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Impact of trade liberalisation on dairy market price co-movements between the EU, Oceania, and the United States

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This study investigates the impact of trade liberalisation on the spatial price co-movements between the dairy markets of the EU, Oceania, and the United States. We consider two main dairy products, namely butter and whole milk powder (WMP), and employ R-Vines to assess the development of the tail dependence between the price series. We split the time span (i.e. 2000-2017) in December 2007 to capture the change in the tail dependence as well as in the potential of each region to act as the central market. Our findings indicate that the EU acts as the central market for butter in both sub-periods, whereas the EU succeeds Oceania in acting as the central market for WMP from the first sub-period to the next. Further findings highlight slightly increasing tail dependence in the butter market and in the WMP market for the EU-OCE and EU-US pairs. However, the tail dependence for the WMP prices between Oceania and the United States weakens, in which we attribute to the 2013 Chinese ban on milk powder imports from Oceania.

Key words: agricultural commodities, dairy markets, R-Vine copulas.

JEL classifications: C10, Q13, Q17

1. Introduction

Spatial price transmission offers an area for empirical research of particular interest to economists and policy makers. This interest is based on the idea that the strength and the pattern of price linkages provide information regarding the integration (or segmentation) of geographically separated markets. Prices that tend to co-move provide evidence of well-integrated markets. Furthermore, the transmission of price shocks from one spatial market to another is recognised as a necessary condition for economic efficiency (Ghoshray 2010; Reboredo 2011; Fousekis *et al*. 2017), whereas the degree of integration bears implications for the total welfare and the distribution of benefits among the trading markets (Meyer and von Cramon-Taubadel 2004; Serra *et al*. 2006). In this context, the signing of new bilateral and multilateral trade agreements as well as the policy changes enacted around 2008 were significant. Several countries with major dairy trade activity sought to liberalise the dairy sector and facilitate trade.

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More specifically, the free trade agreement between China and New Zealand in October 2008 reduced and progressively eliminated tariffs and customs duties on dairy products, including butter and milk powders. Nevertheless, safeguards may come into effect when the volumes from New Zealand exceed specific levels (World Trade Organization 2010). The authorisation of negotiations within the scope of the free trade agreement between the EU and India, Korea, and the ASEAN countries in April 2007 targets the new prospects in the vast and growing market of South-East Asia. Concerning India, the EU will seek the reduction or abolition of non-tariff barriers and the reduction of traditional import tariffs, which have provided high levels of protection against the EU exports (Wouters *et al.,* 2013).

Moreover, the removal of trade restrictions associated with the US exports of agricultural commodities such as non-fat dry milk to Mexico, within the North American Free Trade Agreement (NAFTA) in January 2008, marked the end of a process during which Canada, Mexico, and the United States gradually removed agricultural trade barriers (Zahniser and Roe 2011). The Central America Free Trade Agreement (CAFTA) came into effect fully in March 2007 between the United States and the Dominican Republic and in January 2009 between the United States and Costa Rica (U.S. Customs and Border Protection 2007; U.S. Customs and Border Protection 2009). The specific agreement phases out tariffs and gradually eliminates trade barriers for agricultural and dairy goods (United States Trade Representative 2004a). These changes as depicted in the price relation patterns are of primary interest to economists and policy makers, given the degree of integration between the markets indicates the total welfare; and the transmission of price shocks across the different spatial markets is necessary for economic efficiency. The measures adopted under the different agreements are summarised in Table 1. From this table, it can be seen that the agreements were enacted around 2008 but were enforced gradually during the period from 2008 onwards.

Regarding the dairy policy, the United States has traditionally set floors on prices through the Milk Price Support Program (MPSP), established in 1949 and amended several times. The MPSP allowed government purchases of dairy products to support milk prices. The 2008 Farm Act renamed the program the Dairy Product Price Support Program (DPPSP) and specified support prices for the purchased products instead of milk prices. In general, the Government disposed of dairy products in ways that exerted minimal impacts on the domestic US prices, such as donations, export sales, and sales restricted to animal feed. Nevertheless, when the domestic prices were high, the Government sold products to the US market for unrestricted use (Cessna *et al.,* 2016). More recently, the purchases made under the DPPSP decayed, since the US dairy market prices rose whereas the support prices were low. The declining price supports led to export increases, with dairy products that would have been purchased by the Government being directed to commercial exports. The DPPSP was finally abolished with the 2014 Farm Act. Before 2004, the US commercial exports of dairy products were low and subsidised

Table 1 Summary of the FTAs

NAFTA US-Mexico	Enacted in Dec 1992, fully enforced in Jan 2008.		Tariff elimination for non-fat dry milk from the United States.	
Transitional restriction for 2007, duty-free quota of 58,741 metric tons; overquota tariff equalled the greater of 11.8 per cent or dollars 98 per metric ton.				
CAFTA US-DR	Enacted in Aug 2005, enforced since Mar 2007.		Tariff elimination within 20 years, tariff rate quotas expansion.	
Butter, TRQs increase from 220 in 2004 to 280 in 2007; and from 300 in 2008 to unconstrained in 2013.				
WMP, TRQs increase from 2,970 in 2004 to 3,780 in 2007; and from 4050 in 2008 to unconstrained in 2023.				
CAFTA US-CR	Enacted in August 2005, enforced since Jan 2009.		Tariff elimination within 20 years, tariff rate quotas expansion.	
Butter, TRQs increase from 150 in 2004 to 174 in 2007; and from 182 in 2008 to unconstrained in 2023.				
WMP, TRQs increase from 200 in 2004 to 232 in 2007; and from 243 in 2008 to unconstrained in 2023.				
China-New Zealand	Enacted in Apr 2008, enforced in Oct 2008.		Tariff elimination.	
WMP schedule, base year 2008 with tariff rate 10 gradually reduced to 0 until 2019.				
Butter schedule, base year 2008 with tariff rate 10 gradually reduced to 0 until 2017.				
EU-India, Korea, ASEAN	Enacted in Apr 2007, last round for India in 2013, not enforced for ASEAN, fully enforced for Korea since Jul 2016.			
WMP	Tariff maintained, tariff rate quota of 1,000 tons in year 2011, incremented by 3% annually until 2027 and fixed onwards.			
General rate duty	Most Favoured Nation duty.		Preferential Trading Area duty.	
176%	40% within a tariff quota of 573 tons.	176%	0% within a tariff quota of 1,194 tons.	176%
Butter	tariff rate quota of 350 tons in year 2011, incremented by 3% annually until 2021.			
General rate duty	Most Favoured Nation duty.		Preferential Trading Area duty.	
89%	40% within a tariff quota of 420 tons.	89%	0% within a tariff quota of 417 tons.	24.2%

Sources: EEAS 2011, New Zealand Foreign Affairs and Trade 2008, United States Trade Representative 2004a, United States Trade Representative 2004b and United States Trade Representative 2004c, Zahniser and Crago 2009.

exports through the Dairy Export Incentive Program (DEIP) often surpassed them, with dairy production being directed to the local market (Vitaliano 2016). The DEIP allowed exporters to buy at high US prices and sell abroad at lower prices through cash bonuses and further removed non-fat dry milk, butterfat, and certain cheeses from the US market, directing them to exports. However, since 2004, the US commercial exports have grown significantly and exports need not be subsidised, which led to the 2014 Farm Act abolishing the DEIP (Cessna *et al.,* 2016).

