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## Article

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# An analysis of price and volatility transmission in butter, palm oil and crude oil markets

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## Abstract

Recent changes to the common agricultural policy (CAP) saw a shift to greater market orientation for the EU dairy industry. Given this reorientation, the volatility of EU dairy commodity prices has sharply increased, creating the need to develop proper risk management tools to protect farmers' income and to ensure stable prices for processors and consumers. In addition, there is a perceived threat that these commodities may be replaced by cheaper substitutes, such as palm oil, as dairy commodity prices become more volatile. Global production of palm oil almost doubled over the last decade while butter production remained relatively flat. Palm oil also serves as a feedstock for biodiesel production, thus establishing a new link between agricultural commodities and crude oil. Price and volatility transmission effects between EU and World butter prices, as well as between butter, palm oil and crude oil prices, before and after the Luxembourg agreement, are analysed. Vector autoregression (VAR) models are applied to capture price transmission effects between these markets. These are combined with a multivariate GARCH model to account for potential volatility transmission. Results indicate strong price and volatility transmission effects between EU and World butter prices. EU butter shocks further spillover to palm oil volatility. In addition, there is evidence that oil prices spillover to World butter prices and World butter volatility.

**Keywords:** Volatility transmission, Price transmission, Dairy industry, Palm oil, Multivariate GARCH, VAR

## Background

Recent changes to the common agricultural policy (CAP) saw a shift to greater market orientation for the EU dairy industry with the aim of bringing EU dairy prices more in line with World prices, which were historically significantly lower than EU prices. At the same time, price variability has sharply increased. Prices for EU butter increased from 209 EUR per 100 kg (=290 USD) in January 2009 to a high of 424 EUR (=608 USD) in July 2011 before falling back to 241 EUR (=306 USD) in May 2012. After this trough, butter prices started to rise again with a peak of 421 EUR (=565 USD) in September 2013, followed by a trough of 283 EUR (=311 USD) in December 2015. This shows that price variability has become a serious problem for farmers, processors and consumers with a need for appropriate risk management tools to cope with this increased variability. While this issue has been addressed by both the private market

and at EU policy level, the issue of price variability remains. The establishment of EU dairy futures by the Eurex was a positive development—however, liquidity and uptake remain low. Likewise implementation of the “Milk Package”,<sup>1</sup> while welcome, has had limited effect.

While a certain degree of price variation is desirable, as it provides price signals of changing market conditions, extremely high prices can lead to product substitution, while extremely low prices cause financial problems and ultimately threaten solvency (Keane and O’Connor 2009). In addition, stable prices are usually preferred by farmers, processors and consumers because they provide increased planning security.

To be effective, risk management tools must consider which factors drive dairy commodity prices. Given the reorientation of recent policy in the EU, the law of one price (LOP)<sup>2</sup> should hold if there are no, or low, market barriers to trade. This implies that there should be spatial price transmission between EU and World dairy commodity prices in more recent times, although these transmission effects might not be perfect as barriers are still not sufficiently low for full, short-term price transmission.

Besides any alignment of price levels, there can be also an alignment of price volatility. The studies of Bergmann et al. (2015) and O’Connor and Keane (2011) showed that volatility of EU dairy commodities has sharply increased and is historically high. In addition, O’Connor and Keane (2011) showed that EU price volatility is now more aligned with World price volatility for butter and skimmed milk powder (SMP). While these studies quantify volatility, they do not account for any transmission effects between EU and World price volatility which might exist.

Given the recent volatile nature of dairy commodity prices, there exists a perceived threat that these commodities may be replaced by cheaper substitutes. This is underlined in FAO and OECD (2011a) which states “Under very high prices, demand may retreat and dairy ingredients can be replaced by cheaper substitutes in food manufacturing”. This statement suggests that there might not only be spatial transmission effects among different regions but also between dairy commodities and substitutes, such as vegetable oils for butter. This substitution effect is reported in Keane and O’Connor (2009). However, there may be limits to this, especially in the short-term, because of the large investment required in product reformulation.

