

Volatility Spillovers Between Energy and Agricultural Markets in Theory and Practice

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Abstract: Energy and agricultural commodities and markets have been examined extensively, albeit separately, for a number of years. In the energy literature, the returns, volatility and volatility spillovers (namely, the delayed effect of a returns shock in one asset on the subsequent volatility or covolatility in another asset), among alternative energy commodities, such as oil, gasoline and ethanol across different markets, have been analysed using a variety of univariate and multivariate models, estimation techniques, data sets, and time frequencies. A similar comment applies to the separate theoretical and empirical analysis of a wide range of agricultural commodities and markets. Given the recent interest and emphasis in bio-fuels and green energy, especially bio-ethanol, which is derived from a range of agricultural products, it is not surprising that there is a topical and developing literature on the spillovers between energy and agricultural markets. Modelling and testing spillovers between the energy and agricultural markets has typically been based on estimating multivariate conditional volatility models, specifically the BEKK and DCC models. The purpose of the paper is to evaluate the theory and practice in testing for volatility spillovers between energy and agricultural markets using the multivariate BEKK and DCC models, and to make recommendations as to how such spillovers might be tested using valid statistical techniques. Three new definitions of volatility and covolatility spillovers are given, and the different models used in empirical applications are evaluated in terms of the new definitions and statistical criteria.

Keywords: *Energy and agricultural markets, volatility and covolatility spillovers, univariate and multivariate conditional volatility models, definitions of spillovers*

1. INTRODUCTION

Energy and agricultural commodities and markets have been examined extensively, albeit separately, for a number of years. In the energy literature, the returns, volatility and volatility spillovers (namely, the delayed effect of a returns shock in one financial asset on the subsequent volatility or cointegration in another asset), among alternative energy commodities, such as oil, gasoline and ethanol across different markets, have been analysed using a variety of univariate and multivariate models, estimation techniques, data sets, and time frequencies. A similar comment applies to the separate theoretical and empirical analysis of a wide range of agricultural commodities and markets. Given the recent interest and emphasis in bio-fuels and green energy, especially bio-ethanol, which can be derived from a range of agricultural products, it is not surprising that there is a topical and developing literature on the spillovers between energy and agricultural markets, where the emphasis is on testing the magnitude and direction of the volatility spillovers between alternative commodities in these markets.

The purpose of the paper is to evaluate the theory and practice in testing for volatility spillovers between energy and agricultural markets using the BEKK and DCC models, and to make recommendations as to how spillovers might be tested using valid statistical techniques.

2. FULL AND PARTIAL VOLATILITY SPILLOVERS

Volatility spillovers are defined as the delayed effect of a returns shock in one asset on the subsequent volatility or cointegration in another asset. Therefore, a model relating Q_t to returns shocks is essential, and this will be addressed in the following sub-section. Spillovers can be defined in terms of full volatility spillovers and full cointegration spillovers, as well as partial cointegration spillovers, as follows, for $i, j, k = 1, \dots, m$:

$$(1) \quad \text{Full volatility spillovers: } \partial Q_{iit} / \partial \varepsilon_{kt-1}, \quad k \neq i; \quad (1)$$

$$(2) \quad \text{Full cointegration spillovers: } \partial Q_{ijt} / \partial \varepsilon_{kt-1}, \quad i \neq j, \quad k \neq i, j; \quad (2)$$

$$(3) \quad \text{Partial cointegration spillovers: } \partial Q_{ijt} / \partial \varepsilon_{kt-1}, \quad i \neq j, \quad k = \text{either } i \text{ or } j. \quad (3)$$

Full volatility spillovers occur when the returns shock from financial asset k affects the volatility of a different financial asset i . Full cointegration spillovers occur when the returns shock from financial asset k affects the cointegration between two different financial assets, i and j . Partial cointegration spillovers occur when the returns shock from financial asset k affects the cointegration between two financial assets, i and j , one of which can be asset k . When $m = 2$, only (1) and (3) are possible as full cointegration spillovers depend on the existence of a third asset.

3. CRITICAL ANALYSIS OF THE EMPIRICAL LITERATURE

A useful analysis of the empirical literature on examining volatility spillovers has been presented in “The dynamic pattern of volatility spillovers between oil and agricultural markets” by Saucedo, Brümmer and Jaghdani (2015). The authors examined 23 published papers predominantly on the basis of univariate and multivariate conditional volatility models, as well as one paper on each of univariate stochastic volatility and univariate realized volatility. For this reason, in this paper we have chosen 11 of the 23 published empirical papers that have used the multivariate full BEKK model (in one paper, the diagonal BEKK model), and two papers that estimated both full BEKK and scalar DCC. Scalar BEKK was not used at all, and in some cases a univariate conditional model was presented in addition to its multivariate counterpart.

