The linkage between international dairy commodity prices and volatility: a panel-GARCH analysis

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Abstract

Purpose - The study's objective is to investigate the price volatility of four dairy commodities (skim milk powder [SMP], whole milk powder [WMP], butter, and cheddar cheese) in the three most significant regional markets (EU, Oceania, and US) in the international dairy market.

Design/methodology/approach – The study uses a panel-Generalized Autoregressive Conditional Heteroskedastic (panel-GARCH) modeling technique and data from January 12, 2001, to April 28, 2017.

Findings - Conditional volatility was higher during sub-periods 2007–2010 and 2014–2016 when conditional cross-correlations between prices had the lowest values. In some cases, they were negative (i.e., between EU and US and between Oceania and US for both butter and cheese). Interdependence across the three dairy markets, especially for skim milk powder and whole milk powder markets and for the butter market between EU and Oceania is also strongly evidenced. Interdependence is responsible for the spillover of price shocks across the three regions.

Research limitations/implications – The data set used should be extended to cover the COVID-19 pandemic period.

Originality/value – Thisis the first study to use panel-GARCH to examine international dairy prices and volatility linkages, where previous studies mainly used multivariate GARCH models. Panel-GARCH allow a high-dimensional data series (i.e., 12 dairy prices) and generate potential efficiency gains in estimating conditional variances and covariances by incorporating information about heterogeneity across markets and considering their interdependence.

Keywords: conditional volatility, implied conditional cross-correlation, panel-GARCH, global food crisis

Paper type Research paper

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1. INTRODUCTION

Increased volatility in international agricultural commodity prices , particularly in the dairy industry, has become a major concern for farmers, processors, and policymakers. Dairy products account for around 14% of global agricultural trade, hence their significance in international agricultural trade flows (OECD/FAO, 2016), and volatility in dairy prices has implications for farmers with regard to business planning, debt repayment capacity, the viability of the business, and solvency. Since 2007, the three leading dairy-producing regions, namely the European Union (EU), Oceania (New Zealand and Australia), and the US have become interrelated, forming a global market (Fousekis and Trachanas, 2016). International dairy price volatility is the result of several factors including the 2006-2007 global financial crisis, regional dairy policy changes (O'Connor and Keane, 2011), and various bilateral and multilateral trade agreements enacted around 2007-2008.Volatility in the prices of EU butter and skim milk powder may reflect the volatility in world market prices (Bergmann *et al*., 2016; O'Connor and Keane, 2011) and regional dairy policies may have affected dairy prices, particulary in EU and US (Rezitis and Rokopanos, 2019).

Previous studies have examined price co-movements (and transmission) in international dairy markets without explicitly investigating price volatility relations. For example, Fousekis and Grigoriadis (2016a) employed wavelet analysis on price co-movements in EU, Oceania, and US. Fousekis and Grigoriadis (2016b) investigated price dependence in the international butter markets using copula and wavelet methodologies. Fousekis and Trachanas (2016) explored price relations in skim milk powder for the three major exporters (EU, Oceania, and US) using a nonlinear autoregressive distributed lag approach. Fousekis *et al*. (2017) evaluated the integration of the international skim milk powder market using nonparametric and time-vaying copulas to investigate the price linkages among EU, Oceania, and US. Rezitis and Rokopanos (2019), employed R-vine copulas and investigated the impact of trade liberalization on price co-movements of butter and whole milk powder between the three leading markets. .

Other studies have examined vertical transmission (e.g. Acosta and Valdes, 2014), and spatial transmission (e.g., O'Connor, 2006; Acosta *et al.,* 2014), but they fail to address the issue of price volatility at the international level. As noted by O'Connor *et al.,* (2009), the extreme volatility that EU experienced in the first two decades of the 21st century presented significant price issues for EU dairy farmers and required them to examine their risk management strategies. Further, world prices of dairy products have shown significant price variability in recent years.

As such, this study investigates the price volatility of four dairy commodities (skim milk powder [SMP], whole milk powder [WMP], butter, and cheddar cheese) in three regional markets (EU, Oceania, and the US). A panel-Generalized Autoregressive Conditional Heteroskedastic (panel-GARCH) modeling technique is used to analyse biweekly data from January 12, 2001, to April 28, 2017.

Cermeño and Grier's (2006) approach extends conventional GARCH models to a panel setting and this is implemented here. Few studies have used a panel-GARCH model[1], most opting instead for multivariate GARCH models. However, a major disadvantage of the latter comparatively is the high number of unknown parameters that must be estimated. Furthermore, in contrast to previous studies using lower-dimensional data series (Apergis and Rezitis, 2003; Yang *et al.,* 2001; Gilbert and Morgan, 2010; Jacks *et al.,* 2011; Serra and Gil, 2013; Ji and Fan, 2012; Wang *et al.,* 2014; Cabrera and Schulz, 2016; Li *et al.,* 2017; Bohl and Sulewski, 2019;), the panel-GARCH approachallows for a high-dimensional data series (i.e., 12 international dairy prices). In all, panel-GARCH models generate potential efficiency gains in estimating the conditional variance and covariance processes by incorporating relevant information about heterogeneity across markets and considering their interdependence. The study is of interest to dairy industry participants, researchers, and policymakers for the following reasons: It provides a visualization of price volatilities of all dairy commodities under investigation and supplies model-implied Value at Risk (VaR) measures at the 5% and 1% levels for each dairy commodity and the VaR measure indicates the maximum expected loss on the dairy returns under

[1] Lee (2010) examined output growth and volatility for G-7 countries; Escobari and Lee (2015) analyzed demand uncertainty and capacity utilization in the U.S. airline industry. Lee and Valera (2015) explored volatility spillovers in Asian rice markets; Valera *et al.* (2017) investigated the relation between inflation and volatility across Asian countries, and Bouras *et al.* (2019) examined the impact of geopolitical risks on volatility and returns for 18 countries.

consideration at the 5% and 1% degrees of confidence. It is anticipated that the VaR measures will fall within periods of high volatility implied by the estimated panel-GARCH model used in the study.

The prices of the four dairy commodities examined are linked to the cost of raw milk and are interrelated. For example, when cheese inventories are tight, the price increases, initiating an increase in cheese production and causing a price increment in the milk used in cheese to attract more milk to cheese plants. These changes will affect the price of milk used in producing other dairy products like butter, skim milk powder, and whole milk powder.

The next section reviews previous studies, followed by Section 3 which presents Cermeño and Grier's (2006) panel-GARCH model, Section 4 in which the data is discussed, Section which 5 explains the empirical results, and Section 6 concludes the study.

2. LITERATURE REVIEW

Milk and dairy commodity prices tend to be sensitive to volatility because of perishability, seasonality of production, and inelastic demand (Nicholson and Fiddaman, 2003; Rezitis and Kastner, 2021). Evidence shows that changes in policies, such as abolishing milk quotas in EU, may also contribute to increased volatility. In line with this, using a dynamic multivariate Tobit model, Chavas and Kim (2004) found that the price floor support program decreased price volatility in US dairy markets, and in their study of price dynamics and price volatility specifically in the US cheese market (2005) price support programs contributed to a reduction in price volatility in that market which was greater in the short run than in the long run. This implies that market liberalization tends to increase volatility, as concluded by Chavas and Kim (2006) in their study of the US butter market. This is supported by Nicholson and Fiddaman (2003) who in their examination of US dairy markets through a dynamic systems model, argued that trade policies may amplify price stabilization behavior. Thraen (2011) also applied GARCH models to evaluate the volatility of US dairy commodity prices and similarly concluded that it did not persist over time. In the same vein, Rezitis and Pachis (2020) estimated that Greek producers in non-regulated fresh produce markets are more exposed to spillover effects from consumers than in additional regulated markets. Also, Birthal *et al.,* (2019) concluded that market power and anti-competitive practices intensified price volatility in the Indian onion market whereas implemented policies did not successfully tackle price fluctuations.

Studies on price transmission in dairy commodities are sporadic and largely relate to one of two categories, namely, vertical transmission (e.g. Acosta and Valdes, 2014) or spatial transmission (e.g., O'Connor, 2006; and Acosta *et al*., 2014). O'Connor (2006) studied the spatial transmission of wholesale prices for EU butter and skim milk powder for four different states while Acosta *et al.* (2014) showed that milk prices variability in global markets transmitted to Panama's domestic market, albeit with a lower magnitude. While significant changes in milk prices were found to be driven primarily by the domestic market, the study highlighted that volatility in global markets has significant implications for food security in the domestic country.

