2007-2008 confirmed that these series can hardly be represented by I(d) processes. Therefore, the recent literature has increasingly expressed the need for an extension of the basic framework, particularly taking advantage of the developments of applied econometrics coping with the combination of nonstationarity and nonlinearity. More specifically, in the case of agricultural prices, two lines of research can be identified.

The first concentrates on *nonlinearities found in the individual price series* and on the consequences on price transmission. In particular, the attention is on price series showing a temporary explosive root in addition to a unit root: indeed, for these series, no univocal order of integration may be found[14]. Engsted (2006) and Nielsen (2010) show that, even if one series shows a temporary explosive root, the cointegration model (and the VECM specification) remains an «ideal framework» for analyzing the linkage between variables that have a common stochastic trend (they are cointegrated), but in which one of the series also has an explosive root. Under this circumstance, specification (5) should be written in a form that admits two structural relations. The first contains the usual cointegrating parameters (the linear combination of prices that is I(0)); the second contains the co-explosive parameters (the linear combination of prices that is not I(0) but not explosive) (Engested, 2006):

$$\Delta_1\Delta_\rho \mathbf{p}_t = \boldsymbol{\alpha}_1\boldsymbol{\beta}_1'\Delta_\rho \mathbf{p}_{t-1} + \boldsymbol{\alpha}_\rho\boldsymbol{\beta}_\rho'\Delta_1 \mathbf{p}_{t-1} + \sum_{i=1}^{k-2}\boldsymbol{\Gamma}_i\Delta_1\Delta_\rho \mathbf{p}_{t-i} + \boldsymbol{\varepsilon}_t \tag{6}$$

where $\mathbf{p_t}$ is the $(n\times1)$ vector of prices at time t; $\Delta_\rho = (1-\rho L)$ and ρ is the explosive ($\rho>1$) root. $\boldsymbol{\alpha}_1$ is the conventional cointegration vector[15] while $\boldsymbol{\beta}_\rho$ contains the co-explosive parameters. All other parameter matrices ($\boldsymbol{\alpha}_1$, $\boldsymbol{\alpha}_\rho$, $\boldsymbol{\Gamma}_i$) can be interpreted according to equation (5). It is worth noticing that, if the interest rests prevalently in the usual cointegrating (i.e., long run) relationship between the prices (and/or we have not a reliable estimate of ρ), the standard Johansen (1995) estimation procedure holds its validity, and we may simply proceed to estimate (5) (see Esposti and Listorti, 2011) for an application to agricultural prices). However, if we were also interested in investigating the price relationships

[14] As mentioned in section 2.2, also fractional integration could generate temporarily non-linear patterns. The presence of long memory in price series can be represented with an ARFIMA (Autoregressive Fractionally Integrated Moving Average) model (Geweke and Porter-Hudak, 1983; Phillips 1999a,b). An application of this approach to agricultural markets can be found in Wei and Leuthold (1998). Wang and Garcia (2011) present an extension of this modelling framework to the analysis of time-varying volatility within a GARCH representation. Nonetheless, this approach has found quite limited interest in the analysis of the transmission of agricultural prices and seems less insightful with respect to the recent turbulence of agricultural markets (Esposti and Listorti, 2010). Therefore, it will not be considered in the present review anymore.

[15] It can be demonstrated that $\boldsymbol{\beta}_1$ corresponds to the $\boldsymbol{\beta}$ of specification (5) (Nielsen, 2010).

within the (co)explosive period, we should firstly find out the value of $\rho>1$ and then estimate (6) to obtain an estimate of $\boldsymbol{\beta}_\rho$[16].

The second direction of research on linearity concentrates on the *nonlinearity of the relations among price series* (the VECM representation). This is, in fact, what is commonly intended as the «non-linearity problem» within price transmission literature. This issue has already received much attention also because it took advantage of the continuous developments in the concepts and tools of nonlinear cointegration over the last fifteen years (Dufrénot and Mignon, 2002). Three different empirical strategies to include nonlinearity within the conventional VECM can be identified[17].

An easy and intuitive way to account for nonlinearity is to assume that a regime change intervenes at a certain point in time. It consists in a change in the relationship among prices and is deterministic, that is, induced by some observed exogenous factor (for instance, a new policy, a new regulation, a new technology, etc.). This kind of regime change is introduced in the VECM in the form of a *structural break* within the cointegration relationship. Johansen et al. (2000) generalize the standard Johansen cointegration framework by admitting up to two predetermined breaks in the cointegration space, and propose a model where breaks in the deterministic terms are allowed at known points in time. Johansen et al. (2000) propose to divide the sample in q periods, separated by the occurrence of structural breaks, where j denotes each period. The general VECM becomes:

$$\Delta_1\mathbf{p}_t = \boldsymbol{\alpha}\begin{bmatrix} \boldsymbol{\beta} \\ \boldsymbol{\mu} \end{bmatrix}' \begin{bmatrix} \mathbf{p}_{t-1} \\ t\mathbf{E}_{t-1} \end{bmatrix} + \boldsymbol{\gamma}\mathbf{E}_t + \sum_{i=1}^{k-1}\boldsymbol{\Gamma}_i\Delta_1\mathbf{p}_{t-i} + \sum_{i=1}^{k}\sum_{j=2}^{q}\mathbf{k}_{i,j}\mathbf{D}_{j,t+k-i} + \sum_{m=1}^{d}\boldsymbol{\Theta}_m\mathbf{w}_{m,t} + \boldsymbol{\varepsilon}_t \quad (7)$$

where $\mathbf{p_t}$ is the $(n\times1)$ vector of prices at time t; k is the lag length of the underlying VAR. $\boldsymbol{\beta}$ contains the usual long run coefficients in the cointegrating vector and $\boldsymbol{\mu}=\begin{bmatrix} \mu_{1t} & \mu_{2t} & \cdots & \mu_{qt} \end{bmatrix}'$ is the vector containing the long run drift parameters of the q periods. $\mathbf{E}_t$ is a vector of q dummy variables that take the value 1, i.e.,E_{jt} = 1, if the observation belongs to the j^{th} period (j = 1, …, q), and 0 otherwise; that is, $\mathbf{E}_t=\begin{bmatrix} E_{1t} & E_{2t} & \cdots & E_{qt} \end{bmatrix}'$. $\boldsymbol{\alpha}$ includes the adjustment coefficients. $\boldsymbol{D_t}$ is an impulse dummy (with its lagged values) that equals unity if the observation t is the i^{th} of the j^{th} period, and is included to allow the conditional likelihood function to be derived given the initial values in each period. $\boldsymbol{w_t}$ are the intervention dummies (up to d) included to obtain well-behaving residuals. The short run parameters are included in matrices γ (2 x q), $\boldsymbol{\Gamma}$ (2 x 2), $\mathbf{k}$ (2 x 1) for each j and i, and $\boldsymbol{\Theta}$ (2 x 2). $\boldsymbol{\varepsilon_t}$ are assumed to be i.i.d. with zero mean and symmetric and positive definite variance, $\boldsymbol{\Omega}$. The cointegration hypothesis

[16] Once an explosive root is found with an appropriate testing procedure (Phillips and Magdalinos, 2009; Philips et al., 2009; Phillips and Yu, 2009) and then estimated (Engested, 2006), the analysis of price transmission can be carried through this adaptation of the conventional VECM framework.

[17] An extensive survey on how to cope with nonlinearities within price transmission analysis can be found in Ihle (2009); see also Hassouneh et al. (2012).

is formulated by testing the rank of $\boldsymbol{\pi} = \boldsymbol{\alpha}\begin{bmatrix} \boldsymbol{\beta} \\ \boldsymbol{\mu} \end{bmatrix}'$; its asymptotic distribution cannot be generalized as it depends on the number of non-stationary relations, on the location of breakpoints and on the trend specification (Johansen et al., 2000).

In this approach, the regime changes (the breaks) must be known ex-ante, though appropriate tests can be run in this respect (Listorti, 2009). Dawson et al. (2006), Dawson and Sanjuan (2006), Listorti (2009) and Esposti and Listorti (2011) present applications of this structural break approach to the analysis of agricultural price transmission, each with possible variants or adaptations to specific contexts[18].

A second and more sophisticated approach has received a great deal of attention especially in the last five years[19]. It collects a set of alternative variants under the common label of *regime-dependent* or *state-dependent VECM models*. The underlying assumption is that price series behave as autoregressive processes whose parameters are not constant but change under different regimes, or, in other words, under different values of the prices. This leads to a non-linear representation of the individual data generating process and, possibly, to a non-linear relationship among cointegrated prices. Such representation is particularly appealing in the analysis of price interdependence as the presence of transaction costs make arbitrage (thus, the LOP) occur only (or differently) when the price differential exceeds a given threshold.

The general case of this non-linear VECM (Teräsvirta, 1994), is the Smooth-Transition VECM (STVECM):

$$\Delta\mathbf{p_t} = \left(\boldsymbol{\alpha}^1\boldsymbol{\beta}'\mathbf{p_{t-1}} + \sum_{i=1}^{k-1}\boldsymbol{\Gamma}_i^1\mathbf{p_{t-i}}\right)\left(1 - G(s_t,\gamma,c)\right) + \left(\boldsymbol{\alpha}^2\boldsymbol{\beta}'\mathbf{p_{t-1}} + \sum_{i=1}^{k-1}\boldsymbol{\Gamma}_i^2\mathbf{p_{t-i}}\right)G(s_t,\gamma,c) + \boldsymbol{\varepsilon}_\mathbf{t} \tag{8}$$

where superscripts 1,2 indicate the two regimes in which observed prices can be. (8) evidently represents a combination of two VECMs which, eventually, implies a non-linear representation of the linkage between prices. While the long run relationship ($\boldsymbol{\beta}$) remains the same, all the other parameters expressing the adjustment and short-run dynamics differ across the regimes. In fact, the basic justification behind this approach is to capture the role of transaction costs in regime switching under the assumption that transaction costs actually concern the adjustment and short-run dynamics, not the underlying LR relationship.