The relationship between crude oil, as a proxy for energy costs, and agricultural commodities (and dairy commodities in particular) has received attention in recent times. As stated by Baffes (2011), “any analysis of non-energy commodity markets cannot be undertaken in isolation to developments in energy markets”. This is underlined by the study of Huchet-Bourdon (2011), who found that butter and whole milk powder agricultural products had prices that most closely correlated with crude oil price over the last decade. In that study, the authors assume that this relationship might be due to the direct effect of crude oil price on agricultural commodity prices, through transportation and production costs. Another reason might be the increasing use of agricultural commodities for the production of biofuel, which provides a new link between oil and agricultural commodities. This points to relationships between crude oil, dairy products and vegetable oils, which are used for biofuel production (e.g. palm oil)—the latter also being considered a substitute for dairy products. In addition to these direct price links, there is the global concern that volatile energy prices may stimulate agricultural price volatility (Gardebroek and Hernandez 2013).

Price transmission studies involving dairy commodities are rare. Most of these studies focus on price transmission along the supply chain. Chavas and Mehta (2004) used a reduced form model to analyse transmission effects between wholesale and retail butter prices. Capps and Sherwell (2007) found asymmetric price transmission between farm and retail milk prices in seven cities in the USA. Asymmetric price transmission from farm gate milk prices to retail prices for a variety of dairy products in Spain was reported in Serra and Goodwin (2003). Vertical transmission effects between wholesale and small dairy producers' prices in Panama were analysed in Acosta and Alberto (2014). Spatial transmission between EU butter and SMP wholesale prices for four different EU member states was studied by O'Connor (2006), who found transmission between these member states. In a recent study, Acosta et al. (2014) found that there is evidence for price transmission from global prices to domestic markets for milk prices using an (asymmetric) error correction model. However, none of these studies investigated whether there was transmission in both prices and volatility between EU and World dairy prices, or between dairy prices and prices of substitutes, or crude oil.

In contrast, research analysing price transmission between oil and agricultural commodities has received much attention in recent times. This growing interest is mainly triggered by the recent expansion in biofuel production. However, findings in the literature are not conclusive. For example, the study of Zhang et al. (2009) found that there is no long-run relationship between fuel prices and agricultural commodity prices. Gardebroek & Hernandez (2013) used multivariate generalized autoregressive conditional heteroscedasticity (GARCH) models and found that there is volatility transmission from corn to ethanol for the US market, but not the converse. They did not find spillover<sup>3</sup> from oil to corn and concluded that there is no evidence that volatility in energy markets stimulated corn markets. Spillover effects from corn to ethanol markets were found in the study of Trujillo-Barrera et al. (2012) using futures prices. In contrast to the study of Gardebroek and Hernandez (2013), they also found spillover effects from oil to corn and ethanol markets. These results support the study of Wu et al. (2010), who also found spillover between oil and corn using futures prices. Using a stochastic volatility model, Du et al. (2011) reported volatility spillover from oil, corn and wheat markets using futures prices post 2006. Serra (2011) used a semiparametric GARCH model to analyse spillover effects between oil, ethanol and sugar prices in Brazil. Results of this study indicated strong volatility links between these prices. In a more recent study, Nazlioglu et al. (2013) found volatility transmission between oil and selected agricultural commodities post the commodity crisis of 2008, using a causality in variance test developed by Hafner and Herwartz (2006). Transmission effects between oil, ethanol and corn prices in China were analysed by Wu and Shiping (2013). They found evidence for transmission from oil to ethanol and corn prices.

Besides the studies mentioned above, which focus on the relationship between oil and agricultural commodities acting as main inputs for biofuel, there are studies which directly analyse the relationship between oil and food prices. For example, Huchet-Bourdon (2011) found increasing correlation between oil and agricultural commodities, including butter and whole milk powder.

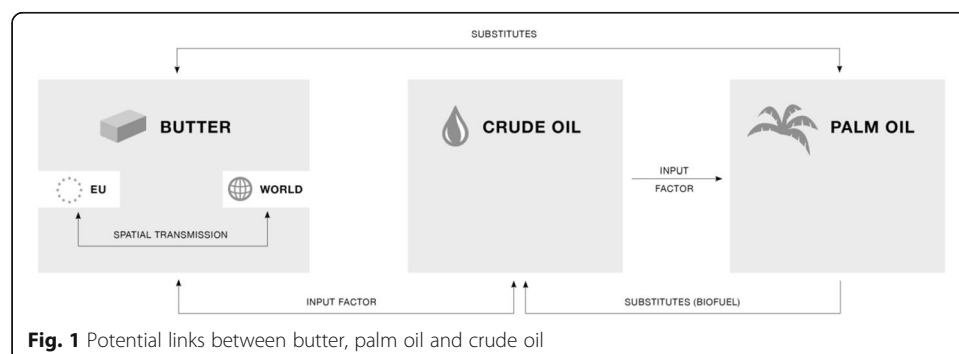
This paper analyses which factors affect butter prices and butter price volatility and thus provides the basis for the development of appropriate risk management tools. It contributes to the literature in three ways. Firstly, transmission effects in prices and