The EU had long relied on price floors, that is, intervention prices for dairy products. According to the relevant program, dairy producers have the option to sell into intervention at prices set by the EU Commission. The 2003 CAP Reform lowered the dairy intervention prices (Council of the European Union 2003) and, under the Single Payment Scheme (SPS), adopted direct payments to farmers, which were decoupled from milk production. These payments did not depend on production and thus were less trade distorting. Prior to the 2003 CAP Reform, the dairy prices in the EU matched the intervention prices. However, after the reform, the intervention was used in response to exceptionally low-price margins in 2009 and 2015 (Cessna *et al.,* 2016). Furthermore, the EU uses the Private Storage Aid (PSA) program, which aims to stabilise price fluctuations through financial support for dairy processors who take products off the market temporarily during peak production periods. The PSA program has been used for butter for several years (Cessna *et al.,* 2016). On the other hand, the export subsidies adopted by the EU as a means of price support have been lowered substantially. Exports have not been subsidised since 2006 (with the exception of 2009), as both the domestic and the export prices have been considerably higher than the intervention prices. With decreasing subsidised exports, the commercial exports have gained momentum. Another key instrument of the European dairy policy has been the milk production quotas. Introduced in 1984, milk quotas were used to restrict growth in surplus production and to limit government spending on domestic support and export subsidies (Cessna *et al.,* 2016). The quotas generally increased both the consumer and the farmer prices by limiting the supply (Cessna *et al.,* 2016). However, as the domestic support and export subsidies were reduced, the need for quotas decreased. In November 2008, the EU reached an agreement on the CAP Health Check, within the scope of which the milk quotas were increased gradually until their final abolition in April 2015. After the abolition of the dairy quotas, the EU milk production and exports increased substantially (Cessna *et al.,* 2016). Furthermore, the 2008 CAP Health Check removed, with very few exceptions, the remaining coupled payments, thus directing dairy farmers towards more market orientation. Finally, even though import tariffs (both for butter and for WMP) remain on paper, in practice these are alleviated through the free trade agreements.

However, international trade was constrained by a rapid rise in food prices with global food prices increasing by 83 per cent between 2005 and 2008. Price increases were observed in nearly all food commodities, affecting mostly the low-income populations in developing countries. The prices eventually started to decline in 2008 after several months of sharp increases (Mittal 2009). Further, electronic trade had a role in liberalising dairy markets. In 2008, Global Dairy Trade, owned by Fonterra, started providing electronic auctions in internationally traded commodity dairy products, including WMP and butter. The auctions, held twice a month, allow registered bidders from around the world to interact with sellers from North America, Oceania, Europe and India and thus provide a credible channel for price discovery. Such initiatives may also facilitate liberalisation and are expected to play a more influential role in the future. Given the liberalising effect of these changes in the policies of countries and the commercial practices of market participants, it is important to examine how these changes impact market prices and performance.

Copulas provide an effective way to approach price transmission and thus to assess market integration. They possess certain attractive attributes: they allow the joint behaviour of stochastic processes to be modelled independently of their marginal distributions; they need not assume that marginal distributions belong to the same family; they are suitable for capturing both linear and non-linear co-movements; and they provide information about the degree as well as the structure of the co-movement (Fermanian and Scaillet 2004; Grigoriadis *et al.* 2016). Thus, copulas are highly appropriate for analysing co-movement between stochastic processes. In the context of market integration, a high degree of price co-movement, combined with symmetric and strictly positive co-movement at the extremes of the joint distribution, highlights well-integrated markets (Grigoriadis *et al.* 2016).

Initially intended for financial applications, copulas have recently gained momentum in agricultural economics. Panagiotou and Stavrakoudis (2015) use bivariate static copulas to determine whether product differentiation in the US pork market leads to asymmetric price co-movements between certain pork cuts at the retail level. Similarly, Grigoriadis *et al.* (2016) employ the R-Vine to evaluate the degree of integration in the pork markets of seven European countries.

Concerning dairy markets, Fousekis *et al.* (2017) explore the spatial price linkages in the SMP markets of Oceania, the EU and the United States using the nonparametric time-varying copula. Their results indicate strong and increasing overall price co-movement, especially between the EU and Oceania, with the increasing interconnection between the United States and the rest of the markets. Fousekis and Grigoriadis (2016) investigate price co-movement in the butter markets of Oceania and the EU, combining wavelets with nonparametric copulas, to determine the price linkage changes throughout different time horizons. This study finds weak price linkages in the short-run, which become stronger in the long-run. Asymmetry is observed in the long-run, such that positive shocks are transmitted with higher intensity than negative shocks, whereas price dependence is symmetric in the short-run.

Excluding Grigoriadis *et al.* (2016), the previous studies employ bivariate copulas. However, multidimensional models are more appropriate when assessing spatial market integration, since R-Vines may shed more light on the ways in which geographically separated markets are connected and therefore evaluate the success of policy initiatives pursuing market integration.

This study investigates the degree of integration in the dairy markets of the EU, the United States and Oceania, using the statistical tool of the mixed R-Vine copula. We gain insights into the ways that dairy prices are linked from one producing region to another. More specifically, we split the time span into two sub-periods, specifically January 2000-December 2007 and January 2008-May 2017 for WMP and February 2000-December 2007 and January 2008-May 2017 for butter, to assess how liberalisation change has affected the price linkages between the series considered. We split the period in 2008 due to the many liberalisation initiatives taking place in 2008 (i.e. the CAP Health Check, NAFTA US-Mexico, China-NZ FTA and launch of the Global Dairy Trade auctions) and the fact that 2008 marked the end of the respective food price crisis. Note that the free trade agreement measures were implemented gradually throughout the period after 2008. These developments are expected to have played a main role in reshaping the price linkage patterns and to have affected the degree of integration between the regional markets. R-Vines provide information regarding the central markets and thus allow us to identify the market leaders. Market leaders are capable of essentially determining the prices; therefore, identifying the market leaders in light of the policy changes and the free trade agreement developments becomes crucial. This study considers whole milk powder (WMP) and butter, two commodities that are widely consumed worldwide.

The remainder of this article is structured as follows. Section 2 introduces the bivariate copulas and their extension to the higher-dimension R-Vines, the marginal models and the estimation and testing procedures. Section 3 describes the main features of the data, and Section 4 presents the empirical results of the marginal models, the R-Vines, and the respective implications for the dairy markets of Europe, Oceania and the United States. Finally, Section 5 summarises the main findings and concludes the article.

2. Measuring dependence

2.1. Copulas

The theorem of Sklar (1959) links multivariate distribution functions to their univariate margins. Let F be the d-dimensional distribution function of the random vector $X = (X_1, \ldots, X_d)^T$ with margins $F_1, \ldots, F_d$. Then, there exists a copula C such that for all:

$$x = (x_1, \ldots, x_d)^T \in \mathbb{R}^d, F(x) = C(F_1(x_1), \ldots, F_d(x_d)) \quad (1)$$

where C is unique if $F_1, \ldots, F_d$ are continuous. C can be interpreted as the distribution function of a d-dimensional random variable on $[0, 1]^d$ with uniform margins. The corresponding densities are denoted as c, and the random variables $X_1, \ldots, X_d$ are assumed to be continuous.