$G(s_t)$ is the so-called *transition function*; its value ranges between 0 and 1 and represents the extent to which the price relationship lies in the two regimes. s_t is the *transition variable* which usually takes the form of some lagged price values or lagged residuals from the error correction relationship, while c and γ are just two parameters expressing the thresholds between the two regimes and the speed of transition from one regime to another, respectively. The logistic and exponential specifications of $G(s_t)$ are the ones that are most frequently adopted in the literature[20].

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[18] An alternative approach is proposed by Barassi and Ghoshray (2007) that assume that the structural break affects the cointegration rank r rather than the cointegrating relationship: the break generates (or eliminates) the cointegrating relationship among the prices.

[19] See Hassouneh et al. (2012).

[20] Ubilava and Holt (2009), for instance, adopts an Exponential STVECM to analyse price transmission across vegetable oil world markets.

With respect to the structural break approach, this second stream of literature has the advantage that the regime change is not entered as an exogenous instantaneous shifter, and the movement across the regimes depends on price data themselves. Thus, it seems more suited to analyse nonlinear price transmission during period of market instability and whenever the timing and the causes of this change in regime are hardly identifiable.

Though, in principle, (8) can take many different forms, two specific cases on nonlinear agricultural price transmission have become prevalent in the empirical literature[21]. In the first one, it is $\gamma = 0$. Given s_t, the threshold variable c establishes whether the price linkage is in regime 1 or 2. This is the popular threshold cointegration framework (already mentioned in section 2.4); a Threshold VECM (TVECM) specification (Ihle, 2009) can be even generalised to more than two regimes, provided that the sum of the value of the transition functions in any regime remains = 1. An early application to agricultural markets comparing a STVECM and a TVECM can be found in Mainardi (2001). Recent applications of the TVECM approach to agricultural price transmission, just to mention a few, are Goodwin and Piggott (2001), Sephton (2003), Serra et al. (2006), Ihle and Cramon-Taubadel (2008), Serra et al. (2008), Amikuzuno (2010), Brosig et al. (2011), Greb et al. (2011), Rezitis and Stavropoulos (2011).

In the second case, the actual regime depends on a probabilistic process behaving like a Markov chain. The chain determines regime switching; the transition probabilities from one regime to another are established by a time-invariant transition matrix. This version of (8) is the so-called Markov-switching VECM (MSVECM) specification. Among others, recent applications to agricultural price transmission are Ihle and Cramon-Taubadel (2008), and Ihle et al. (2009), Djuric et al. (2011).

Out of these two modelling approaches many variants have been proposed (Natanelov et al., 2011). Analysing in details all these variants as well as their pros and cons is well beyond the scope of this article[22]. It is worth emphasizing, however, that the common feature of all these TVECM and MSVECM approaches is that they all concentrate on the nonlinearity of price transmission (i.e., on the regime change) in the adjustment (error correction) and short-run parameters, leaving the long run equilibrium unchanged (non-regime dependent). For this reason, such models can be called *nonlinear error correction models* to distinguish them from those where the cointegrating relationship may also be nonlinear (*nonlinear cointegration models*; see below). Therefore, these approaches reflect the idea that nonlinearities in price movements mostly occur during periods of market turbulence or instability and represent temporary changes in how prices respond to deviations from

[21] For instance, either symmetric or asymmetric TVECM can be specified (Liu, 2011) as well as exogenous or endogenous thresholds (the so-called Self-extracting TVECM; Ihle, 2009). Moreover, in this context, though not necessarily after a formal derivation from (8), other specifications have been proposed to model the adjustment processes and the short-run dynamics. The main purpose of these approaches is to minimize the *ex ante* restrictions imposed on data with respect to these dynamics. Nonlinear parametric (Sephton, 2003) and nonparametric specifications (Serra et al. 2006; Hassouneh et al., 2011) have been used, the latter receiving increasing attention by analysts in this field.