The 11 papers that will be appraised in chronological order are given in Tables 1A to 1C. The appraisal of the empirical literature in this section does not consider the empirical findings as these are already given in Saucedo, Brümmer and Jaghdani (2015), albeit not critically from either a mathematical or statistical perspective. In addition to the energy commodities, agricultural commodities, countries, multivariate conditional volatility models, sample periods, and data frequencies that were discussed in Saucedo, Brümmer and Jaghdani (2015), the paper also considers the journals in which the papers were published, the energy and agricultural prices (namely spot or futures prices), data sources, software packages used in estimation and testing, the univariate conditional volatility models used in estimation as a first step in estimating their multivariate counterparts, the types of spillover effects considered (namely full volatility, full cointegration and partial cointegration spillovers), the analytical and statistical properties of the conditional volatility models, the purported hypothesis tests, the purported statistical significance

of the tests, and an overall assessment of each of the published papers. The 11 papers were published in some of the leading energy, agricultural and natural resource economics, and futures market journals, namely *Energy Economics* (3 papers), *European Review of Agricultural Economics* (2 papers), *Energy Policy* (2 papers), and one paper in each of the *Journal of Agricultural and Resource Economics*, *Energy Journal*, *Energies*, and *Journal of Futures Markets*.

Also given in Table 1A are the countries for which the energy and agricultural products data are obtained, predominantly the USA for ethanol, fuel ethanol, crude oil, light crude oil, heating oil, biodiesel, gasoline, and heating oil. Other countries or regions include France for ethanol, crude oil and biodiesel, European Union for oil, heating oil and gasoline, China for crude oil and fuel ethanol, international countries for crude oil and ethanol, and Brazil for crude oil and ethanol. Agricultural commodities include corn, rapeseed, soybeans, soybean oil, sugar and wheat for USA and France, barley, corn, sorghum and wheat for the USA and European Union, sugar for USA, Brazil and other international countries, and corn for USA and China.

Table 1A also shows that the most frequently used data on prices were for spot (or cash) prices (5 papers), futures prices (3 papers), and one paper each for both spot and futures prices, both spot prices and index, and nominal prices. The sample periods ranged from 1989, 1990, 1992, 1997, 2000, 2003, 2005-2006, and 2007-2013 for weekly data (7 papers), daily data (3 papers), and one paper that used monthly data for ethanol and corn (see also Table 1B)).

Table 1B also shows that the primary data sources included Bloomberg, EIA (energy, oil, crude oil, gasoline), IGC (cereal), CBOT (ethanol, corn, corn futures), FAO (corn), National Bureau of Statistics of China, Nebraska Government (ethanol), NASS (corn), CME (corn, ethanol, gasoline, light crude oil), NYMEX (gasoline, WTI, crude oil), CEPEA (ethanol, sugar), Center for Advanced Studies on Applied Economics (ethanol, sugar), USDA (corn cash), Ethanol and Biodiesel News (ethanol), and USDA (corn soybean).

The same table shows that only one paper stated the statistical, econometric or financial econometric software package, specifically, WinRATS version 6.30, that was used in estimation, whether for univariate or multivariate conditional volatility models. Consequently, there was no discussion of convergence of any algorithms that were used to estimate the models. This is a disappointing finding as it can be quite difficult to reproduce empirical results, especially for multivariate conditional volatility models, when the software package is not stated explicitly. Moreover, the “curse of dimensionality” cannot be determined when there is no discussion of the convergence of the algorithms, despite the fact it is well known that convergence is problematic when more than three financial assets are used to estimate the full BEKK model.

Table 1B provides some useful insights regarding the types of univariate and multivariate conditional volatility models that are estimated, as well as the alternative volatility spillovers that can be considered. Full BEKK is estimated in 7 papers, both full BEKK and scalar DCC are estimated in 2 papers, and diagonal BEKK and scalar DCC are each estimated separately in one paper. Full BEKK incorporates full volatility, full cointegration and partial co-volatility spillovers, while diagonal BEKK and scalar DCC allow only partial co-volatility spillovers.