Vines are graphical representations that specify pair copula construction (PCCs) introduced in Aas *et al.* (2009). For the three-dimensional case let $X = (X_1, X_2, X_3)^T \sim F$ with marginal distribution functions F_1, F_2, F_3 and marginal density functions f_1, f_2, f_3, we obtain:

$$f(x_1, x_2, x_3) = f_1(x_1) f(x_2|x_1) f(x_3|x_2, x_1) \tag{2}$$

and by the theorem of Sklar we have:

$$\begin{aligned} f(x_2|x_1) &= \frac{f(x_1, x_2)}{f_1(x_1)} = \frac{c_{1,2}(F_1(x_1), F_2(x_2)) f_1(x_1) f_2(x_2)}{f_1(x_1)} \\ &= c_{1,2}(F_1(x_1), F_2(x_2)) f_2(x_2) \end{aligned} \tag{3}$$

and $f(x_3|x_1, x_2) = \frac{f(x_2, x_3|x_1)}{f(x_2|x_1)} = \frac{c_{2,3|1}(F(x_2|x_1), F(x_3|x_1)) f(x_2|x_1) f(x_3|x_1)}{f(x_2|x_1)} =$

$$= c_{2,3|1}(F(x_2|x_1), F(x_3|x_1)) f(x_3|x_1) \Rightarrow$$

$$f(x_3|x_1, x_2) = c_{2,3|1}(F(x_2|x_1), F(x_3|x_1)) c_{1,3}(F_1(x_1), F_3(x_3)) f_3(x_3) \tag{4}$$

Thus, the three-dimensional joint density (2) is written using the bivariate copulas $C_{1,2}, C_{1,3}$, and $C_{2,3|1}$ with densities $c_{1,2}, c_{1,3}$, and $c_{2,3|1}$. These pair copulas can be chosen independently of each other to achieve different dependence structures. In general, the conditional copula $C_{2,3|1}$ is assumed to be independent of the conditioning variable X_1 to facilitate inference. Note that decomposition (2) is not unique and many iterative PCCs can be defined. Therefore, a graphical model called vine is introduced to classify these PCCs.

An R-vine for the three-dimensional process considered is a sequence of linked/nested trees wherein tree 1 consists only of unconditional pair copulas, e.g. $c_{1,2}, c_{1,3}$, and tree 2 consists of the bivariate copula conditioned on a single stochastic process, i.e. $c_{2,3|1}$, that is drawn from tree 1 (Figure 1). The factorisation of the joint density function of the three-dimensional process is:

$$f(x) = f_1 \cdot f_2 \cdot f_3 \cdot \left(c_{1,2} \cdot c_{1,3}\right) \cdot c_{2,3|1} \tag{5}$$

Based on the Akaike information criterion (AIC) and the Bayes information criterion (BIC), the most appropriate bivariate copulas are applied on each pair-copula term in decomposition (5), and thus, the multivariate copulas obtained as R-Vines are able to capture complex dependence structures potentially including asymmetric dependence or strong joint tail dependence.

The application of R-Vines is very relevant for this study, since R-Vines provide information upon the central markets, that is, markets with direct linkages with at least two other markets, which cannot be provided by

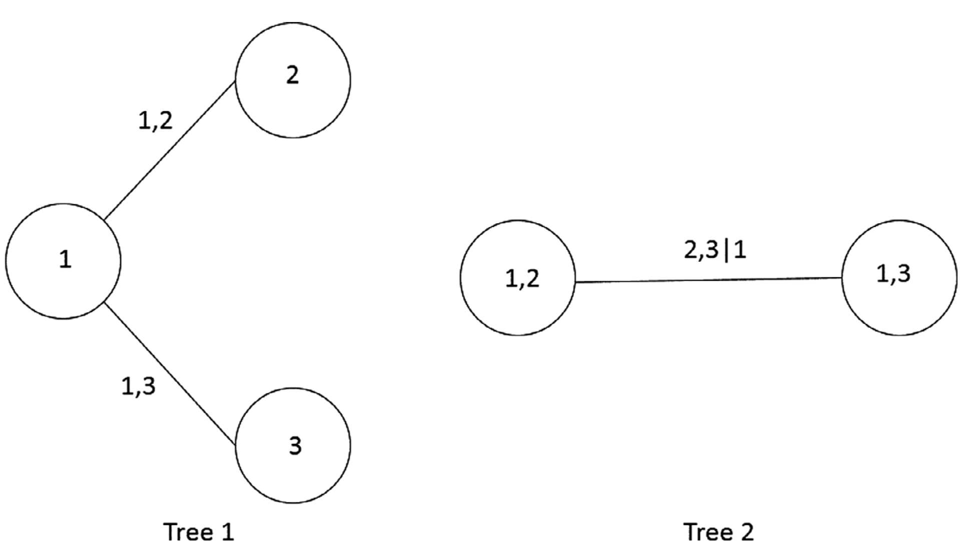

Figure 1 Example of a three-dimensional R-Vine.
Source: own creation

standard bivariate copulas. Assuming that the prices in geographically separated markets are stochastic processes, the prices in central markets are the conditioning stochastic processes for the construction of the subsequent tree. Furthermore, R-Vines highlight potential clusters of markets, since a cluster may be seen as a group of markets, directly linked to the same central market. Markets within the same cluster exhibit common attributes including the strength and the pattern of price co-movement.

Furthermore, the influence of a third stochastic process may make co-movement between two other stochastic processes seem more intense or it may cloud it. It is therefore essential that the conditional measures of co-movement are presented in empirical studies. When under the condition of a third price, the co-movement between two prices is found to decrease (increase), it is concluded that their interdependence was magnified (clouded) due to the third price (Aguiar-Conraria and Soares 2014; Grigoriadis *et al.* 2016). Hence R-Vines may reveal aspects of co-movement that standard bivariate copulas cannot capture. However, positive association between price changes in geographically separated markets commonly leads to co-movement that gets weaker after conditioning (Dißmann *et al.* 2013, Grigoriadis *et al.* 2016, Kellner and Rösch 2016). Therefore, higher numbered trees may involve the independence copula and thus become redundant.

2.2. Bivariate copula families

The R-Vines are composed by the bivariate, elliptical, or Archimedean copulas presented below. The elliptical copulas (Gaussian and Student’s t) are obtained directly through Sklar’s theorem by inverting relationship (1). Given a bivariate distribution function F with invertible margins F_1 and F_2, we obtain:

$$C(u_1, u_2) = F\big(F_1^{-1}(u_1), F_2^{-1}(u_2)\big) \tag{6}$$

which is a bivariate copula for $u_1, u_2 \in [0, 1]$, and is elliptical if F is elliptical. The bivariate Gaussian copula is given as

$$C(u_1, u_2) = \Phi_\rho\big(\Phi^{-1}(u_1), \Phi^{-1}(u_2)\big) \tag{7}$$

and the bivariate Student's t copula is given as:

$$C(u_1, u_2) = t_{\rho,v}\big(t_v^{-1}(u_1), t_v^{-1}(u_2)\big) \tag{8}$$

with dependence parameter $\rho \in (-1, 1)$ and degrees of freedom parameter $v > 2$ for the Student's t copula. Φ_ρ denotes the bivariate standard normal distribution function with correlation parameter ρ and Φ^{-1} the inverse of the univariate standard normal distribution function. Furthermore, $t_{\rho,v}$ is the bivariate Student's t distribution function with correlation parameter ρ and v degrees of freedom whereas t_v^{-1} denotes the inverse univariate Student's t distribution function with v degrees of freedom. Both copulas are symmetric with the same lower-tail and upper-tail dependence coefficients.