[22] Note that a sort of structural break approach could also be obtained as a special case of (8). If $\gamma = 0$ and the change in regime does not depend on a transition variable, s_t, but only on an exogenous threshold, c, we obtain a specification where, however, an exogenous break only operates in the adjustment and short-run dynamics, not in the long run (cointegrating) relationship. In this sense, such a solution cannot be regarded, strictly speaking, as a real «structural» break model.

long run equilibria. This somehow implicit choice of introducing nonlinearities only in the short-run components of the VECM not only prevents the identification (and interpretation) of problems of possibly multiple long-run equilibria, but also expresses the assumption of an underlying theoretical long-run relationship whose validity holds regardless of 'disturbing' variables, such as policy interventions, temporary market turbulence, etc. This is evidently appealing in the case of the LOP. It must be noticed, however, that some of these 'disturbing' variables affecting the short-run dynamics may, in fact, limit spatial arbitrage (thus, the LOP itself), as in the case of trade and market policy measures.

The rapid development of these nonlinear correction models raised several issues on their estimation and interpretation. On the one hand, the STVECM (and the TVECM variant, in particular) gives the analyst a great flexibility in adapting the model specification to the observed price data. On the other hand, however, it remains true that these models depend on several subjective aspects (how many regimes, which transition functions and/or which thresholds) and generate *ad hoc* specifications, where transitions to new regimes or thresholds are determined by the specific price series under study, and results are sometimes hardly replicable, generalizable and even interpretable. A further concern is the appropriate estimation of these nonlinear specifications. Classical estimation procedures are based on the Nonlinear Least Squares (NLS) or Maximum Likelihood (ML) estimator, but the application of such estimation procedures to these generalized models may generate results that lack robustness and consistency with theory and expectations. In recent years, Bayesian techniques have been often suggested to avoid some of these problems (Balcombe et al., 2007; Balcombe and Rapsomanikis, 2008; Greb et al., 2011).

A third empirical strategy to cope with nonlinear price transmission responds to the need of consistently admitting nonlinearities and changes in regime in both long run relationships and in adjustment and short run dynamics. For the sake of simplicity, we can call this approach *nonlinear cointegration models*. In fact, we can group under this category a pretty heterogeneous set of approaches whose common feature is to admit both kinds of nonlinearity.

It is worth noticing that an easy way to impose nonlinear short and long run relationships is to specify a VECM, like (5), not in the levels of prices but in some nonlinear transformation of them. Cointegration would represents the stationary relationship occurring not among price levels but rather among nonlinear functions of prices. These functions may take the form of n-order polynomials, for instance, though imposing these specifications *ex ante* may be arbitrary and have a poor theoretical justification. This simple solution to introduce nonlinearities is more frequent in empirical literature than usually acknowledged. In particular, very often the VECM of price transmission is expressed in the logarithm of prices rather than in price levels (Listorti, 2009; Esposti and Listorti, 2011). As mentioned before, this transformation not only facilitates the interpretation of results (estimated parameters can be directly interpreted as elasticities) but it often provides a larger goodness of fit in the estimation stage. Still, this transformation implicitly imposes nonlinearities both in the long-run equilibrium and in the adjustment and short-run dynamics.

In this third stream of empirical works on agricultural price transmission, however, we actually include those relatively few applications in which a regime switch is admitted in both the short run and in the long-run parts of the VECM. In doing this, as in the structural break case, these works relax the already mentioned limiting assumption underlying the conventional VECM in price transmission analysis, namely, that long run price spreads ($\beta' p_{t-1}$) and, consequently, all their determinants are time invariant. In particular, Götz et al. (2008) propose an approach where not only the short-run adjustment process towards equilibrium is non-linear, as in threshold VECM and Markov switching VECM frameworks, but also the long-run equilibrium relationship can display threshold-type nonlinearity. In Listorti (2009), both the adjustment parameters and the cointegrating relationship are assumed to vary according to regime changes that enter the model as structural breaks. Stephens et al. (2012) apply GRRR (Generalized Reduced Rank Regression) techniques to estimate a VECM model admitting regime-dependent long-run and short-run coefficients[23]. This kind of generalized regime-dependent modelling framework, however, still needs to be developed not only in the estimation stage but also in achieving a consistent regime-switching representation of the different parts of the VECM in addition to providing a sound theoretical justification[24].

3.2 Price transmission and time-varying volatility

The problem of volatility is somehow related to non linearities, and especially to market 'bubbles' and instability. Volatility is a key concept in the analysis of financial markets: it expresses the standard deviation of the logarithmic returns of a given financial instrument. The major interest in the concept of volatility within price transmission analysis lies in the fact that periods of exuberance can be generated by a temporary increase in volatility (*volatility clustering*) rather than by a temporary or permanent change in price formation and transmission mechanisms. In fact, one possible reconciliation of conventional I(1) series with the nonlinearities implied by «price bubbles» can be found in a sharp and temporary increase in volatility.