Meanwhile, several studies have emphasized trade policies in price transmission and volatility spillovers between the global and domestic markets. Baffes and Gardner (2003), Dawe (2009), and Baltzer (2013) pointed to a causal relationship between government price support programs and incomplete or low-price transmission of agricultural commodity prices. Conversely, Conforti (2004), Rapsomanikis (2011), Ghoshray (2011), and John (2013) found the relationship between international and domestic agricultural commodity prices to be robust when underpinned by government intervention,. In the 2010s, prices of EU dairy commodities were historically high and volatile and had increased sharply (Bergmann *et al*., 2016; O'Connor and Keane, 2011). Bergmann *et al*. (2016) examined butter prices and volatility transmission between EU and the world before and after the Luxembourg agreement and found that it had a significant impact. The strong link between EU and world markets is attributed to policy changes that enabled integration. In another study, examining price volatility in EU and world markets for skim milk powder and butter for the period 1990-2009, O'Connor and Keane (2011) used annualized standard deviation and ARMA-GARCH models for the 2007-2008 period which revealed that EU and world dairy prices experienced the highest levels of volatility during that period. The study concluded that less regulated markets tend to be more volatile than heavily regulated markets, and it proposed the EU's involvement in future markets and insurance products as a possible solution.

More recently, Szenderák *et al.* (2019) used the Diebold-Yilmaz Spillover Index to measure volatility spillover effects among EU milk markets concluding that international prices affect the milk prices of the member states and that price volatility had increased substantially since 2013. With the aim of aligning EU dairy prices to world prices (O'Connor *et al.,* 2015), reforms in the Common Agriculture Policy (CAP) such as the abolition of milk quotas, led to an increase in global supplies and the termination of export subsidies in the sector enhanced the co-movement of EU and international prices (Zhang *et al.,* 2017). Therefore, EU milk and dairy prices are interconnected with international prices and are prone to shifts and shocks in the global demand and supply (Schulte *et al.,* 2018).

Consequently, EU prices become more volatile as they are exposed to local and international shocks due to trade liberalization. This is supported by O' Connor *et al*. (2009) who using ARMA and GARCH models, determined price volatility in EU and world butter and skim milk powder. Results highlighted that the stabilization of EU prices until 2004 was due to a successful EU dairy policy. However, during 2007-2008, extreme volatility in EU and world butter and skim milk powder prices was noted and since 2007, dairy products have exhibited high levels of price volatility (Müller *et al.,* 2018). Volatility in commodity prices creates uncertainty, in turn affecting stakeholders' investments (Szenderák *et al*., 2019).

Shadbolt and Apparao (2016) argue that since 2007, volatility in New Zealand (NZ) milk prices has increased because of global market shocks and exchange rates. The farm system there is based extensively on pastures and largely depends on weather conditions, thus, a seasonal pattern in milk production and price variability has prompted processors to turn to long-life products like whole milk powder, skim milk powder, and butter. Moreover, trade between China and New Zealand has intensified since the 2008 free trade agreement and China is now the primary market for Oceania's exports of whole milk powder. Demand in China for milk and dairy products, especially butter, is growing, driven by an increased population with higher incomes, a change in consumers' preferences, and food safety issues (Shadbolt and Apparao, 2016; Szenderák *et al.,* 2019). China has become one of the major producers of whole milk powder globally, and has provided government support for local milk production (Shadbolt and Apparao, 2016; Zhang *et al.,* 2017).

New Zealand has targeted whole milk powder processing and production, establishing its presence in Asian markets. Additionally, international prices of milk and milk products will be affected by the free trade agreement between China and EU, the abolition of milk quotas, and increased EU dairy exports to the Asian market. Based on data released by the International Dairy Federation (2019), global butter prices exhibited the most robust price dynamics during 2018-2019, and EU butter exports decreased due to high domestic demand. In the same period, a substantial price dispersion was observed among EU, US, and Oceania dairy markets, which may be attributed to a lack of market integration. Moreover, institutional organizations like cooperatives can influence the dairy process., Müller *et al.* (2018) claimed that cooperatives tend to stabilize dairy price volatility while Szenderák *et al.* (2019) reinforced this argument and supported the idea that diversified production structures minimize price variation. In addition, cooperatives have been the main driver of milk packaging on behalf of the EU. However, the above studies fail to address price volatility in the international context. Specifically, they do not account for heterogeneity and interdependence in their analysis nor for any transmission effects between EU and world price volatility.

3. THE MODEL AND EMPIRICAL STRATEGY

Based on Cermeño and Grier (2006) and Lee (2010), the conditional mean equation for dairy returns (y_{it}) can be expressed as the following dynamic panel model with fixed effects:

$$y_{it} = \mu_i + \sum_{k=1}^{K} \phi_k y_{i,t-k} + x_{it}\beta + u_{it}, \quad i = 1,\ldots,N, \quad t=1,\ldots,T \qquad (1)$$

where N and T are the number of cross-sections and periods, respectively. There are 12 cross-sections (i.e., skim milk powder, whole milk powder, butter, and cheese for each of the three regions: EU, Oceania and the US) and approximately 425 time periods with biweekly dairy returns used for the period January 12, 2001, to April 28, 2017; y_{it} is the dependent variable that corresponds to the 12 biweekly dairy returns of the 12 dairy prices at time t (i.e., eusm, ocsm, ussm, euwm, ocwm, uswm, eubu, ocbu, usbu, euch, occh and usch; where the first two letters correspond to each of the three regions and the last two to each of the four dairy products under consideration); μ_i captures possible dairy specific effects; x_{it} could be a vector of exogenous variables, and β is a vector of coefficients. The disturbance term u_{it} is assumed to have a zero mean normal distribution with the following conditional moments:

$$E[u_{it}u_{js}] = 0 \text{ for } i \neq j \text{ and } t \neq s \quad (2)$$

$$E[u_{it}u_{js}] = 0 \text{ for } i = j \text{ and } t \neq s \quad (3)$$

$$E[u_{it}u_{js}] = \sigma_{ij,t}^2 \text{ for } i \neq j \text{ and } t = s \quad (4)$$

$$E[u_{it}u_{js}] = \sigma_{i,t}^2 \text{ for } i = j \text{ and } t = s \quad (5)$$

Equation (2) rules out non-contemporaneous cross-sectional correlation, and equation (3) indicates no autocorrelation. Equations (4) and (5) state the general conditions of the conditional variance-covariance process. The conditional variance and covariance process of dairy returns are assumed to follow a GARCH (1,1) process, as developed by Bollerslev *et al*. (1988).

$$\sigma_{it}^2 = \alpha_\iota + \delta\sigma_{i,t-1}^2 + \gamma u_{i,t-1}^2, \quad i=1,\ldots,N, \quad (6)$$

$$\sigma_{ijt} = \eta_{ij} + \lambda\sigma_{ij,t-1} + \rho u_{i,t-1}u_{j,t-1}, \quad i \neq j. \quad (7)$$

The model defined by equation (1) (conditional mean), equation (6) (conditional variance), and equation (7) (conditional covariance) is a dynamic panel model with conditional (co)variance. In this panel framework, the number of parameters is significantly reduced by imposing common dynamics on the individual dairy units' conditional variance and covariance process. Thus, in this case, the covariance matrix has $\left(\frac{1}{2}N(N+1)+4\right)$ parameters. The conditional variance, equation (6), and covariance, equation (7), imply that each provides common dynamics; however, their values are different for each dairy unit or pair of units. Furthermore, there are three conditions (i.e., $a_i > 0, (\delta+\gamma) < 1$ and $(\lambda+\rho) < 1$) that should be satisfied for the conditional variance and covariance to converge to some fixed (and non-negative, in the case of variance) values. However, there is no assurance of the positive definiteness of the covariance matrix of disturbances or that it converges to some fixed positive definite matrix.