Bivariate Archimedean copulas are defined as:

$$C(u_1, u_2) = \varphi^{[-1]}(\varphi(u_1) + \varphi(u_2)) \tag{9}$$

where $\varphi : [0, 1] \to [0, +\infty)$ is a continuous strictly decreasing convex function such that $\varphi(1) = 0$, $\varphi^{[-1]}$ is the pseudo-inverse defined as:

$$\varphi^{[-1]}(t) = \begin{cases} \varphi^{-1}(t), 0 \le t \le \varphi(0) \\ 0, \varphi(0) \le t \le \infty \end{cases} \tag{10}$$

and φ is the generator function of copula C.

We apply the single-parameter Archimedean families of Clayton, Gumbel, Frank and Joe and the two-parameter Archimedean copula families of Clayton-Gumbel (BB1), Joe-Gumbel (BB6), Joe-Clayton (BB7), and Joe-Frank (BB8), since their flexible structure allows for different non-zero lower-tail and upper-tail dependence coefficients. Moreover, we employ the rotated versions of Clayton, Gumbel, Joe, BB1, BB6, BB7, and BB8. Rotating a copula by 180 degrees leads to the respective survival copula, whereas rotating by 90 and 270 degrees allows modelling negative dependence which is otherwise impossible.

The measure of dependence used is Kendall's τ. This measure reflects the difference between the probability of concordance and the probability of disconcordance for two independent pairs of observations drawn from the joint distribution of X_1 and X_2. Given a copula function C, Kendall's τ ranges from + 1 (perfect concordance) to −1 (perfect disconcordance) and is calculated as:

$$\tau = 1 - 4 \int_0^1 \int_0^1 \frac{\partial C}{\partial u_1} \frac{\partial C}{\partial u_2} du_1 du_2 \tag{11}$$

Tail dependence is assessed by the lower-tail and the upper-tail coefficients, measuring the probability that X_1 is below (above) a low (high) quantile, given that X_2 is also below (above) that low (high) quantile and defined as:

$$\lambda_L = \lim_{u \to 0^+} \Pr(U_1 < u | U_2 < u) = \lim_{u \to 0^+} \frac{C(u,u)}{u} \tag{12}$$

$$\lambda_U = \lim_{u \to 1^-} \Pr(U_1 > u | U_2 > u) = \lim_{u \to 1^-} \frac{1 - 2u + C(u,u)}{1 - u} \tag{13}$$

The two-tailed dependence coefficients provide information about the likelihood for the two stochastic processes to crash and/or to boom together.

2.3. The marginal distribution models

The semi-parametric approach of Chen and Fan (2006a) and Chen and Fan (2006b) consists of three steps: a) specifying a GARCH model which is fit to the price changes; b) the filtered data, that is, the standardised residuals are converted into copula data, that is, data lying on (0,1); and c) the copula models are estimated by the maximum-likelihood estimator applied on the copula data. For the empirical part, we consider ARMA(p,q)-GARCH(1,1) and GJR(p,q)-GARCH(1,1) models, and choose between them through the usual information criteria (Akaike, Bayes, Shibata, and Hannan-Quinn).

2.4. Testing and estimation

We conduct tests for time-varying dependence, that is, tests revealing whether tail dependence between the prices exhibits constant characteristics over time. We apply the tests of Busetti and Harvey (2011), which are based on the sample *τ-quantics* and the sample *τ-biquantics* for the individual and the bivariate time series.

Selection of the most appropriate structure (C-Vine or D-Vine) proceeds tree by tree given that the conditional pairs in trees $2, \ldots, d-1$ depend on the specification of the previous trees through the h-functions. The R-Vines are specified as maximum spanning trees with respect to some edge weights (usually the absolute value of the empirical Kendall's τ). The C-Vine and

D-Vine specifications are fitted sequentially tree by tree, performing bivariate copula estimation for each individual pair-copula term. Estimation of the copula parameter(s) for each pair copula is conducted using inversion of Kendall's τ or maximum-likelihood estimation.

Although sequential estimation usually provides a good fit, typically maximisation of the log-likelihood function of the vine specification is required. Thus, for observations $\mathbf{u} = \left(u_{k,j}\right)$ with $k = 1, \ldots, N$ and $j = 1, \ldots, d$ the log-likelihood function of the C-Vine with parameter set $\theta_{\mathbf{CV}}$ is given as:

$$\mathcal{L}_{CV}\left(\theta_{CV|u}\right) = \sum_{k=1}^{N} \sum_{k=1}^{d-1} \sum_{j=1}^{d-i} \log\left[c_{i,i+j|1:(i-1)}\left(F_{i|1:(i-1)}, F_{i+j|1:(i-1)}|\theta_{i,i+j|1:(i-1)}\right)\right] \tag{14}$$

where $F_{j|i_1:i_m} = F(u_{k,j}|u_{k,i_1}, \ldots, u_{k,i_m})$ and the marginal distributions are uniform; i.e., $f_k(u_k) = 1_{[0,1]}(u_k)$ and $F_{j|i_1:i_m}$ depend on the parameters of the pair copula terms in tree 1 up to tree i_m. Moreover, the log-likelihood function of the D-Vine with parameter set $\theta_{\mathbf{DV}}$ is given as:

$$\mathcal{L}_{DV}\left(\theta_{DV|u}\right) = \sum_{k=1}^{N} \sum_{i=1}^{d-1} \sum_{j=1}^{d-i} \log\left[c_{j,j+i|(j+1):(j+i-1)}\left(F_{j|(j+1):(j+i-1)}, F_{j+i|(j+1):(j+i-1)}|\theta_{j,j+1|(j+1):(j+i-1)}\right)\right] \tag{15}$$

When obtaining the R-Vine, the most appropriate pair copulas are selected for each conditional and unconditional pair of variables, based on AIC and BIC. Furthermore, the conditional distribution functions $F(x|\upsilon)$ for an m-dimensional vector υ are obtained by applying the relationship:

$$h(x|\upsilon,\ \theta) := F(x|\upsilon) = \frac{\partial C_{x\upsilon_j|\upsilon_{-j}}(F(x|\upsilon_{-\mathbf{j}}), F(\upsilon_j|\upsilon_{-\mathbf{j}})|\theta)}{\partial F(\upsilon_j|\upsilon_{-\mathbf{j}})} \tag{16}$$

where υ_j is an arbitrary component of υ, $\upsilon_{-\mathbf{j}}$ represents the (m-1)-dimensional vector υ excluding component υ_j, and $C_{x\upsilon_j|\upsilon_{-\mathbf{j}}}$ is a bivariate copula distribution function with parameter(s) θ specified in tree m. The previous relationship is sequentially applied on each pair-copula term of tree $m+1$, using the pair copulas of the previous trees $1, \ldots, m$.