In recent years, in particular, the turmoil observed in many agricultural markets has increased the attention of researchers and policy makers on the increasing volatility of prices (Balcombe, 2011; European Commission, 2011; FAO, 2011; Hernandez et al., 2011; Huchet-Bourdon, 2011; Prakash, 2011) and on the need for explicitly modelling the change of volatility over time (time-varying volatility) in price transmission analysis[25]. The modelling issue is, in fact, twofold: how do we include time-varying volatility in price

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23 Another application to agricultural markets of a modelling framework where both short-run and long-run parameters may be regime-dependent can be found in by Myers and Jayne (2011). They actually present a single-equation approach which is, however, analogous to a conventional VECM specification.

24 A mention has to be made to a quite different line of research recently emerged in the empirical literature on nonlinearities in agricultural price transmission. As imposing *ex ante* some forms of these nonlinearities may be arbitrary and hardly confirmed by the data, an alternative approach is to maintain the conventional linear VECM representation and then use the method of local projections to compute nonlinear impulse response functions. Kuiper and Bunte (2011) analyse price transmission along the meat supply chain by applying the Jorda's method (Jorda, 2005) to compute nonlinear responses without the need to specify and estimate an underlying nonlinear dynamic system.

25 Here, the interest in the volatility of agricultural prices concentrates on its empirical implications for price transmission analysis. A detailed discussion on its theoretical explanations as well as on its micro and macro implications is beyond the scope of this paper (see Stigler, 2011, for a valuable review on the topic). Moreover, in the present review of the literature, we only consider studies where volatility (GARCH effects) is admitted within price transmission models (VECM) while we disregard those empirical works concentrating only on the analysis of the volatility in agricultural price series (Piot-Lepetit and M'Barek, 2011; Busse et al., 2011).

transmission models[26]? How is the change in volatility itself transmitted across markets (volatility spillovers or contagion)?

Regarding the first aspect, it is natural to analyse volatility by looking at the variance of the error term of the stochastic process generating the price series under observation. The typical tool of such analysis is the specification of GARCH (Generalized Autoregressive Conditional Heteroskedasticity) effects, that is, the specification of a price generating stochastic process whose error term follows itself a stochastic (ARMA) process. As far as the second aspect is concerned, it is worth noticing that in multivariate stochastic processes, as in price transmission models, these GARCH effects can also arise across individual series, consequently allowing the time-varying variance of one series to affect that of another series. These are also called Multiple GARCH (MGARCH) effects (Bollerslev, 1990) and are appropriate tools to analyse volatility spillovers.

More generally, admitting MGARCH effects in price transmission analysis means to make the difference between market interdependence and contagion explicit. Interdependence identifies the permanent «normal (or tranquil) times» linkage across prices, while contagion indicates the temporary increase of this interdependence after a significant shock, that is, in «turbulent times» (Bukug et al., 2003). In a context of a remarkable change in price volatility, therefore, the key issue in modelling price transmission is how to take into account these two different situations (Forbes and Rigobon, 2002; Bacchiocchi and Bevilacqua, 2009). Although the empirical literature ranges over a broader set of methodologies (Dungey et al., 2004), MGARCH models are one of the currently prevalent methodological solutions to model, at once, market interdependence and contagion during market crises. The flexibility of the MGARCH specification and its capacity to give a parsimonious representation of the formation and transmission of time-varying volatility across markets explains the increasing interest in this kind of models.

In principle, admitting a MGARCH effect within the basic price transmission modelling framework (VECM) is relatively straightforward. This VECM-MGARCH model is specified as follows:

$$\begin{aligned} \Delta\mathbf{p_t} &= \boldsymbol{\alpha\beta}'\mathbf{p_{t-1}} + \sum\nolimits_{i=1}^{k-1}\Gamma_i\Delta\mathbf{p}_{\mathbf{t}-i} + \boldsymbol{\varepsilon}_\mathbf{t} \\ \boldsymbol{\varepsilon}_\mathbf{t} &= \mathbf{H}_\mathbf{t}^{1/2}\boldsymbol{\nu}_\mathbf{t} \end{aligned} \tag{9}$$

where, in addition to the usual notation (see equation 5) $\boldsymbol{\nu}_\mathbf{t}$ is an ($n\times1$) vector of zero-mean, unit-variance, and independent and identically distributed disturbances[27], while $\mathbf{H_t}^{1/2}$ is the Cholesky factor of the time-varying ($n\times n$) conditional covariance matrix $\mathbf{H_t}$. This latter is the matrix generalization of univariate GARCH models and expresses how the current shocks and current volatility of a given price depend on past shocks and past volatility of the same price as well as those of other prices (volatility spillovers). The specification of $\mathbf{H_t}$ is the key issue underlying the specification and estimation of the VECM-MGARCH models (Bauwens et al., 2006). The easiest solution is the Conditional Correlation MGARCH (CC-

[26] Actually, many studies, especially applications to financial markets, also focus on how volatility affects asset returns (Smith, 2009). In agricultural markets, this kind of application may be of interest in the case of futures prices.
[27] Multivariate normality is usually assumed.