Using matrix notation, equation (1) can be rewritten as:

$$y_t = \mu + Z_t\theta + u_t, \qquad t = 1,\ldots,T \tag{8}$$

where $Z_t = [y_{t-1} \ldots \vdots X_t]$ is a matrix and $\theta = [\phi_k \ldots \vdots \beta']'$ is a conformable column vector providing the corresponding coefficients of this matrix. The error term, u_t, follows a multivariate normal distribution $N(0,\ \Omega_t)$. The log-likelihood of the fixed-effects panel model can be given as:

$$L = -\tfrac{1}{2}NT ln(2\pi) - \tfrac{1}{2}\sum_{t=1}^{T} ln|\Omega_t| - \tfrac{1}{2}\sum_{t=1}^{T}\left[(y_t - \mu - Z_t\theta)' \times \Omega_t(y_t - \mu - Z_t\theta)\right] \tag{9}$$

The log-likelihood function given by equation (9) is maximised using Cermeño and Grier's (2006) maximum-likelihood (ML) method. It should be noted that the least-squares estimator is consistent but inefficient because the disturbance term, u_t, is conditionally heteroskedastic and cross-serially correlated.

4. DATA

The data comprise biweekly prices for skim milk powder, whole milk powder, butter, and cheddar cheese in EU, Oceania, and the US. The data series is obtained from the Dairy Marketing and Risk Management Program/University of Wisconsin databases and collected from the Dairy Market News of USDA Agricultural Marketing Service. Price data are measured in dollars per metric ton, and refer to the period January 12, 2001 to April 28, 2017. Thus, the data set contains i=12 biweekly dairy price series (i.e., prices of four dairy commodities in three regions) on T=426 dates (i.e., January 12, 2001–April 18, 2017). Table 1 presents descriptive statistics on log dairy prices (i.e., $ln(p_t)$) and their percentage changes or returns (i.e., $y_t = ln(p_t) - ln(p_{t-1})$), and Figures 1.1 and 1.2 provide the corresponding plots. They illustrate that dairy prices are more dispersed after 2006, especially during the sub-periods 2007–2010 and 2014–2016 with volatility clustering during 2007–2010 and 2014–2016 indicated in Figure 1.2. The Engle test for ARCH effects applied to residuals of the series under consideration rejects the null that the residual series is homoscedastic for different lag levels suggesting that the variance of each series is not constant and that each series might follow an ARCH or a GARCH structure.

During the period 2013–2015, Oceania's share of dairy exports was around 38% (New Zealand 32% and Australia 6%), followed by EU (31%), and US (12%). While the EU-28 is the top exporter in the international skim milk powder and cheese markets, Oceania leads in the export of whole milk powder and butter. Major importers of skim milk powder, whole milk powder, and butter are southeast Asia, north Africa, and China with Mexico, the Middle East and Russia importing significant quantities of skim milk powder, whole milk powder and butter respectively. Among the largest cheese importers in 2015 were Russia, the US, Japan, Latin America, North Africa, and the Middle East.

5. RESULTS AND DISCUSSION

To begin univariate and panel unit root tests are described and tested for the percentage price change (returns) data. The top part of Table 2 shows the results of the augmented Dickey–Fuller (1981), Phillips–Perron (1988), and KPSS (Kwiatkowski *et al.,* 1992) unit root tests indicaingthat the null hypothesis of a unit root is rejected in all cases. In other words, the test results support integration, or I(1), for all international dairy price series under consideration. The bottom part of the table shows the Levin–Lin–Chu (2002), Im–Pesaran–Shin (2003), and Breitung (2001) panel unit root tests of the dairy price return data. Most panel-based test statistics strongly reject the null hypothesis of a panel unit root, enabling this panel to be treated as stationary.

Table 3 displays estimation results for the panel-GARCH model given by equations (1)-(7). The appropriacy of some unique versions of the panel-GARCH model (1–7) might be more appropriate is also tested by, first, restricting $\mu_\iota = \mu$ and $\eta_{ij} = \eta_i$ where i = 1,…,12, and, second, if $\eta_{ij} = \eta_i$ where i = 1,…,12. The likelihood ratio test in the first case provides a value of $\chi^2_{76} = 209.84$, and in the second $\chi^2_{65} = 122.37$, which both show strong support of the unrestricted model given in Table 3. Furthermore, other test results rejected the hypothesis that product-specific effects are equal for skim milk powder, whole milk powder, butter, and cheddar cheese. The empirical results indicate that all the individual-specific effects in the mean equation (i.e., μ_ι) are statistically significant at the 1% level of significance. Additionally, the mean equation follows an AR(1) process because almost all one-time lagged dairy return coefficients are statistically significant.

Results in Table 3 suggest that dairy price volatility can be designated as a significant and relatively persistent, although stationary, GARCH(1, 1) process. Likewise, the empirical results of the covariance equation stipulate that this is a quite persistent GARCH(1, 1) process. It is noteworthy that all the individual specific coefficients (α_i) in the variance equation are statistically significant at the 1% level of significance. Moreover, all 66 pairs of specific coefficients ($\eta_{\iota j}$) in the covariance equation are positive, with 51 being statistically significant at the 1% level, eight at the 5% level, four at the 10% level, and the remaining three statistically insignificant.

The individual-specific coefficients (α_i) of the conditional variance equation (Table 3), as well as the calculated mean level of conditional volatility of dairy prices (Table 4), indicate that US skim milk powder (*ussm*), US-whole milk powder (*uswm*), and EU-Cheese (*euch*) have the lowest levels of conditional volatility. Furthermore, Table 4 shows that for most dairy products under study, the mean level of conditional volatility is higher after 2006 (i.e., the sub-period 2007–2017) which could be due to the increased integration of the international dairy market that took place after 2006. Additionally, various multilateral trade agreements and agricultural policy changes took effect in EU and the US (O' Connor *et al.,* 2009; Müller *et al.,* 2018; Chavas and Kim, 2006; and Nicholson and Fiddaman, 2003). The conditional volatility is particularly high during the sub-periods 2007–2010 and 2014–2016. In general, these findings are also supported by Figure 2.1. graphs which show the conditional volatility of each dairy price under examination for the whole study period (i.e., 2001–2017). Notably, dairy price conditional volatilities of each dairy commodity increase after the 2006-2007 global financial crisis, coinciding with the free trade agreements enacted in 2007 and EU and US liberalization policy changes.

Concerning cross-sectional dependence among the dairy price returns, the results of the pair-specific coefficients (η_{ij}) of the conditional covariance equation (Table 3) show the highest dependence to be between EU and Oceania, possibly because EU and Oceania are the largest dairy exporters, and the US follows. This finding is supported by Fousekis *et al.* (2017) and Fousekis and Grigoriadis (2016b) who revealed that price integration is stronger between EU and Oceania than between Oceania and US, which is a latecomer to the international dairy market. The descriptive statistics of implied conditional cross-correlation and the graphs of cross-correlations are shown in Table 5 and Figure 2.2, respectively. The results indicate that the lowest cross-correlation, in descending order, is between EU and Oceania cheese (*euch-occh*), EU and US cheese (*euch-usch*), EU and US butter (*eubu-usbu*), Oceania and US butter (*ocbu-usbu*), and Oceania and US cheese (*occh-usch*). In contrast, the highest cross-correlation, in descending order, is between EU and Oceania whole milk powder (*euwm-ocwm*), EU and Oceania skim milk powder (*eusm-ocsm*), EU and US skim milk powder (*eusm-ussm*), Oceania and US skim milk powder (*ocsm-ussm*), EU and Oceania butter (*eubu-ocbu*), EU and US whole milk powder (*euwm-uswm*), and Oceania and U.S. whole milk powder (*ocwm-uswm*). Thus, the results suggest a much lower price integration between the three regions under considerationin the cheese and butter markets (except for a high price integration between EU and Oceania in the butter market) compared to that of the milk markets (i.e., skim milk powder and whole milk powder). This finding is consistent with the results of several studies. Fousekis *et al.* (2017), found an increasing degree of price linkages for the three main regions producing skim milk powder (EU, Oceania, and US); Fousekis and Grigoriadis (2016a) found a solid long-run price relationship in the two butter-producing regions (EU and Oceania), and Fousekis and Trachanas (2016), found a stable long-run price relationsip in skim milk powder in the three regions (EU, Oceania, and US).