3. Data

Prices for two dairy commodities, namely butter and whole milk powder (WMP), in three regions, the EU, Oceania (New Zealand and Australia), and the United States, were obtained from the databases of the Dairy Marketing and Risk Management Program at the University of Wisconsin and collected from the Dairy Market News of USDA/AMS. Both price series regarding

Oceania and the EU are reported on a bi-weekly basis. However, the US butter and WMP prices are reported on a weekly basis; thus, these prices are averaged with a bi-weekly frequency to align them with the rest of the series (following Bergmann *et al.* 2016 and Newton 2016). The WMP prices correspond to the dry whole milk prices which are free-on-board (FOB) spot prices collected nationwide. The time span for butter is 5 February 2000 to 13 May 2017, yielding 450 observations, and that for WMP is 8 January 2000 to 13 May 2017, with 452 bi-weekly observations. The prices are measured in dollars per metric ton. Note that Australia and New Zealand are modelled as a single market. Australia and New Zealand both enjoy advantages relating to competitive production costs (Zhang *et al.* 2017) and are both strong supporters of free trade in dairy commodities, unlike the EU and the United States which still apply trade-distorting policies (Fousekis and Trachanas 2016). Therefore, their combination in a single market is quite common in the literature (e.g. Fousekis, Emmanouilides and Grigoriadis 2017, Fousekis and Grigoriadis 2016, Newton 2016, Zhang *et al.* 2017).

Oceania is the primary source of butter in the international market, with a market share of over 57 per cent between 2013 and 2015, followed by Europe and the United States, which accounted for approximately 25 per cent and 6.5 per cent, respectively (OECD/FAO 2016). The major importers include the Middle East, Russia, North Africa, South-East Asia, and China. However, trade agreements and duty-free access for inward processing have led to substantial butter imports into the EU originating from New Zealand (Fousekis and Grigoriadis 2016), and considerable butter volumes are imported into the United States both from EU countries (mainly Ireland) and New Zealand (Groves 2016). Therefore, the largest butter exporters interact with each other through direct trade, besides competing in international markets.

The WMP markets have been dominated by producers from Oceania, which accounted for slightly more than 57 per cent of the market share between 2013 and 2015. Europe followed, with a market share of almost 17 per cent, and the United States accounted for less than 1 per cent of the total quantity exported (OECD/FAO 2016). The principal import markets are China, the Middle East, North Africa, and South-East Asia. However, the trade flows are negligible among Europe, Oceania, and the United States, and market integration is achieved only through competition in the international WMP market. Table 2 summarises the exports of the two dairy commodities during the period 2013-2015.

Here, we note that New Zealand is the most formidable competitor of the EU on international dairy markets, being the largest exporter and exerting a major influence on the international prices (Chatellier 2017). However, the domestic prices in New Zealand, given the small size of its market, are unlikely to mirror the world prices, which are realised by exporters from New Zealand, and the domestic demand increases in New Zealand are not very likely to affect the prices in the United States or Europe.

Table 2 Dairy commodity exports. Averages 2013-2015 (in 1,000 tons product weight)

Exports 2013-2015	Butter		WMP	
	quantity	%	quantity	%
EU	0.229	24.89	0.425	16.94
OCEANIA	0.528	57.33	1.430446	57.02
US	0.060	6.46	0.018	0.70
WORLD	0.922		2.509	

Source: OECD/FAO (2016).

Table 3 Descriptive statistics of price changes (raw price shocks)

	Europe		Oceania		United States	
	Butter	WMP	Butter	WMP	Butter	WMP
mean	0.0029	0.0014	0.0031	0.0017	0.0019	0.0004
Std. dev.	0.0401	0.0344	0.0365	0.0416	0.0543	0.0265
max	0.2921	0.1271	0.1484	0.1886	0.2299	0.1032
min	−0.1287	−0.1417	−0.1324	−0.1422	−0.3470	−0.1387
Observations	450	452	450	452	450	452

Note. Bi-weekly data, period for butter is 05/02/2000 to 13/05/2017 and for WMP 08/01/2000 to 13/05/2017.

This study considers the main producing and exporting regions for dairy products. Note that we consider the United States even though its share in the total exports is relatively small in the cases of butter and WMP (6.46 per cent and 0.70 per cent, respectively). Despite its small share, the United States is expected to play a role in the dairy markets, especially regarding its bilateral trade with the EU (Boulanger *et al.* 2016). On the other hand, we do not consider China, even though the Chinese market is emerging as a substantial importer of dairy products. This is due to the fact that, in China, despite the large growth in the milk production capacity, the supply still lags behind the demand, which has to be met through imports of dairy products (Van der Meer *et al.,* 2007).

Table 3 reports the descriptive statistics for the three regions and the dairy prices.

The price series (in logarithmic form) for the two dairy commodities in the three areas are plotted in Figure 2.

The highest butter prices are observed in the United States, followed by the prices in Europe, while the lowest prices are observed in Oceania, until June 2007. However, after June 2007, this pattern changes, with the EU displaying the highest butter prices and Oceania and the United States following successively until May 2014. Finally, after May 2014, the US butter prices become the highest and are followed by the prices in Europe and Oceania successively. The butter prices in Europe and Oceania appear to move

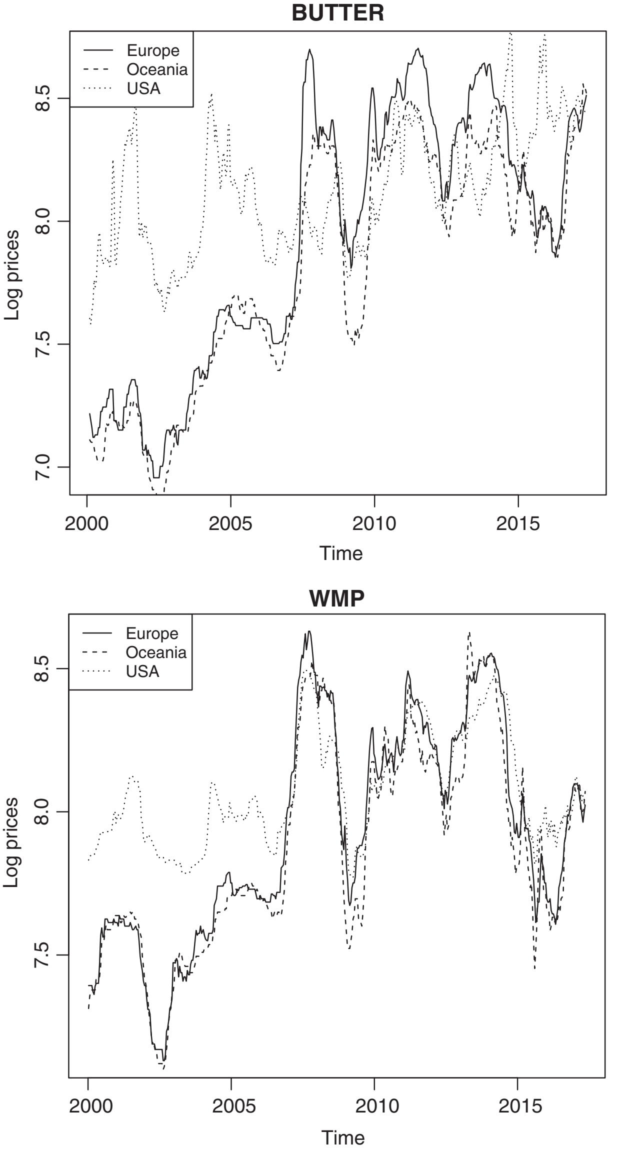

Figure 2 Development of log-prices for the dairy commodities

together throughout the whole period, whereas the prices in the United States approach them after June 2007. The highest average price is observed in Oceania and is followed by the average price in Europe, whereas the United States exhibits the lowest average butter price. The greatest variance is found in the United States, followed by the variance in the EU, while Oceania exhibits the lowest variance.