MGARCH) where the conditional covariance matrix has a simple structure as it is decomposed into a matrix of conditional correlations, $\mathbf{R_t}$, and a diagonal matrix of conditional variances, $\mathbf{D_t}$, of the error terms $\boldsymbol{\varepsilon}_\mathbf{t}$: $\mathbf{H_t} = \mathbf{D_t^{1/2} R_t D_t^{1/2}}$. In order to facilitate the estimation of such specification, Bollerslev (1990) originally proposed a parameterisation of $\mathbf{R_t}$ that assumes time invariance (Constant Conditional Correlation MGARCH, or CCC-MGARCH). Such specification, however, is not particularly helpful in price transmission analysis as it strongly restricts the capacity of the model to take into account time-varying volatility and volatility spillovers. Empirical applications of the VECM-MGARCH model to agricultural price transmission thus adopt time-variant parameterisation of $\mathbf{R_t}$. It is the case of the Dynamic Conditional Correlation MGARCH (DCC-MGARCH)[28] and of the BEKK-MGARCH specifications. The latter has been originally proposed by Engle and Kroner (1995) and specifies the conditional covariance matrix as follows: $\mathbf{H_t} = \mathbf{C'C} + \mathbf{A'}\boldsymbol{\varepsilon}_{\mathbf{t-1}}'\boldsymbol{\varepsilon}_{\mathbf{t-1}}\mathbf{A} + \mathbf{B'H_{t-1}B}$ where **A**, **B** and **C** are $(n \times n)$ matrices containing time-invariant parameters to be estimated. **C** is a lower triangular matrix, **A** models the influence of past market shocks on current price volatility, while **B** models the influence of past volatility on current volatility. Therefore, with a limited amount of time-invariant parameters, this specification provides a highly flexible representation of how volatility varies and is transmitted.

Serra (2011) presents an application to agricultural price transmission of this VECM-BEKK-MGARCH model. The two parts of the model (the VECM modelling the price conditional mean and the BEKK-MGARCH modelling the conditional heteroscedasticity) are estimated jointly using the standard maximum likelihood procedures. Several other VECM-MGARCH approaches to agricultural price transmission have been proposed. All can be considered variants of the approach depicted above. The focus is particularly on possible parametric misspecifications of the conditional covariance. Nonlinear specifications have thus been proposed as in the case of the Exponential GARCH (EGARCH) model (Bukug et al., 2003) that also allows for an asymmetric representation of the impact of positive and negative innovations on conditional variances function. Serra (2011) proposes a semiparametric variant of the VECM-BEKK-MGARCH model while IFPRI (2011) adopts a combination of both linear and nonlinear specifications of univariate GARCH models.

Further possible specifications of the approach admit more complex nonlinearities like in the case of regime-dependent GARCH structures (the Switching Regime, SWGARCH, the Smooth Transition, STGARCH, and the Threshold, TGARCH, GARCH models) (Bacchiocchi and Bevilacqua, 2009). In other cases, modifications are introduced to relax the assumption of multivariate normality of the disturbance terms (Copula-GARCH models) (Lee and Long, 2009). These latter developments, that can enrich the representation of how volatility varies over time and transmits across markets, are currently less explored in the agricultural price transmission analysis.

3.3 Price transmission and policy interventions

A final major field of research on horizontal price transmission is the analysis of the role played by policy measures. Whatever the underlying theoretical justification be, sev-

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[28] Applications of the DCC-MGARCH specification within VECM approaches to agricultural price transmission can be found in Rapsomanikis (2011) and Rapsomanikis and Mugera (2011).

eral policy instruments may affect price formation and the relationships among prices generating regime-switching and nonlinearities in price linkages, as well as volatility clustering and volatility spillovers.

This is particularly evident in the case of spatial (especially cross-country) price transmission. Though not always fully understood (Stigler, 2011), it is evident that border and domestic policies (notably, price stabilisation policies) can have a strong influence on cross-country price transmission. In particular, variable levies, export subsidies, non tariff barriers, tariff rate quotas, and prohibitive tariffs are expected to prevent prices from convergence, whereas ad valorem and fixed tariffs should affect price spreads behaving as proportional or fixed transaction costs. In all cases, variations in the adoption of such instruments interfere with spatial arbitrage (that is, the LOP) and, thus, affect price and volatility transmission.

As a matter of fact, policy factors remained at the margin of the literature on price transmission in agricultural markets (Fackler and Goodwin, 2001) at least until the recent price crisis. This created a major interest in researchers on the eventual effect of changes in trade policies (introduction of export taxes, reduction of import duties, etc.). While analysing the key-forces underlying an unprecedented price rally, the role of policy factors has become an area that deserves increasing attention, also leading to a constant monitoring of the individual (country-level) policy measures in place[29], and to a careful assessment of their intended and unintended consequences on price transmission and volatility (Tangermann, 2011).