The graphs in Figure 2.2 indicate that the implied conditional cross-correlation of dairy price volatility shows one distinct V-type trend during the sub-period 2007–2010 and another during the sub-period 2014–2016. Furthermore, during both sub-periods, most of the conditional cross-correlations take their lowest values and in some cases, they are negative (i.e., between EU and US and between Oceania and US for both butter and cheese). This is supported by the negative minimum values of the descriptive statistics of implied cross-correlation in Table 5, which tends to decrease during high conditional volatility periods (i.e., 2007–2010 and 2014–2016). Findings suggest an increasing degree of diversification during periods of high price volatility. Note that diversification benefits are greater when conditional cross-correlation takes negative values (i.e., between EU and US and between Oceania and the US for butter and cheese). The univariate values at risk (VaR) are presented in Figure 3. Considering VaR at the 5% and 1% levels, the most extreme values of the VaR estimate occur after 2006, and especially during the 2007–2010 and 2014–2016 sub-periods. This supports the abovementioned empirical findings. Specifically, the most extreme value for skim milk powder in EU occurs on 22.8.2014; in Oceania on 3.5.2013, and in US on 12.2.2010; for whole milk powder in EU on 2.1.2009, in Oceania on 20.3.2015, and in US on 16.1.2009; for butter in EU on 20.7.2007, in Oceania on 19.12.2008, and in US on 17.10.2014; for cheese in EU on 7.11.2008, in Oceania on 2.1.2009, and in US on 16.1.2009.

6. CONCLUSIONS

The study used a panel GARCH model to estimate conditional volatility and implied conditional cross-correlation of dairy prices of four commodities (skim milk powder, whole milk powder, butter, and cheddar cheese) in three main regional markets (EU, Oceania, and US) from January 12, 2001 to April 28, 2017. The empirical results indicate that most of the individual-specific effects in the mean, variance, and covariance equations are statistically significant, justifying the use of the panel-GARCH model. Conditional volatility was higher after 2006, especially during sub-periods 2007–2010 and 2014–2016, in which conditional cross-correlations between prices had the lowest values and in some cases, were negative (i.e., between EU and US and between Oceania and US for both butter and cheese). Findings suggest greater diversification possibilities for farmers. Diversification benefits increase during periods of high volatility, when the strategy is most needed.

Interdependence across the three dairy markets, especially for skim milk powder and whole milk powder markets and for the butter market between EU and Oceania was strongly indicated, and the extent of interdependence is responsible for the spillover of price shocks across them. Improved understanding of the conditional mean and variance of dairy product prices' can enhance price and income stability for stakeholders through policy making. Indeed, this research underscores the importance of trade and domestic support policies. International trade and regional trade agreements can aggravate the impact of price changes on farmers' welfare and on actors in the value chain. The finding regarding liberalization in trade policies on dairy prices implies that government intervention in the dairy sector in one country may cause price volatility in another. Furthermore, strong evidence of interdependence among three major dairy markets internationally has implications for global policy coordination. Further study should extend the data set to cover the COVID-19 pandemic and comparison made with pre-COVID-19 international dairy commodity price and volatility linkages.

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Figure 1.1: Biweekly prices of SMP, WMP, Butter and Cheese