The United States clearly exhibits the highest WMP prices followed by the prices in Europe and Oceania, which follow each other closely and alternate

Table 4 ADF and Phillips-Perron test results

	Europe		Oceania		United States	
	Butter	WMP	Butter	WMP	Butter	WMP
Test statistic	−5.8577	−5.8005	−6.1072	−5.7928	−7.6703	−4.5218
Z(alpha)	−284.6686	−291.7836	−260.3741	−232.6221	−207.2331	−462.5536

Note. Null hypothesis: the series has a unit root. Test critical values: 1% level −2.5758, 5% level −1.9600, and 10% level −1.6449.

as the second-highest and the lowest WMP price regions until December 2006. After December 2006, however, all three price series seem to move together until May 2015, when the United States again starts displaying the highest prices, with Oceania and Europe following each other closely. The prices in Europe and Oceania seem to move together throughout the whole period, whereas the US prices approach the previous series after December 2006. The highest average WMP price is observed in Oceania, followed by Europe, while the United States exhibits the lowest average WMP price. Finally, the greatest variance is found in Oceania, with Europe and the United States following successively.

The stationarity properties of the log-returns are examined using the augmented Dickey-Fuller (ADF) and the Phillips-Perron unit root test. These results are presented in Table 4 and confirm that all the series are stationary on the first differences.

4. Empirical findings

4.1. Butter

4.1.1. Results for the marginal models

The empirical approach undertaken begins by obtaining the filtered rates of the price changes. Therefore, ARMA(p,q)-GARCH(1,1) and GJR(p,q)-GARCH(1,1) models are fit to each of the series. The selection amongst the different models is based on four information criteria (Akaike, Bayes, Shibata, and Hannan-Quinn). The selected models are ARMA(1,1)-GARCH (1,1) for the prices in Europe and Oceania and ARMA(0,2)-GARCH(1,1) for the US prices.[1] The standardised residuals are used to calculate the respective empirical distribution functions, thus providing the copula data.

To obtain the most appropriate copula, the tests of Busetti-Harvey are employed as an initial step. These tests indicate whether the data exhibit static or time-varying characteristics and therefore whether a static or time-varying structure would best describe the tail dependence. Table 5 reports the results of the constancy tests on the empirical copulas.

[1] For the sake of brevity, we do not present the results of these models in full. However, they are available on request.

Table 5 Constancy tests on the quantiles of the empirical copulas for butter

Empirical copula	Quantiles		
	$\tau = 0.25$	$\tau = 0.5$	$\tau = 0.75$
EU–OCE	0.0558	0.0404	0.2662
EU–US	0.0741	0.0326	0.1084
OCE–US	0.0471	0.1725	0.3596

Note. Critical values: 0.743 at 1% level, 0.461 at 5% level, and 0.347 at 10% level.

Table 6 The R-Vines for butter, first sub-period (i.e. February 2000 to December 2007)

Butter	R-Vine							
	Copula	Par. 1	SE	λ	τ	AIC	BIC	LL
EU–OCE	sur. Joe	1.2561	0.0800	$\lambda_L = 0.2636$	0.1272	−8.1164	−4.7934	5.0582
EU–US	Clayton	0.1308	0.0506	$\lambda_L = 0.0050$	0.0614	−0.2369	3.0861	1.1185
OCE|EU–US|EU	Frank	−0.3233	0.3871	$\lambda = 0.0000$	−0.0359	1.4487	4.7717	0.2756

The constancy tests for all the quantiles (i.e. 0.25, 0.5, and 0.75) of the bivariate empirical copulas show that the empirical values of the relevant test statistics are below the 5 per cent critical value (0.461). These results highlight that all the bivariate empirical copulas exhibit constant tail dependence. Therefore, there is insufficient statistical evidence indicating breaks and/or gradual but persistent shifts in the bivariate empirical copulas, and a static copula structure is adequate to describe the price tail dependence among the butter markets.

4.1.2. Results for the copula models

Given that the constancy tests indicate that static copulas are the most appropriate, we proceed to select the R-Vine copula. Table 6 summarises the R-Vine selected for the butter prices in the first sub-period (i.e. February 2000 to December 2007).

Our results indicate that the EU acts as the central market for butter, since the EU establishes unconditional pair copulas, that is, direct connections with both Oceania and the United States (i.e. EU-OCE and E-US). This is somewhat surprising given that Oceania dominates the butter market in terms of volume. However, Europe maintains butter trade connections with both Oceania and the United States, exporting butter to the United States and importing butter from Oceania (Groves 2016; Fousekis and Grigoriadis 2016), and therefore, the EU butter prices are affected by both the other markets. The higher empirical Kendall's τ observed between the EU and Oceania and between the EU and the United States (as compared with the Kendall's τ observed between Oceania and the United States) establish the connections in the maximal spanning tree of the R-Vine and highlight the stronger association of the respective markets. Moreover, based on both the AIC and the BIC, the survival Joe copula is selected between the markets of Europe and Oceania, indicating lower-tail dependence. The specific dependence is weak (Kendall's $\tau = 0.1272$) and indicates asymmetry, since dependence is shown only in the lower tail. The lower-tail dependence between Europe and Oceania is due to the protection policies used by the EU during that period (i.e. intervention prices, quotas, and export subsidies), rendering the EU domestic butter prices immune to the international butter price changes. Therefore, we do not find evidence of upper-tail dependence between the butter prices in Europe and Oceania. However, lower-tail price dependence could exist due to the subsidised EU exports, especially during periods of overproduction and price crashes.

Furthermore, the Clayton copula is chosen for the EU and US pair, indicating lower-tail dependence between the corresponding prices. The tail dependence is weak (Kendall's $\tau = 0.0614$) and highlights asymmetry with dependence only in the lower prices. This lower-tail dependence shows that the policy schemes employed in the two regions have rendered the EU and US prices more dependent on each other during periods of low prices (i.e. price crashes), especially through export subsidies. However, during normal periods the policy measures prevent butter price correlation between these regions.

The asymmetric price co-movements that we observe bear implications regarding the distribution of benefits between the trading regions. More precisely, the lower-tail dependence that we identify in the EU-US (Clayton copula) and EU-OCE (sur. Joe copula) pairs in the first sub-period highlight that consumers across the trading regions are likely to benefit during periods of price crashes but they are not likely to be hurt equally during periods of price booms. Consumers in the United States (a high-price region) are likely to experience higher prices than consumers in the EU, and so are consumers in the EU compared with consumers in Oceania (a lower-price region).

Finally, the Frank copula is selected for the OCE-US pair, given the market of Europe, exhibiting weak dependence in the intermediate prices (Kendall's $\tau = -0.0359$ indicating disconcordance). However, this is a poor estimate (i.e. $\theta = -0.3233$ (0.3871)) reflecting independence between the prices in Oceania and the United States and might be due to the protection measures of the US market.

The results in the first sub-period show that the butter market is segmented, probably due to the agricultural protection policies employed in Europe and the United States until recently.

The R-Vine selected for the butter prices in the second sub-period (i.e. January 2008 to May 2017) is reported in Table 7.