The basic question is: how can policy variables enter the above-mentioned price transmission modelling framework? In general terms, introducing policy variables within the VECM is relatively straightforward from a strictly methodological point of view. From an economic perspective, however, whether this representation is really consistent is more questionable. In particular, one may wonder whether the policy variables affect the short-run (adjustment) or the long-run (equilibrium) relationships or both; whether they affect the price expected value or its volatility, or both; whether they can be treated as exogenous variables or are, in fact, endogenous, that is, they depend on price movements themselves[30].

On the one hand, the increasingly sophisticated empirical specifications and econometric procedures mentioned above augment the toolbox one can use to include policy variables within the adopted models. On the other hand, however, these more sophisticated approaches often raise questions about the proper way to account for these variables in the analysis. Interestingly, despite the recent strong interest of policy makers and public institutions in this respect, the empirical studies explicitly analysing the role of policy in agricultural price transmission remain relatively few compared to the great amount of applications that focus on methodological developments[31].

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29 See, for instance, <http://www.fao.org/giews/english/index.htm>.

30 Listorti (2007, 2009) discusses how to derive empirical models from a theoretical framework that consistently considers how domestic and border policies affect the co-movement of commodity prices in international markets.

31 We restrict our attention to studies where policy variables are considered within a VECM framework. Thompson et al. (2002) in some way represent a borderline case as the impact of the 1993 CAP reform on wheat price convergence across EU is analysed within a SURECM approach where price interdependence is expressed through the correlation across error terms of individual price equations.

The prevailing solution to enter policy variables within price transmission analysis remains to interpret the policy regime change as a structural break. Once the breaks have been identified, a straightforward way of taking them into account in the estimating procedure is to split the sample according to the structural breaks (Barassi and Ghoshray, 2007; Mohanty and Langley, 2003; Verga and Zuppiroli, 2003), or to introduce specific dummy variables which allow the transmission parameters to vary according to the various policy regimes (Dawson *et al.*, 2006; Dawson and Sanjuan, 2006). In this latter case, following (7), policy variables enter the VECM representation as exogenous structural breaks.

Even in this apparently straightforward case, however, several practical issues remain. First of all, the location of the structural break points may not be so trivial. In some cases, the policy change intervenes in a well-identified point in time as in Mohanty and Langley (2003), Verga and Zuppiroli (2003), Listorti (2007, 2009), Esposti and Listorti (2011). For instance, a structural break approach is adopted by Ihle et al. (2011) to assess the impact of the different national implementation of the 2003 CAP reform on market integration. The application covers the 2003-2009 period. It concerns the market of young calves, and it also includes, among possible structural breaks, the eruption of the Blue Tongue disease in 2006.

In other cases, dating the structural break may require appropriate unit root or cointegration tests, like in Dawson et al. (2006), Dawson and Sanjuan (2006), Barassi and Ghoshray (2007). Esposti and Listorti (2011) adopt a modified unit root test to date the beginning and the end of the 2007-2008 «price bubble». This structural break is then combined with the policy intervention decided to cope with price exuberance, that is, the temporary suspension of EU import tariff on cereals. The very assumption of an exogenous change in policy regime can be questionable, as in some circumstances this change depends on price movements, therefore it is endogenous (this can be the case of some domestic market measures or some border policies).

More in general, as underlined by Esposti and Listorti (2011), the economic interpretation of how policy instruments affect price transmission may not be trivial and may significantly vary moving from (7) to the more sophisticated specifications in (6), (8) and (9). In these latter cases, at least in principle, policy variables may also have an impact on the co-explosive relationship, in (6), on the short-run and adjustment nonlinear dynamics by affecting regime-switching (either movements between the regimes and behaviour within each regime) in (8), on volatility clustering and transmission by entering the MGARCH part of (9).

The role of trade policies, and in particular of the entry price scheme, is investigated in Cioffi et al. (2011) and Santeramo and Cioffi (2012) in the case of fruit and vegetables within a threshold model (in the TVAR specification). In these applications the threshold is, respectively, exogenously set or endogenously determined, to assess whether prices behave differently according to the functioning of the EU entry price system for fruits and vegetables. Among the most recent applications, also the MSVECM approach seems to be a viable solution to include policy interventions. We can mention Djuric et al. (2011) who analyse how the export restrictions implemented by the Serbian government during the 2007-2008 price crisis affected international price transmission. This analysis is carried out within an MSVECM where the policy change enters the model by determining the regime switch. The same kind of approach is also used by Götz et al. (2010) to assess the impact of the temporary export controls introduced in Russia and the Ukraine on wheat price transmission during the 2007-2008 global food crisis. As in Djuric et al. (2011), the results emerging from this MSVECM approach suggest that the export ban or restrictions increased rather than disciplined market instability. Rezitis et al. (2009) uses an analogous MSVECM framework to analyse the impact of the 2003 CAP reform on vertical price transmission within the Greek lamb market.