EU, Oceania and USA

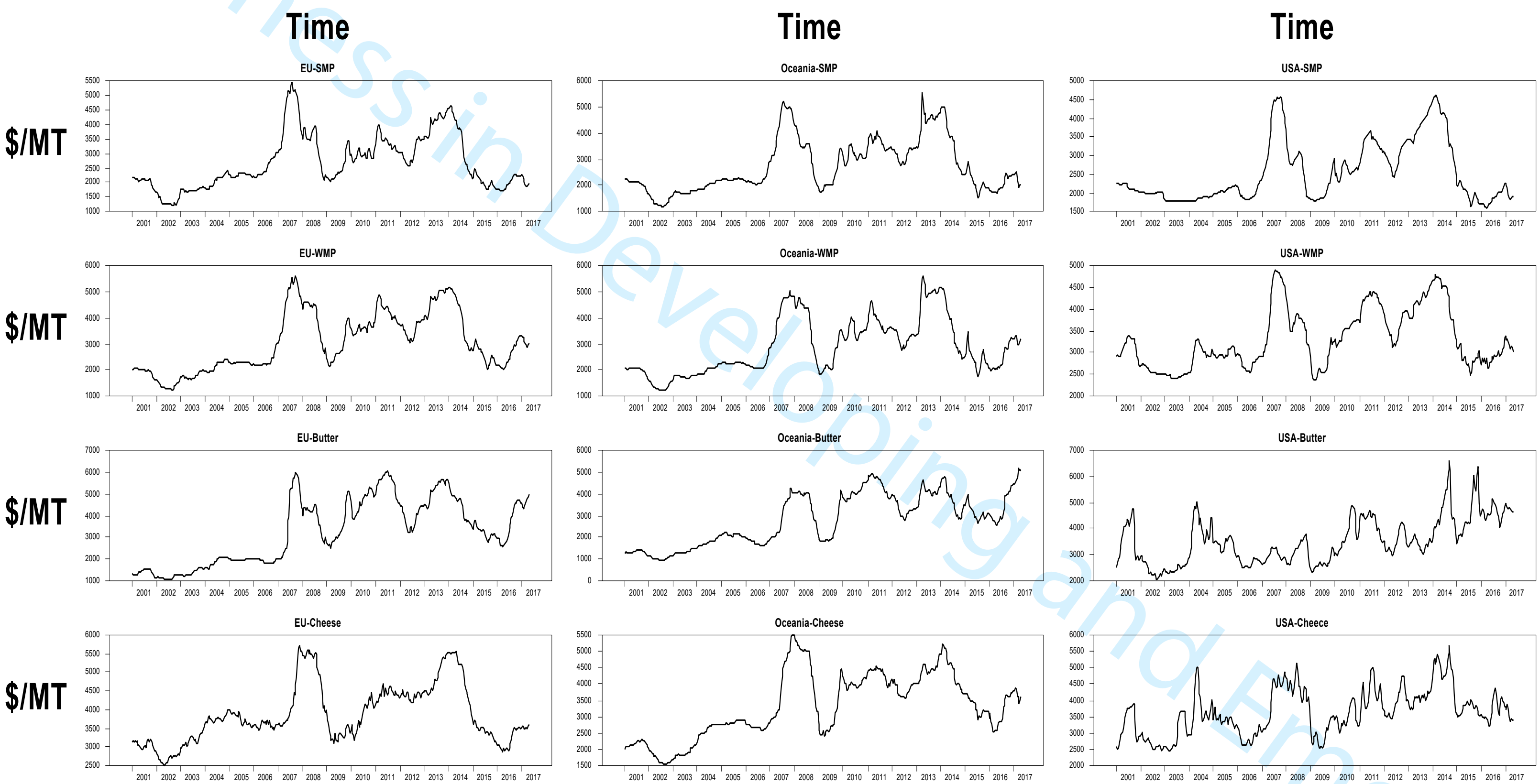


Figure 1.2: Percentage change of SMP, WMP, Butter and Cheese prices

EU, Oceania and USA

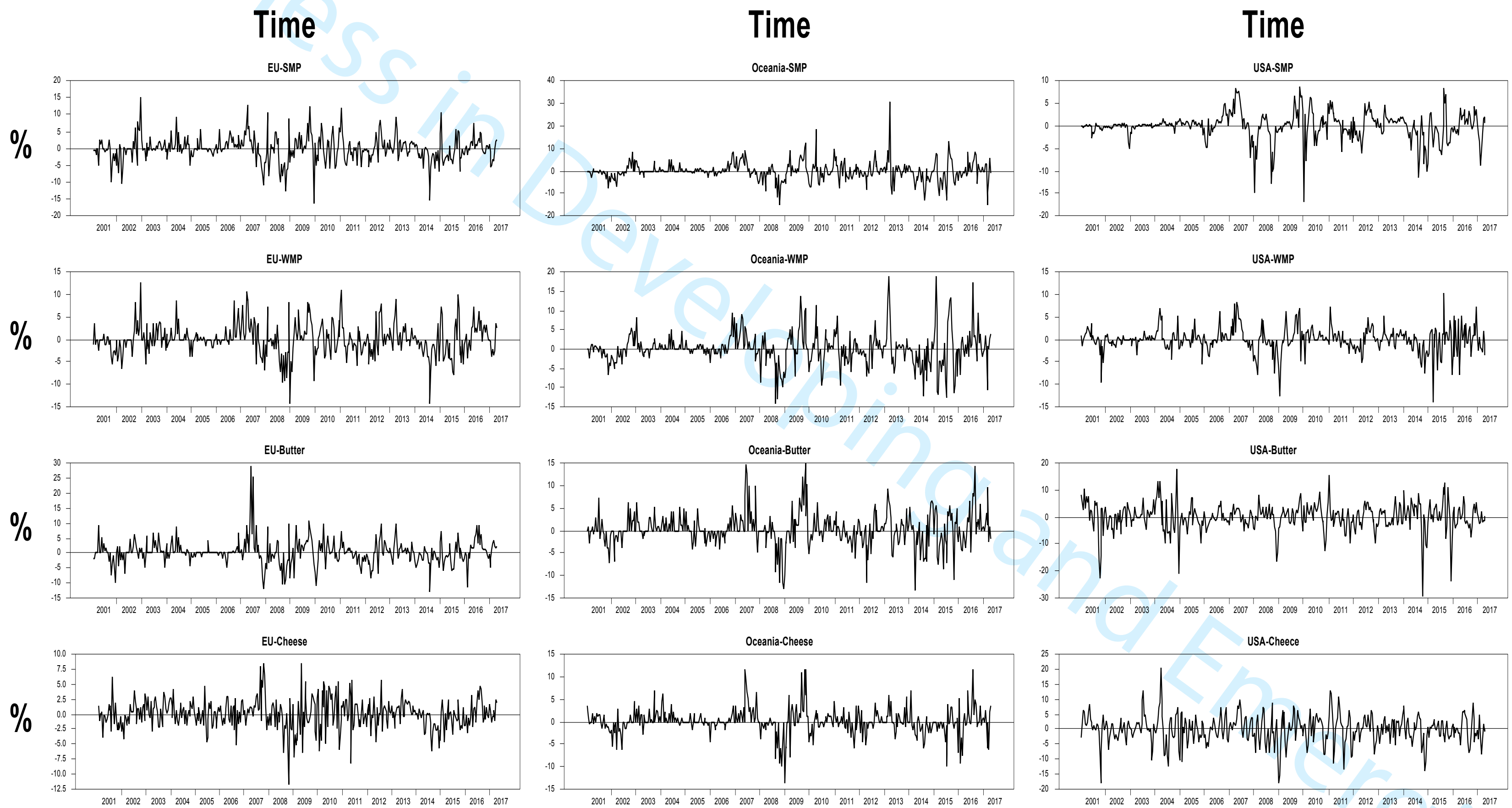
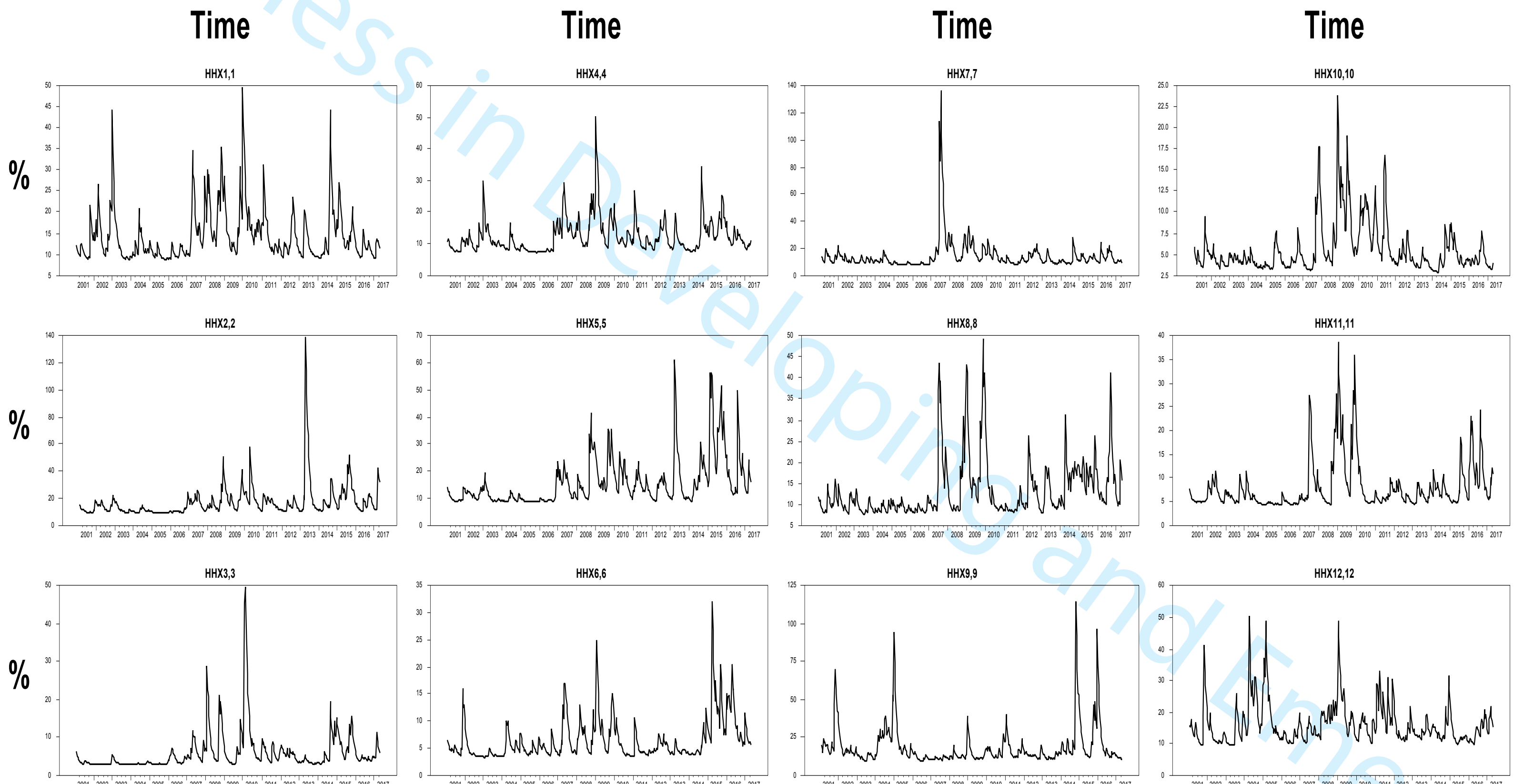