As univariate models are necessary to obtain the standardized residuals for multivariate estimation, each of the papers uses at least one, indeed usually only one, univariate conditional volatility model to initiate the estimation process. Of the 11 published papers, 7 use only GARCH (including one semi-parametric GARCH), 2 use threshold GARCH (also commonly known as GJR), one paper uses only EGARCH, and one uses both GARCH and EGARCH.

The analytical and statistical properties of the QMLE of the univariate and multivariate conditional volatility models are analysed in Table 1C. Somewhat surprisingly and disappointingly, all 11 papers ignore any discussion of the analytical properties of the multivariate conditional volatility models, and 9 of the papers also ignore the analytical properties of the univariate conditional volatility models as a precursor to estimating the multivariate models. Gardebroek and Hernandez (2014) report that $\alpha + \beta < 1$, without explanation, but do not seem to appreciate that this is a sufficient but not necessary condition for the unconditional variance to be finite, and for the QMLE to be consistent. Wu and Li (2013) discuss the conditions for asymmetry and leverage for the EGARCH model, but do so incorrectly by concentrating on the first of two necessary conditions.

The papers purportedly test the hypotheses relating to volatility and cointegration spillovers without recognizing that such tests are invalid except for the diagonal and scalar BEKK models, and not valid

whatsoever for scalar DCC. Only one paper fails to provide any evidence of any purported hypothesis tests or diagnostic checks, which include the standard Ljung-Box Q test for the absence of serial correlation in the residuals of the conditional mean equation (in 2 papers), normality tests of the returns shocks (in 4 papers), both unit root tests and cointegration tests (in 6 papers), tests of causality (in 3 papers), and a test for long memory (in one paper).

As can be seen from Table 1C, all 11 papers reported on the purported statistical significance of the estimated parameters, despite the fact that there is no proof that the statistical properties hold for diagnostic checks and statistical significance of estimated presence in the absence of asymptotic results for the multivariate conditional volatility models. These diagnostic checks are generally invalid in the presence of estimating volatility and cointegration spillovers, except under the null hypothesis that such spillovers do not exist, which would seem to destroy the primary purpose of the analysis. As 7 of the 11 papers used weekly data and one paper used monthly data, with the remaining 3 papers having used daily data, it is surprising that there were no tests conducted for seasonal unit roots or seasonal cointegration.

The last column in Table 1C makes it clear that the overall assessment of the empirical literature in estimating and testing for volatility and cointegration spillovers between the energy and agricultural markets is one of disappointment. In short, the theoretical and empirical analyses in every paper are questionable. The only tests that are valid asymptotically are for the scalar and diagonal BEKK models. Diagonal BEKK was estimated only in one paper, but without any explanation regarding statistical validity. The diagonal BEKK model was almost certainly estimated to overcome the “curse of dimensionality” regarding convergence in estimating full BEKK. This raises serious questions and reservations about the unstated convergence in estimating full BEKK in 9 of the 11 published papers.

Table 1A
Summary of Literature on Volatility Between Energy and Agricultural Markets using BEKK and DCC

Author(s)	Journals	Countries	Energy commodities	Agricultural commodities	Sample periods	Prices
Algieri (2014)	Energy Policy	USA, France	Ethanol, crude oil, biodiesel	Corn, rapeseed, soybeans, soybean oil, sugar, wheat	2005-2013	Futures
Du and McPhail (2012)	Energy Journal	USA	Ethanol, gasoline, light crude oil	Corn	2005.3.25-2011.3.25	Futures
Gardebroek and Hernandez (2013)	Energy Economics	USA	Crude oil, ethanol	Corn	1997-2011	Spot
Mensi, Hammoudeh, Nguyen and Yoon (2014)	Energy Economics	USA, EU	Oil, gasoline, heating oil	Barley, corn, sorghum, wheat	2000-2013	Spot
Serra (2011)	Energy Economics	International, Brazil	Crude oil, ethanol	Sugar	2000.7-2009.11	Spot
Serra and Gil (2013)	European Review of Agricultural Economics	USA	Ethanol	Corn	1990.1-2010.12	Nominal
Serra, Zilberman and Gil (2011)	European Review of Agricultural Economics	USA, Brazil	Crude oil, ethanol	Sugar	2000.7-2008.2	Spot
Trujillo-Barrera, Mallory and Garcia (2012)	Journal of Agricultural and Resource Economics	USA	Crude oil, ethanol	Corn	2006-2011	Futures
Wu, Guan and Myers (2011)	Journal of Futures Markets	USA	Crude oil	Corn	1992-2009	Spot, futures
Wu and Li (2013)	Energy Policy	China	Crude oil, fuel ethanol	Corn	2003-2012	Spot, index
Zhang, Lohr, Escalante and Wetzstein (2009)	Energies	USA	Ethanol, gasoline, oil	Corn, soybean	1989.3-2007.12	Spot