volatility between EU and World butter prices are studied in light of the recent greater market orientation of EU dairy policy. This is further expanded by analysing transmission effects between butter, crude oil and palm oil prices. This analysis perfectly fits the growing interest in the literature focusing on the potential links between oil and agricultural commodities, which act as the main input for biofuels, given that an increasing share of palm oil is used for biofuel production. Lastly, the role of palm oil as a substitute for butter is investigated. Figure 1 summarizes the relationships explored in this research.

Answering these questions will have important implications for policy makers and industry participants. If there is transmission between EU and World butter prices, dairy policies need to be considered and modelled in a global context. In addition, if there is transmission from crude oil or palm oil prices to dairy commodities, these relationships should be considered when contemplating future dairy policies. A greater understanding of these relationships may also raise interesting possibilities for dairy industry participants who, for example, may wish to hedge their exposure to more volatile dairy commodities by engaging in the established futures markets for the non-dairy commodities considered in this study.<sup>4</sup>

To investigate these questions, the analysis is divided into two periods (before and after the CAP Luxembourg agreement<sup>5</sup>). Vector autoregression (VAR) models are used to account for price transmission effects. Use of a VAR model is common practice as, for example, John (2014) uses this type of model to test for spatial transmission effects between Asian and American rice prices. To account for volatility dynamics and potential volatility transmission, the VAR model is further combined with a multivariate BEKK (Baba, Engle, Kroner and Kraft) model.<sup>6</sup> The combination of the VAR model with the BEKK model is, for example, used in the studies of Gardebroek and Hernandez (2013), Zhang et al. (2009), Mensi et al. (2014) and Wu and Shiping (2013).

This paper is organized as follows. The following section gives a definition of price and volatility transmission. Following this, a description of the butter and palm oil markets is presented along with an overview of their relationship to each other, as well as their relationship to crude oil. The subsequent section describes the methodology and data used. Thereafter, the results are presented, followed by the conclusion.