Figure 2.1: Conditional volatility of dairy prices

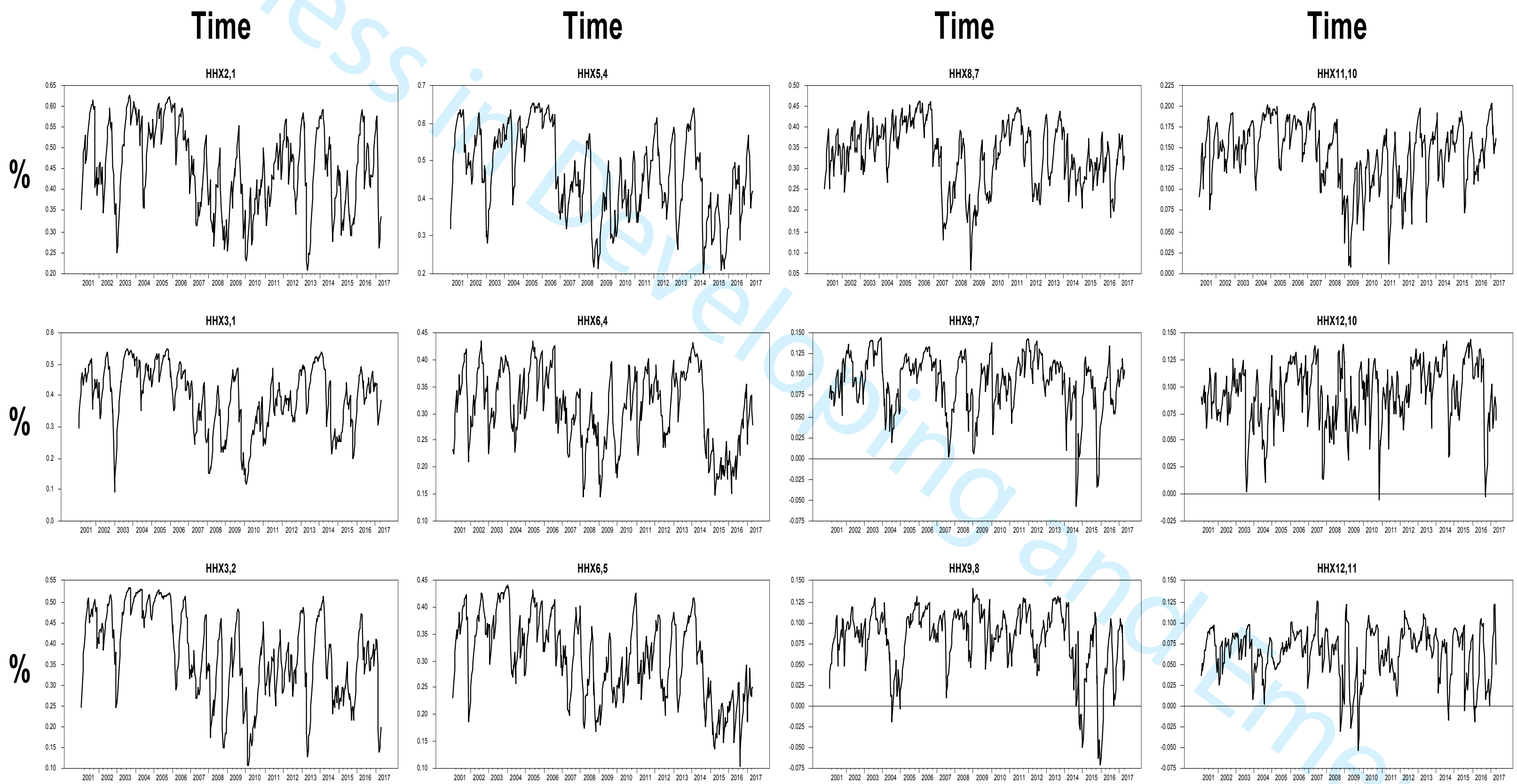
EU, Oceania and USA



1:eusm, 2:ocsm, 3=ussm, 4=euwm, 5=ocwm, 6=uswm, 7=eubu, 8=ocbu, 9=usbu, 10=euch, 11=occh, 12=usch

Figure 2.2: Implied conditional cross correlation of dairy prices

EU, Oceania and USA



1:eusm, 2:ocsm, 3=ussm, 4=euwm, 5=ocwm, 6=uswm, 7=eubu, 8=ocbu, 9=usbu, 10=euch, 11=occh, 12=usch

Figure 3: VaR estimates at the 5% and 1% levels for dairy commodities

SMP, WMP, Butter and Cheese for EU, Oceania and USA

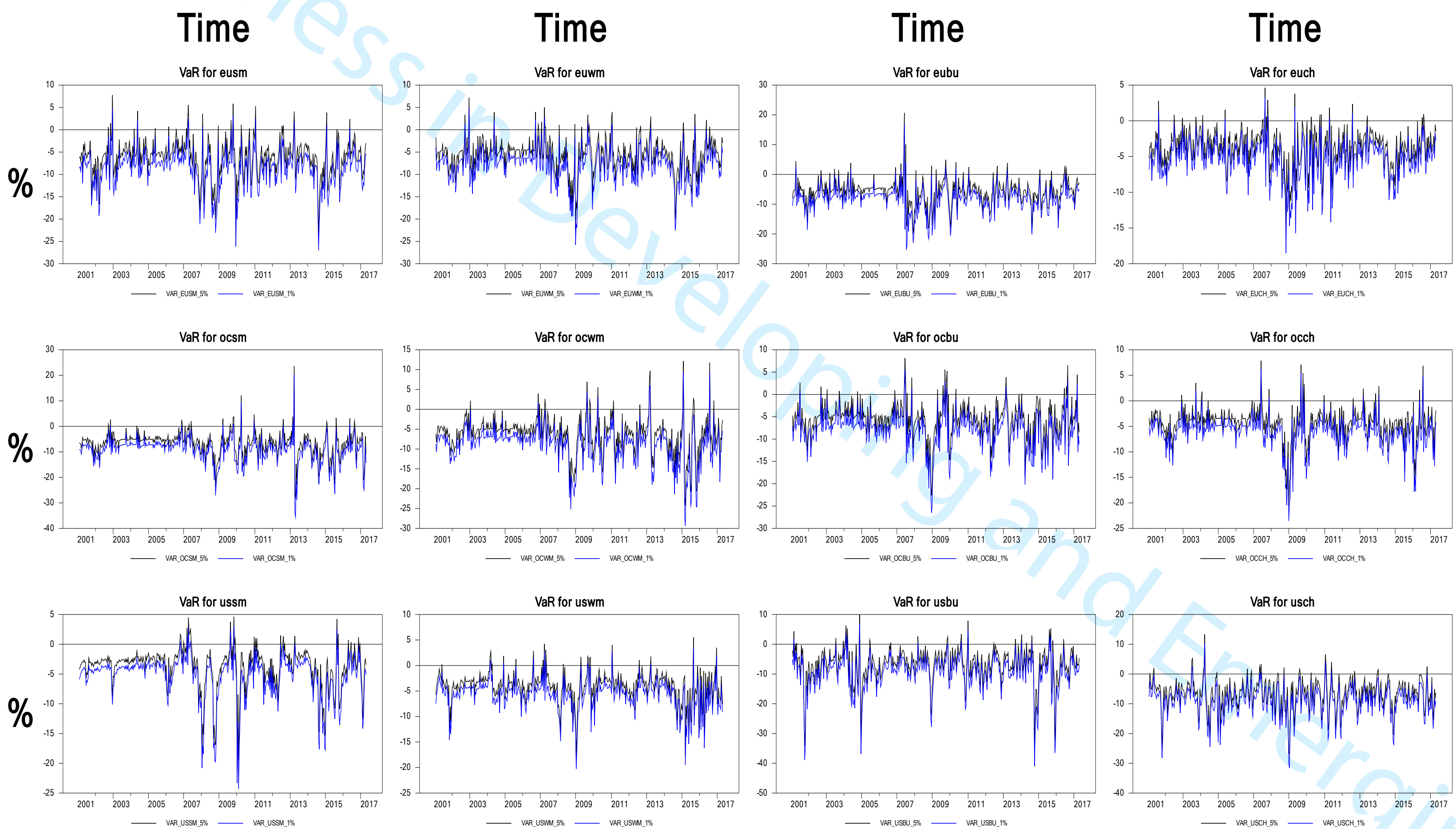


Table 1: Descriptive Statistics of SMP, WMP, Butter and Cheese prices for EU, Oceania and USA

	Biweekly average price ($/TN)				Biweekly percentage price change (%)				
	Mean	SE	Min.	Max.		Mean	SE	Min.	Max.
$eusm_t$	2680.00	928.78	1200	5450	$y_{eusm,t}$	-0.025	3.765	-16.144	15.221
$ocsm_t$	2726.80	1001.10	1187.5	5562.5	$y_{ocsm,t}$	-0.026	4.210	-15.415	30.811
$ussm_t$	2532.43	804.68	1599.88	4614.12	$y_{ussm,t}$	-0.039	3.049	-17.037	8.525
$euwm_t$	3042.35	1116.81	1250	5600	$y_{euwm,t}$	0.096	3.470	-14.174	12.705
$ocwm_t$	2885.42	1064.96	1212.5	5600.0	$y_{ocwm,t}$	0.101	4.244	-14.217	18.859
$uswm_t$	3310.18	673.12	2369.95	4894.21	$y_{uswm,t}$	0.006	2.708	-13.865	10.318
$eubu_t$	3247.77	1492.06	1050	6025	$y_{eubu,t}$	0.311	4.042	-12.872	29.213
$ocbu_t$	2821.15	1179.89	962.5	5212.5	$y_{ocbu,t}$	0.315	3.707	-13.240	14.842
$usbu_t$	3546.35	886.86	2058.77	6593.63	$y_{usbu,t}$	0.146	5.004	-29.548	17.670
$euch_t$	3858.73	773.73	2510.07	5728.26	$y_{euch,t}$	0.033	2.459	-11.777	8.536
$occh_t$	3320.61	1000.40	1550	5500	$y_{occh,t}$	0.138	2.883	-13.580	11.778
$usch_t$	3641.17	700.90	2432.11	5665.60	$y_{usch,t}$	0.063	4.624	-18.094	20.398

Notes: $eusm_t$ ($y_{eusm,t}$): EU SMP price (returns); $ocsm_t$ ($y_{ocsm,t}$): Oceania SMP price (returns); $ussm_t$ ($y_{ussm,t}$): US SMP price (returns); $euwm_t$ ($y_{euwm,t}$): EU WMP price (returns); $ocwm_t$ ($y_{ocwm,t}$): Oceania WMP price (returns); $uswm_t$ ($y_{uswm,t}$): US WMP price (returns); $eubu_t$ ($y_{eubu,t}$): EU butter price (returns); $ocbu_t$ ($y_{ocbu,t}$): Oceania butter price (returns); $usbu_t$ ($y_{usbu,t}$): US butter price (returns); $euch_t$ ($y_{euch,t}$): EU cheese price (returns); $occh_t$ ($y_{occh,t}$): Oceania cheese price (returns); $usch_t$ ($y_{usch,t}$): US cheese price (returns).