Beside these few recent applications, we may acknowledge that the potentials of the current methodological developments on nonlinearities and time-variant volatility in price transmission analysis are still underexploited to assess the role of policy interventions. These few works clearly demonstrate, on the one hand, how far these approaches can take the insight on policy impacts. On the other hand, the way they enter policy measures within the price transmission framework generally remains *ad hoc*. A critical discussion on possible alternative solutions as well as a comparison of respective results could provide a more robust evidence in this respect.

4. Mapping the recent literature: some summary considerations

It seems helpful to conclude this survey on the broad and often very technical recent literature on agricultural price transmission by attempting a general and more detached view on the directions this literature is taking and on the consequent perspectives and challenges. Table 1 tries to offer this wider perspective by mapping the recent contributions with respect to the three major fields of research discussed in the previous section[32]. As a matter of fact, most of the recent empirical literature on agricultural price transmission actually concentrates on one of these three major topics or on a combination of them.

The picture provided in Table 1 suggests some general considerations on the developments achieved as well as on the open issues. First of all, it can be noticed that, although the recent turbulence in agricultural markets demonstrates that these three aspects always co-exist, empirical works taking into account, at the same time, nonlinearities, time-varying volatility and volatility spillovers, and changes in policy regime are still lacking. Many empirical works acknowledge the need for more comprehensive approaches and thus cope with two of these issues but, in fact, the novel contribution is usually focused on one of them (the primary focus). The impression is that the major attention is more on purely methodological issues rather than on understanding the real drivers of price co-movements and interdependence. This impression is reinforced by the bias of the recent empirical works toward some fashionable methodological solutions, often brought to the spotlight by the successful work of some research groups. In particular, much attention is paid to TVECM, MSVEC and MGARCH models.

The prevalence of these approaches, however, does not have to necessarily be intended as a demonstration of their supremacy with respect to alternative methodological solutions. It is clear that the recent evolution of agricultural markets suggests that nowadays a careful analysis of agricultural price transmission and of the respective role of market and trade policies cannot ignore possible nonlinearities, time-varying volatility and volatility spillovers. However, this literature has still to achieve an agreement on which approach

[32] Due the notable amount of studies provided on this topic in the recent years, Table 1 cannot be exhaustive and limits the analysis to the last decade focusing on the most recent contributions (particularly those coping with the 2007-2008 price crisis), and on those introducing some novelty in the methodological toolbox.

can be generally preferred; on the contrary, the choice of the methodology still remains mostly driven by specific conditions (e.g., available data) and objectives of the study.

In more general terms, this emerges as the most significant limit of this recent literature and, consequently, of the present review: it pays a lot of attention to often sophisticated methodological aspects but often disregards, or leaves in the background, several relevant practical issues. These latter issues are critical to find the most suitable and intelligible ways to include policy measures within the existing modelling frameworks and, therefore, to make these empirical studies really able to inform the debate on how policy reforms may «pass-through» across markets (mostly, across national borders) *via* price transmission (Brooks and Melyukhina, 2005).

In particular, the methodological developments have gone much further compared to the improvements in data availability and quality. The implication is that practitioners now have a wide and robust toolkit to study agricultural price transmission but appropriate data are often lacking. Reliable high-frequency agricultural price data remain rare and few research contributions seem to really provide steps forward in this direction. This lack of effort and attention on the availability and quality of data has two major consequences. First of all, researchers may be tempted to apply the abovementioned powerful toolkit to inappropriate data. For instance, Amikuzuno (2010) shows how low frequency (e.g., monthly) data might not capture the dynamics of the arbitrage processes thus providing imprecise estimates and misleading inferences about price transmission mechanisms. In other applications, futures rather than spot price data are used without paying much attention to the appropriateness of the methodological framework, and of the underlying theoretical justification, for this kind of data.

The second consequence is the strong concentration of empirical applications on a limited group of agricultural commodities and sectors. Many studies focus on cereal markets, while several others focus on meat and vegetable oil markets; a significant amount of studies concern the oil-biotehanol-corn or oil-biodiesel-oilseeds price linkage. The bias toward these agricultural commodities can be motivated by the lack of appropriate data for other agricultural products. In particular, the key assumption implied by these studies on horizontal price transmission is that products have a substantially homogenous quality (or time invariant quality differentials) across space. These requirements are quite restrictive and are met only by few agricultural commodities: those on which applications can be found. In many other cases (fruit and vegetables, wine, cheese, just to provide some examples) the suitability of these approaches can be strongly questioned unless data taking into account product quality are available.

Therefore, future research on agricultural price transmission is expected to continue to produce further improvements «vertically», by incessant refinements of the methodological toolkit, but also to make some progresses «horizontally», by improving the availability and the quality of data thus extending the application to a wider set of agricultural markets.

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