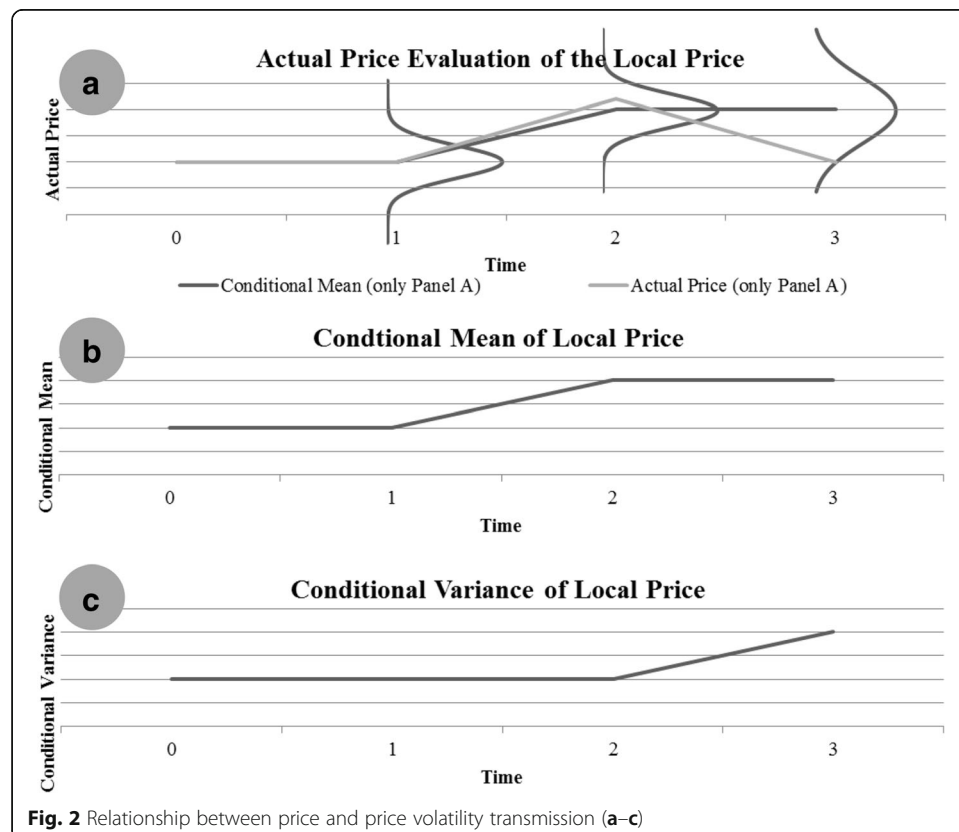


**Fig. 1** Potential links between butter, palm oil and crude oil

### Relationship between price and price volatility transmission

Both price and price volatility transmission are concepts used to analyse the relationships between prices, e.g. prices for the same commodity at different locations, or the prices of different commodities. However, price transmission implies transmission from the conditional mean (first moment of a time series), while price volatility transmission implies transmission from the conditional variance (second moment of a time series) (Assefa et al. 2016). According to Assefa et al. (2016), this implies that “Price transmission deals more generally with the relationship between the predictable “portions” of prices, whereas price volatility transmission deals with the relationship between the unpredictable portions of prices”. Price volatility transmission can also be defined as the degree to which price uncertainty in one market affects price uncertainty in the others (Apergis and Rezitis 2003).

The relationship between price and price volatility transmission is further illustrated by a simple hypothetical example. For this, an arbitrary price series, e.g. a Local price, is considered. It is further assumed that there is price and volatility transmission from a World price to the Local price. The World price itself is not modelled in this example and assumed to be exogenous. From a modelling point of view, the Local price is a time series which, in general, is a sequence of distributions. This implies that the price at any point in time is a distribution. This can be seen in panel a of Fig. 2. Price transmission now implies that the location or mean of this price distribution is affected by another price series. This is illustrated in panel b, which shows the conditional mean or expectation of the Local price distribution. It is now assumed that, in the second



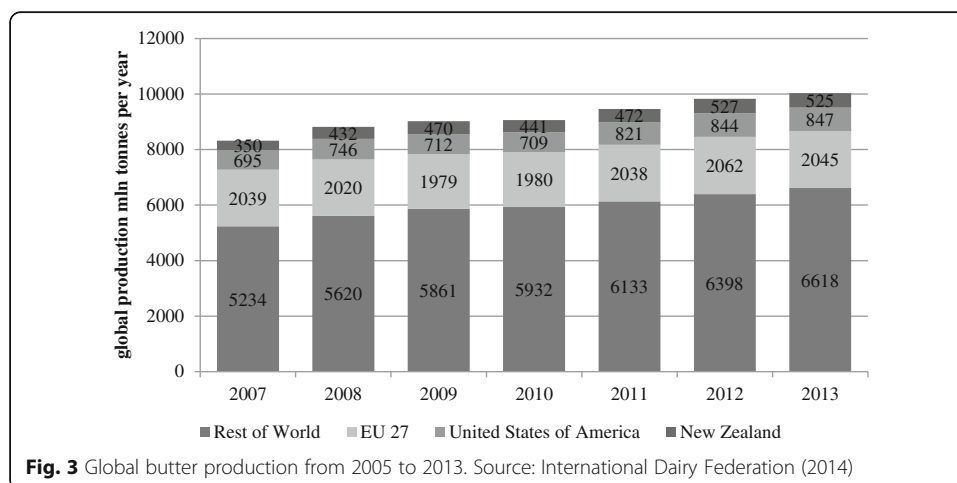
period, World prices rise<sup>7</sup> and transmit to the Local price. As a consequence, the conditional mean of the Local price increases in the second period (panel b). The effect of this conditional mean increase can be seen in panel a, where it is shown that the location of the price distribution has changed from the first period to the second. Volatility transmission, on the other hand, implies that the width of this distribution is affected by another series. To illustrate this, the conditional variance of the Local price is shown in panel c. Now, it is assumed that there is a shock in World markets<sup>8</sup> in the third period and that this uncertainty transmits to the Local price. Thus, the conditional variance in panel c rises in the third period. The effect of this increase on the price distribution is shown in panel a, where it can be seen that the width of the price distribution in the third period widens. Lastly, it should be noted that the actual price might deviate from the conditional mean. Panel a shows one possible path of the actual price for the example above.