Table 2: Unit Root Tests

	Augmented Dickey-Fuller			Phillips-Perron		KPSS	
	None	Constant	C&T	Constant	C&T	Constant	C&T
Monthly average price percentage change of cow's raw milk for 21 European counties							
$y_{eusm,t}$	-12.90 (0)***	-12.88(0) ***	-12.89(0) ***	-12.86(1) ***	-12.88(1) ***	0.191 (1)	0.108 (1)
$y_{ocsm,t}$	-13.62 (0) ***	-13.60(0) ***	-13.60(0) ***	-13.52(1) ***	-13.54(1) ***	0.165(1)	0.107(1)
$y_{ussm,t}$	-8.32 (2)***	-8.31 (2)***	-8.31 (2) ***	-10.85(3) ***	-10.87(3) ***	0.125(3)	0.087(3)
$y_{euwm,t}$	-9.55(1)***	-9.54(1)***	-9.53(1)***	-13.36(2) ***	-13.37(2) ***	0.137(2)	0.094(2)
$y_{ocwm,t}$	-12.08(0) ***	-12.07(0) ***	-12.05(0) ***	-11.99(1) ***	-11.99(1) ***	0.089(1)	0.081(1)
$y_{uswm,t}$	-7.72(2) ***	-7.71(2) ***	-7.71(2) ***	-15.28(3) ***	-15.29(3) ***	0.079(3)	0.059(3)
$y_{eubu,t}$	-9.16(1) ***	-9.21(1) ***	-9.20(1) ***	-13.45(2) ***	-13.46(2) ***	0.094(2)	0.068(2)
$y_{ocbu,t}$	-9.13(1) ***	-9.17(1) ***	-9.16(1) ***	-13.52(2) ***	-13.52(2) ***	0.075(2)	0.076(2)
$y_{usbu,t}$	-13.38(1) ***	-13.37(1) ***	-13.36(1) ***	-12.99(2) ***	-12.99(2) ***	0.023(2)	0.023(2)
$y_{euch,t}$	-11.53(1) ***	-11.52(1) ***	-11.53(1) ***	-18.43(2) ***	-18.45(2) ***	0.142(2)	0.077(2)
$y_{occh,t}$	-8.98(1) ***	-8.99(1) ***	-8.98(1) ***	-15.26(2) ***	-15.28(2) ***	0.148(2)	0.072(2)
$y_{usch,t}$	-13.56(1) ***	-13.55(1) ***	-13.54(1) ***	-13.54(2) ***	-11.95(2) ***	0.040(2)	0.019(2)
Panel Unit Root tests							
Levin-Lin-Chu test (t-adjusted)			Im-Pesaran-Shin test (t-bar)		Breitung test statistic		
None	Constant	C&T	Constant	C&T	None	Constant	C&T
-39.57***	-10.38***	-0.913	-39.92***	-41.41***	-18.09***	-12.25***	-17.05***

Notes: $y_{eusm,t}$: EU SMP returns; $y_{ocsm,t}$: Oceania SMP returns; $y_{ussm,t}$: US SMP returns; : $y_{euwm,t}$: EU WMP returns; $y_{ocwm,t}$: Oceania WMP returns; $y_{uswm,t}$: US WMP returns; : $y_{eubu,t}$: EU butter returns; $y_{ocbu,t}$: Oceania butter returns; $y_{usbu,t}$: US butter returns; : $y_{euch,t}$: EU cheese returns; $y_{occh,t}$: Oceania cheese returns; $y_{usch,t}$: US cheese returns,

Numbers in brackets indicate the number of lags, *** indicate statistical significance at 1% level of significance.

Table 3: Empirical results of panel GARCH on SMP, WMP, Butter and Cheese prices for EU, Oceania and USA for the period 2001-2017

Convergence in 324 Iterations. Final criterion was 0.0000072 <= 0.0000100												
Log Likelihood Value: -12238.1993												
Conditional mean												
$y_{i,t} = \mu_i + \phi_i y_{i,t-1} + u_{i,t}, \quad i = 1,\ldots,12, \quad t = 2001{:}02{:}09,\ldots,2017{:}04{:}28$												
$y_{i,t}$	$y_{eusm,t}$	$y_{ocsm,t}$	$y_{ussm,t}$	$y_{euwm,t}$	$y_{ocwm,t}$	$y_{uswm,t}$	$y_{eubu,t}$	$y_{ocbu,t}$	$y_{usbu,t}$	$y_{euch,t}$	$y_{occh,t}$	$y_{usch,t}$
μ_i	-0.042*** (0.009)	-0.083*** (0.005)	0.034*** (0.003)	-0.023*** (0.005)	-0.140*** (0.009)	-0.023*** (0.008)	0.075*** (0.001)	0.042*** (0.007)	0.096*** (0.009)	0.032*** (0.100)	0.032*** (0.001)	-0.053*** (0.008)
ϕ_i	0.155*** (0.042)	0.105** (0.045)	0.492*** (0.045)	0.135*** (0.044)	0.178*** (0.040)	0.228*** (0.048)	0.243*** (0.046)	0.145*** (0.051)	0.434*** (0.041)	0.084* (0.048)	0.057 (0.054)	0.460*** (0.042)
Conditional variance												
$\sigma^2_{i,t} = \alpha_i + \underset{(0.009)}{0.131^{***}} u^2_{i,t-1} + \underset{(0.017)}{0.720^{***}} \sigma^2_{i,t-1}, \quad i = 1,\ldots,12, \quad t = 2001{:}02{:}09,\ldots,2017{:}04{:}28$												
$\sigma^2_{i,t}$	$\sigma^2_{eusm,t}$	$\sigma^2_{ocsm,t}$	$\sigma^2_{ussm,t}$	$\sigma^2_{euwm,t}$	$\sigma^2_{ocwm,t}$	$\sigma^2_{uswm,t}$	$\sigma^2_{eubu,t}$	$\sigma^2_{ocbu,t}$	$\sigma^2_{usbu,t}$	$\sigma^2_{euch,t}$	$\sigma^2_{occh,t}$	$\sigma^2_{usch,t}$
α_i	2.342*** (0.241)	2.594*** (0.241)	0.794*** (0.091)	1.994*** (0.194)	2.366*** (0.224)	0.927*** (0.091)	2.075*** (0.229)	2.017*** (0.212)	2.450*** (0.272)	0.769*** (0.086)	1.179*** (0.120)	2.421*** (0.265)
Conditional covariance												
$\sigma_{ij,t} = \eta_{ij} + \underset{(0.004)}{0.023^{***}} u_{i,t-1}u_{j,t-1} + \underset{(0.013)}{0.760^{***}} \sigma_{ij,t-1}, \quad i,j = 1,\ldots,12, \quad i \neq j, \quad t = 2001{:}02{:}09,\ldots,2017{:}04{:}28$												
$\sigma_{eusm\ j,t}$	$\sigma_{eusm\ ocsm,t}$	$\sigma_{eusm\ ussm,t}$	$\sigma_{eusm\ euwm,t}$	$\sigma_{eusm\ ocwm,t}$	$\sigma_{eusm\ uswm,t}$	$\sigma_{eusm\ eubu,t}$	$\sigma_{eusm\ ocbu,t}$	$\sigma_{eusm\ usbu,t}$	$\sigma_{eusm\ euch,t}$	$\sigma_{eusm\ occh,}$	$\sigma_{eusm\ usch,t}$	
$\eta_{eusm\ j}$	1.357*** (0.078)	0.663*** (0.071)	1.701*** (0.112)	1.209*** (0.077)	0.568*** (0.064)	1.290*** (0.107)	0.683*** (0.085)	0.476*** (0.119)	0.573*** (0.067)	0.630*** (0.068)	0.258** (0.103)	
$\sigma_{ocsm\ j,t}$	$\sigma_{ocsm\ ussm,t}$	$\sigma_{ocsm\ euwm,t}$	$\sigma_{ocsm\ ocwm,t}$	$\sigma_{ocsm\ uswm,t}$	$\sigma_{ocsm\ eubu,t}$	$\sigma_{ocsm\ ocbu,t}$	$\sigma_{ocsm\ usbu,t}$	$\sigma_{ocsm\ euch,t}$	$\sigma_{ocsm\ occh,t}$	$\sigma_{ocsm\ usch,}$		
$\eta_{ocsm\ j}$	0.663*** (0.067)	1.429*** (0.066)	2.036*** (0.101)	0.599*** (0.064)	1.072*** (0.100)	1.428*** (0.094)	0.189* (0.117)	0.378*** (0.059)	1.085*** (0.075)	0.380*** (0.103)		
$\sigma_{ussm\ j,t}$	$\sigma_{ussm\ euwm,}$	$\sigma_{ussm\ ocwm,t}$	$\sigma_{ussm\ uswm,t}$	$\sigma_{ussm\ eubu,t}$	$\sigma_{ussm\ ocbu,t}$	$\sigma_{ussm\ usbu,t}$	$\sigma_{ussm\ euch,t}$	$\sigma_{ussm\ occh,t}$	$\sigma_{ussm\ usch,t}$			
$\eta_{ussm\ j}$	0.573*** (0.058)	0.660*** (0.068)	0.281*** (0.046)	0.555*** (0.065)	0.348*** (0.062)	0.023 (0.064)	0.110*** (0.036)	0.279*** (0.046)	0.051 (0.062)			
$\sigma_{euwm\ j,t}$	$\sigma_{euwm\ ocwm,}$	$\sigma_{euwm\ uswm,t}$	$\sigma_{euwm\ eubu,t}$	$\sigma_{euwm\ ocbu,t}$	$\sigma_{euwm\ usbu,t}$	$\sigma_{euwm\ euch,t}$	$\sigma_{euwm\ occh,t}$	$\sigma_{euwm\ usch,t}$				
$\eta_{euwm\ j}$	1.243*** (0.066)	0.535*** (0.057)	1.295*** (0.107)	0.763*** (0.078)	0.290*** (0.106)	0.564*** (0.062)	0.642*** (0.061)	0.205** (0.097)				