Table 1B
Summary of Literature on Volatility Between Energy and Agricultural Markets using BEKK and DCC

Author(s)	Data frequency	Data sources	Software packages	Multivariate models	Univariate models	Spillovers
Algieri (2014)	Daily	Bloomberg	Unstated	Diagonal BEKK	GARCH, EGARCH	Partial covolatility
Du and McPhail (2012)	Daily	CME (corn, ethanol, gasoline, light crude oil), NYMEX (gasoline)	Unstated	Scalar DCC	GARCH	Partial covolatility
Gardebroek and Hemandez (2013)	Weekly	EIA (oil), CBOT (ethanol), FAO (corn)	Unstated	Full BEKK, scalar DCC	GARCH	Full volatility, Full covolatility, Partial covolatility
Mensi, Hammoudeh, Nguyen and Yoon (2014)	Daily	EIA (energy), IGC (cereal)	Unstated	Full BEKK, scalar DCC	GARCH	Full volatility, Full covolatility, Partial covolatility
Serra (2011)	Weekly	CEPEA (ethanol, sugar), EIA (crude oil)	Unstated	Full BEKK	Semi-parametric GARCH	Full volatility, Full covolatility, Partial covolatility
Serra and Gil (2013)	Monthly	Nebraska Government (ethanol), NASS (corn)	Unstated	Full BEKK	GARCH	Full volatility, Full covolatility, Partial covolatility
Serra, Zilberman and Gil (2011)	Weekly	Center for Advanced Studies on Applied Economics (ethanol, sugar), EIA (crude oil)	WinRATS (v. 6.30)	Full BEKK	GARCH	Full volatility, Full covolatility, Partial covolatility
Trujillo-Barrera, Mallory and Garcia (2012)	Weekly	NYMEX (WTI), CBOT (ethanol, corn)	Unstated	Full BEKK	Threshold GARCH	Full volatility, Full covolatility, Partial covolatility
Wu, Guan and Myers (2011)	Weekly	USDA (corn cash), CBOT (corn futures), NYMEX (crude oil)	Unstated	Full BEKK	Threshold GARCH	Full volatility, Full covolatility, Partial covolatility
Wu and Li (2013)	Weekly	National Bureau of Statistics of China	Unstated	Full BEKK	EGARCH	Full volatility, Full covolatility, Partial covolatility
Zhang, Lohr, Escalante and Wetzstein (2009)	Weekly	Ethanol & Biodiesel News (ethanol), EIA (gasoline, oil), USDA (corn, soybean)	Unstated	Full BEKK	GARCH	Full volatility, Full covolatility, Partial covolatility

Table 1C
Summary of Literature on Volatility Between Energy and Agricultural Markets using BEKK and DCC

Author(s)	Analytical properties of models	Statistical properties of models	Purported hypothesis testing	Purported significance of estimates	Overall Assessment
Algieri (2014)	Not addressed	Not addressed	Ljung-Box Q, normality, long memory	Yes	Questionable
Du and McPhail (2012)	Not addressed	Not addressed	Unit root, cointegration	Yes	Questionable
Gardebroek and Hernandez (2013)	$\alpha + \beta < 1$ for GARCH	Not addressed	Ljung-Box Q, unit root	Yes	Questionable
Mensi, Hammoudeh, Nguyen and Yoon (2014)	Not addressed	Not addressed	Normality, unit root, causality	Yes	Questionable
Serra (2011)	Not addressed	Not addressed	Unit root, cointegration	Yes	Questionable
Serra and Gil (2013)	Not addressed	Not addressed	None	Yes	Questionable
Serra, Zilberman and Gil (2011)	Not addressed	Not addressed	Unit root, cointegration	Yes	Questionable
Trujillo- Barrera, Mallory and Garcia (2012)	Not addressed	Not addressed	Unit root, cointegration	Yes	Questionable
Wu, Guan and Myers (2011)	Not addressed	Not addressed	Normality, unit root, cointegration	Yes	Questionable
Wu and Li (2013)	Incorrect discussion of leverage effect for EGARCH	Not addressed	Normality, unit root, causality	Yes	Questionable
Zhang, Lohr, Escalante and Wetzstein (2009)	Not addressed	Not addressed	Unit root, cointegration, causality	Yes	Questionable