The results reveal that Europe acts as the central market in the second sub-period as well. Based on both the AIC and the BIC, the Gumbel copula is chosen between the prices in Europe and Oceania, indicating upper-tail dependence. This high-tail dependence is confirmed by Fousekis and

Table 7 The R-vines for butter, second sub-period (i.e. January 2008 to May 2017)

Butter	R-Vine							
	Copula	Par. 1	SE	λ	τ	AIC	BIC	LL
EU–OCE	Gumbel	1.2327	0.0976	λ_U = 0.2453	0.1888	−21.4152	−17.9180	11.7076
EU–US	Gaussian	0.0821	0.0480	λ = 0.0000	0.0523	0.3478	3.8449	0.8261
OCE|EU–US|EU	sur. Joe	1.0246	0.0416	λ_L = 0.0330	0.0140	1.4589	4.9560	0.2706

Grigoriadis (2016). The liberalisation changes employed in Europe seem to have allowed the EU farmers to adjust their production decisions according to the market demand, rather than implementing protection measures, and thus to compete in the high tail with the farmers from Oceania, which is well known for its liberalised market orientation. Moreover, the preference of specific major butter importers (e.g. North African and Middle East countries) for the white-coloured butter from Europe has probably reduced the pressures on the EU exporters to follow the price decreases from Oceania (Thiele *et al.,* 2013; Fousekis and Grigoriadis 2016). The tail dependence is weak (Kendall's τ = 0.1888) but stronger than the tail dependence in the first sub-period. The liberalisation initiatives adopted in the EU after the 2008 CAP Health Check, including the elimination of import taxes and subsidies on export surpluses and the phasing out of the milk quotas, have probably led to stronger tail dependence than in the first sub-period (i.e. Kendall's τ = 0.1272). Thus, we find statistical evidence that the liberalisation changes have led to stronger tail dependence between the EU and Oceania. The upper-tail dependence observed in the EU-Oceania pair (Gumbel copula) indicates that consumers in Oceania (a low-price region) are likely to be influenced by price booms but are not likely to benefit from price drops in the EU (a high-price region).

Furthermore, the Gaussian copula is selected between the EU and the US prices, which shows intermediate-tail dependence. This dependence is again weak (Kendall's τ = 0.0523) and slightly decreased compared with that in the first sub-period (i.e. Kendall's τ = 0.0614).

Finally, the survival Joe copula is shown to capture better the linkages between the prices in Oceania and the United States, given the market of Europe, which exhibits weak lower-tail dependence (Kendall's τ = 0.0140). This very low degree of tail dependence in both sub-periods, suggesting independence of prices, is supported by Carvalho *et al.* (2015), who find independence of milk prices between Oceania, the US and the international markets. The lower-tail dependence that we observe in the US-OCE pair (sur. Joe copula) indicates that consumers in the United States (a high-price region) are likely to be hurt more by higher prices than consumers in Oceania (a low-price region).

All points considered, our results show that the butter market appears to be segmented but the overall tail interdependence (measured as $\sum_{i \neq j} |\tau_{i,j}|$)

Table 8 Constancy tests on the quantiles of the empirical copulas for WMP

Empirical copula	Quantiles		
	τ = 0.25	τ = 0.5	τ = 0.75
EU–OCE	0.2230	0.0498	0.2474
EU–US	0.4180	0.1879	0.4241
OCE–US	0.0441	0.0446	0.1643

Note. Critical values: 0.743 at 1% level, 0.461 at 5% level, and 0.347 at 10% level.

between the trading regions strengthens over time. This increasing price interdependence bears total welfare gains that may increase as the policy changes and the trade liberalisation agreements are progressively realised and take further effect.

4.2. Whole milk powder

4.2.1. Results for the marginal models

The selected marginal models are ARMA(1,1)-GARCH(1,1) for the WMP prices in Europe, ARMA(2,0)-GARCH(1,1) for Oceania, and ARMA(7,7)-GARCH(1,1) for the United States. The standardised residuals of the models are used to calculate the empirical distribution functions that provide the copula data.

The constancy tests of Busetti-Harvey are applied, and their results are reported in Table 8.

The constancy tests for the quantiles (i.e. 0.25, 0.5, and 0.75) and the bivariate empirical copulas indicate that the empirical values of the relevant test statistics are in all cases below the 5 per cent critical value (0.461). Thus, there is insufficient statistical evidence indicating breaks and/or gradual but persistent shifts in the bivariate empirical copulas, and a static structure is adequate to describe the price tail dependence among the WMP markets.

4.2.2. Results for the copula models

We present the R-Vine for WMP in the first sub-period (i.e. January 2000 to December 2007) in Table 9.

We find that Oceania acts as the central market, establishing direct connections (i.e. the unconditional OCE-EU and OCE-US pair copulas) with both the EU and the United States. This is reasonable given that Oceania is the dominant WMP exporter worldwide, accounting for approximately 57 per cent of the total quantity traded in 2013-2015 (OECD/FAO 2016). New Zealand benefitted the most from international dairy trade over the years 2000-2015, particularly considering the Chinese imports of WMP, with China being the largest importer of WMP (Chatellier 2017). The Chinese WMP imports from Oceania are far ahead of the imports from Europe or the United States (Chatellier 2017), and therefore, Oceania is placed as the

Table 9 The R-vine copulas for WMP, first sub-period (i.e. January 2000 to December 2007)

WMP	R-Vine									
	Copula	Par. 1	SE	Par. 2	SE	λ	τ	AIC	BIC	LL
OCE–EU	Frank	1.6627	0.4642	NA	NA	$\lambda = 0.0000$	0.1799	−9.6737	−6.3410	5.8369
OCE–US	BB1	0.3734	0.1671	1.0334	0.0726	$\lambda_L = 0.1659 \lambda_U = 0.0443$	0.1846	−9.3820	−2.7166	6.6910
EU|OCE–US|OCE	sur. Clayton	0.2021	0.0411	NA	NA	$\lambda_U = 0.0324$	0.0918	−3.9363	−0.6036	2.9681

†NA, not applicable.

central market in the first sub-period. The Frank copula is chosen (Kendall's $\tau = 0.1799$) between the prices in Oceania and those in the EU, based on the AIC and BIC. This copula reflects intermediate-tail dependence but no higher/lower-tail dependence, which is probably due to WMP being traded as an undifferentiated commodity. The dependence in intermediate prices is consistent with Zhang *et al.* (2017), who show that the WMP prices in Oceania and in the EU Granger cause each other.

In addition, we find the BB1 copula relating the prices between Oceania and the United States with weak overall tail dependence (Kendall's $\tau = 0.1846$). The BB1 copula reveals both upper-tail and lower-tail dependence, with the lower-tail parameter (1.0334) being larger than the upper-tail parameter (0.3734), thus indicating that the lower-tail dependence is stronger than the upper-tail dependence. This finding is reasonable given that Oceania maintains a liberalised dairy market, whereas the US dairy market has been protected through the milk marketing orders. Therefore, when the WMP prices are low, Oceania's prices are competitive against the rest of the international suppliers, including the United States. On the other hand, most of the US milk production is subject to price pooling under the milk marketing orders, which establishes minimum prices at levels reflecting the value of milk when manufactured into products sold at the domestic US prices (Vitaliano 2016). Thus, the United States realises prices that are well above those of Oceania, as observed in Figure 1 throughout the first sub-period, and during periods of high WMP prices, the US prices become less likely to be competitive against the Oceania prices, which are not regulated. Therefore, the US WMP prices are effectively competing with the Oceanian prices in the low tail but to a lesser extent in the high tail. The larger lower-tail dependence in the US-OCE pair indicates that consumers in the United States are likely to benefit from price crashes but are not likely to be hurt from price booms to the same extent, as consumers in Oceania.