$\sigma_{ocwm\ j,t}$	$\sigma_{ocwm\ uswm}$	$\sigma_{ocwm\ eubu,t}$	$\sigma_{ocwm\ ocbu,t}$	$\sigma_{ocwm\ usbu,t}$	$\sigma_{ocwm\ euch,t}$	$\sigma_{ocwm\ occh,t}$	$\sigma_{ocwm\ usch,t}$					
$\eta_{ocwm\ j}$	0.575*** (0.060)	1.093 *** (0.095)	1.424 *** (0.093)	0.217 ** (0.110)	0.349 *** (0.058)	1.017 *** (0.076)	0.291 *** (0.100)					
$\sigma_{uswm\ j,t}$	$\sigma_{uswm\ eubu}$	$\sigma_{uswm\ ocbu,t}$	$\sigma_{uswm\ usbu,t}$	$\sigma_{uswm\ euch,t}$	$\sigma_{uswm\ occh,t}$	$\sigma_{uswm\ usch,t}$						
$\eta_{uswm\ j}$	0.491*** (0.065)	0.470*** (0.057)	0.336** (0.076)	0.156*** (0.037)	0.318*** (0.047)	0.332*** (0.064)						
$\sigma_{eubu\ j,t}$	$\sigma_{eubu\ ocbu,t}$	$\sigma_{eubu\ usbu,t}$	$\sigma_{eubu\ euch,t}$	$\sigma_{eubu\ occh,t}$	$\sigma_{eubu\ usch,t}$							
$\eta_{eubu\ j}$	0.859*** (0.092)	0.270** (0.106)	0.434*** (0.058)	0.611*** (0.079)	0.215** (0.095)							
$\sigma_{ocbu\ j,t}$	$\sigma_{ocbu\ usbu,t}$	$\sigma_{ocbu\ euch,t}$	$\sigma_{ocbu\ occh,t}$	$\sigma_{ocbu\ usch,t}$								
$\eta_{ocbu\ j}$	0.247** (0.103)	0.282* (0.055)	0.932*** 0.076)	0.229** (0.091)								
$\sigma_{usbu\ j,t}$	$\sigma_{usbu\ euch,t}$	$\sigma_{usbu\ occh,t}$	$\sigma_{usbu\ usch,t}$									
$\eta_{usbu\ j}$	0.113* (0.067)	0.077 (0.076)	0.641*** (0.131)									
$\sigma_{euch\ j,t}$	$\sigma_{euch\ occh,t}$	$\sigma_{euch\ usch,t}$										
η_{euchj}	0.179*** (0.045)	0.176*** (0.061)										
$\sigma_{occh\ j,t}$	$\sigma_{occh\ usch,t}$											
$\eta_{occh\ j}$	0.143* (0.076)											

Notes: *i, j* = 1: eusm, 2: ocsm, 3: ussm, 4: euwm, 5: ocwm, 6: uswm, 7: eubu, 8: ocbu, 9: usbu, 10: euch, 11: occh, 12: such.
Numbers in brackets are standard errors, ***, **,* indicate statistical significance at 1%, 5%, and 10% level of significance, respectively.

Table 4: Mean of conditional volatility of SMP, WMP, Butter and Cheese prices for EU, Oceania and USA for the period 2001-2017 and for various sub-periods.

	eusm	*ocsm*	*ussm*	*euwm*	*ocwm*	*uswm*	*eubu*	*ocbu*	*usbu*	*euch*	*occh*	*usch*
Whole period (2001:02:09-2017:04:28)	14.324	16.941	5.821	12.285	15.759	6.469	14.119	13.087	18.353	5.579	7.978	16.169
1st sub-period of the whole period (2001:02:09-2006:12:22)	12.251	11.436	3.376	9.911	10.251	4.939	10.490	9.578	**19.958**	4.417	5.704	**16.435**
2nd sub-period of the whole period (2007:01:05 2017:04:28)	**15.507**	**20.080**	**7.216**	**13.639**	**18.901**	**7.342**	**16.188**	**15.088**	17.437	**6.241**	**9.275**	16.017
Three periods of the second sub-period												
1st period (2007:01:05-2010:12:31)	**18.479**	19.219	**9.317**	**15.570**	**17.784**	**7.410**	**22.596**	**16.821**	13.658	**8.291**	**11.563**	**17.160**
2nd period (2011:01:14-2013:12:27)	13.169	**21.239**	4.954	11.622	15.784	4.968	11.681	11.460	14.649	5.286	6.353	16.574
3th period (2014:01:10-2016:12:23)	**14.306**	19.706	**6.720**	**13.576**	**23.870**	**9.611**	**12.779**	**16.608**	**25.972**	4.765	**9.285**	13.835

Table 5: Descriptive statistics of implied conditional cross-correlation of dairy prices for EU, Oceania and USA for the period 2001-2017

Implied cross-correlation of dairy prices for EU, Oceania and US	*eusm, ocsm*	*eusm, ussm*	*ocsm, ussm*	*euwm, ocwm*	*euwm, uswm*	*ocwm, uswm*	*eubu, ocbu*	*eubu, usbu*	*ocbu, usbu*	*euch, occh*	*euch, usch*	*occh, usch*
Mean	0.454	0.394	0.376	0.463	0.310	0.305	0.333	0.090	0.080	0.143	0.093	0.063
SE	0.101	0.100	0.104	0.114	0.070	0.075	0.075	0.034	0.038	0.038	0.028	0.029
Min.	0.204	0.091	0.106	0.200	0.144	0.101	0.056	-0.058	-0.071	0.006	-0.006	-0.054
Max.	0.626	0.551	0.533	0.654	0.435	0.441	0.464	0.144	0.140	0.205	0.144	0.126