Finally, we find the survival Clayton copula (Kendall's $\tau = 0.0918$) associating the prices between the EU and the United States given the market of Oceania, which highlights upper-tail dependence. However, the tail dependence between the two regions is probably captured inadequately in this copula, since the volumes of WMP exported from the United States during the first sub-period are negligible in contrast to those of Europe, and therefore, price competition between the two regions is not likely to be present. More precisely, the US dairy exports appear to increase substantially only after 2009 and with regard to WMP after 2011 (U.S. Dairy Export Council). The low degree of dependence is in line with Newton (2016), who finds that price shocks in the US market do not significantly alter prices in the EU. These findings taken together suggest a segmented market, wherein substantial improvement may be realised with further trade liberalisation.

Table 10 summarises the R-Vine chosen for WMP in the second sub-period (i.e. January 2008 to May 2017).

Table 10 The R-vine copulas for WMP, second sub-period (i.e. January 2008 to May 2017)

WMP	R-Vine							
	Copula	Par. 1	SE	λ	τ	AIC	BIC	LL
EU–OCE	Gaussian	0.2998	0.0326	λ = 0.0000	0.1938	−24.0960	−20.5988	13.0480
EU–US	Gumbel	1.1440	0.0944	λ_U = 0.1671	0.1258	−10.6397	−7.1426	6.3199
OCE|EU–US|EU	Frank	0.6836	0.3673	λ = 0.0000	0.0756	−1.7756	1.7216	1.8878

In the second sub-period, the EU is found to act as the central market for WMP, establishing direct connections with both Oceania and the United States. The choice of the Gaussian copula is based on the AIC and BIC for the price dependence between the EU and Oceania, indicating weak dependence (Kendall's τ = 0.1938) in the intermediate prices but no tail dependence. This lack of tail dependence probably relates to the fact that WMP from Europe and Oceania is undifferentiated. The dependence in the intermediate prices is consistent with Zhang *et al*. (2017) who find that the EU and Oceania Granger cause each other in the WMP market. We further observe slightly increased dependence in the intermediate prices between the EU and Oceania compared with the first sub-period.

The copula selected between Europe and the United States is the Gumbel copula (Kendall's τ = 0.1258), indicating upper-tail dependence, and larger than that in the first sub-period. A potential argument for this upper-tail dependence may be the quality difference in the European WMP compared with the US WMP. More precisely, the EU milk quality standards set in the EU Council Directive 92/46/EEC require all dairy products sold in the EU (local and imported) to have a somatic cell count below 400,000 cells/ml, based on the geometric average of monthly samples taken over a period of three months (More 2009). The US national limit is 750,000 cells/ml. Therefore, the EU WMP may realise higher prices than the US WMP in most of the sub-period, and during periods of price crashes, the US prices are less likely to compete with the EU prices. Furthermore, this upper-tail dependence signals that consumers in the United States are likely to be hurt from extreme positive shocks in Europe but are not likely to gain from extreme negative shocks.

Regarding the OCE-US pair given the market of Europe, the Frank copula (Kendall's τ = 0.0756) is selected, indicating dependence in the intermediate prices but no upper-tail or lower-tail dependence. This dependence, however, is substantially lower than that in the first sub-period. In August 2013, China imposed a ban on the milk powder imports from Australia and New Zealand, following Fonterra's announcement that the whey production had been contaminated by a bacterium that can cause botulism (Tajitsu 2013; Tuffley *et al.,* 2013). This ban on milk powder imports from Oceania probably caused an impact on the WMP price dependence between Oceania and the United

States. Given that China is the largest import market for WMP, in which Oceania and the United States compete, the collapse of the WMP imports from Oceania may have resulted in a substantial decrease in the price dependence between the two regions. The low dependence observed between Oceania and the United States is consistent with Zhang *et al*. (2017) finding no relationship between the WMP prices in Oceania and the United States; Newton (2016) showing that price shocks in the United States do not significantly alter the dairy commodity prices in Oceania; and Carvalho *et al*. (2015) finding independence of milk prices between New Zealand and the United States.

Our findings now suggest a market that seems to improve compared with the first sub-period (i.e. the tail interdependence, as measured by the Kendall's τ, increases for the EU-OCE and EU-US pairs), with the exception of the price linkage between Oceania and the United States, for which the ban of 2013 has probably resulted in lower-price dependence. Therefore, we conclude that the liberalisation changes show some impact.

5. Concluding remarks

In recent decades, multiple governments have negotiated to achieve liberalisation of dairy markets and this has resulted in reduced barriers and the establishment of several free trade agreements. More specifically, the Free Trade Agreement between China and New Zealand has strengthened the dairy trade relations between the corresponding countries, whereas the Free Trade Agreement between the EU, India, Korea, and the ASEAN countries has opened new prospects for the EU in the vast Asian markets. Furthermore, the North American Free Trade Agreement (NAFTA) and the Central America Free Trade Agreement (CAFTA) have provided measures eliminating dairy trade barriers between countries on the American continent. Moreover, within the scope of the CAP Health Check, the EU has decided to phase out the milk quota system, to establish a more liberalised and essentially a more competitive agri-food sector. This study considers butter and WMP to examine the impacts of liberalisation changes on spatial price transmission between Europe, Oceania, and the United States. We employ the Busetti and Harvey constancy tests and find that the price dependence between the regions is static. Thus, we apply static R-Vines to determine the corresponding tail dependencies. Our period is split in December 2007 to capture the changes between the two sub-periods, and the R-Vines are constructed drawing from ten bivariate copula families and their rotations.

In the butter market, our results indicate that Europe acts as the central market in both sub-periods, with the overall tail dependence increasing from one sub-period to another. We thus conclude that liberalisation has affected the price transmission between Europe and Oceania and between Europe and the United States but that its impact between Oceania and the United States has been negligible.

Concerning WMP, our results indicate that Oceania acts as the central market in the first sub-period. However, in the second sub-period, Oceania is succeeded by Europe as the central market. The tail dependence between Europe and Oceania and between Europe and the United States increases between the two sub-periods. On the other hand, the tail dependence between Oceania and the United States decreases substantially. This could be attributed to the 2013 Chinese ban on milk powder imports from Oceania due to the botulism scare. This ban resulted in the collapse of the WMP trade between Oceania and China in most of the second sub-period, affecting the price transmission between the two regions that compete in the Chinese WMP market. Taken together, these results suggest that the liberalisation changes occurring from 2008 onwards have affected the spatial price transmission in the WMP markets of the EU, Oceania and the United States. Their effects are depicted in tail dependence measures that, with the exception of OCE-US, are shown to increase.

We note that the change in tail dependence between the sub-periods may also be attributed to a series of macroeconomic factors, such as the 2008 financial crisis, which, however, is not modelled here. Esposti and Listorti (2013) find that economic bubbles have only a slight impact on the price spreads, supporting our claim that the change in tail dependence is most likely to be due to liberalisation change rather than to macroeconomic factors such as the financial crisis.

The strengthening of international trade, presumably due to free trade agreements and trade liberalisation initiatives, is expected to result in total welfare gains and economic efficiency increases for the trading regions. Our results provide evidence that the dairy market is segmented rather than well integrated, but the overall price dependence increases illustrate that the price linkages are stronger in the aftermath of the liberalisation changes. We conclude that further removal of trade barriers may be of benefit.

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