Figure 2 shows how price and price volatility transmission are related. It also illustrates that in order to fully understand the dynamics of a price series, both price, and price volatility transmission, from possible explanatory series, must be analysed.

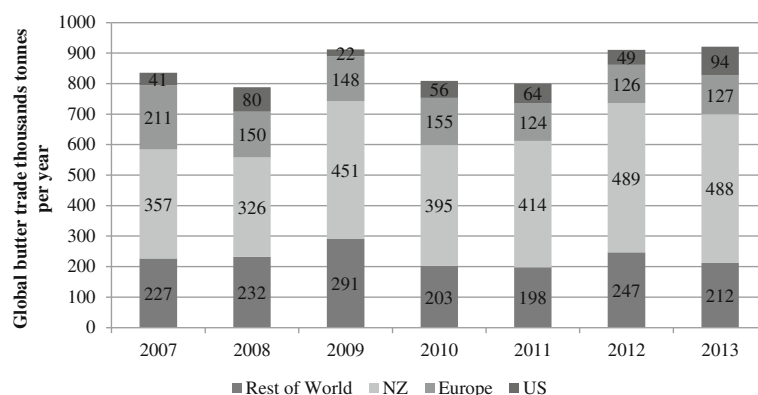
#### Butter and palm oil markets

Global butter production, including butter oil, increased by about 17.5 % from 2007 to 2012 with an annual global production of about 10 million tonnes in 2012, as can be seen in Fig. 3. This was mainly driven by increased production in India, while production in the EU, the second largest producer, remained relatively flat during this period. Figure 4, which shows global butter trade for the period 2007 to 2012, highlights the market share of New Zealand, the EU and the USA. In general, world markets for butter are considered thin, with approximately 9 % of world output traded on global markets. New Zealand is the largest exporter of butter, accounting for approximately 52 % of World trade, with the EU being the second largest exporter, with about 14 %. In addition, the five major exporters (New Zealand, EU, Belarus, Australia, and the USA) account for about 86 % of World trade (International Dairy Federation 2014).

Agricultural policies play an import role within the dairy industry. The EU dairy industry, for example, is subject to the CAP. In the past, the CAP focused on maintaining



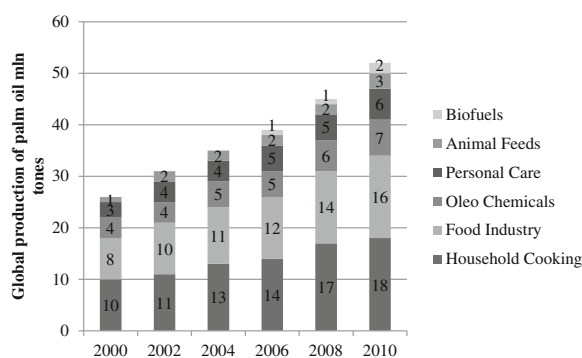




**Fig. 4** Global butter trade from 2005 to 2013. Source: International Dairy Federation (2014)

adequate and stable prices for particular dairy commodities, such as butter and SMP. In turn, it was expected that the enhanced returns from these commodities would be transmitted to the farm gate price for milk. This aim was mainly achieved by purchasing to intervention stores, setting production quotas, export refunds, import tariffs and subsidized consumption. These measures resulted in isolating EU dairy commodity prices from lower and more volatile World prices. However, more recent changes to the CAP, and in particular the Luxembourg 2003 agreement, resulted in a greater market orientation with a lower level of price support (intervention buying,<sup>9</sup> import tariffs and export refunds) for EU dairy commodities. To compensate for the resultant losses, the Single Payment Scheme (SPS) was introduced to provide income support at farm level. In addition, the supply quota, introduced in 1984, expired in 2015. This aim of bringing EU dairy prices more in line with World prices was observed in O'Connor and Keane (2011) who reported a convergence of volatility between EU and World dairy commodity prices. A more comprehensive discussion of the CAP policy changes can be found in Keane and O'Connor (2015).

Given the volatile and relatively high prices of butter, palm oil can serve as a cheaper substitute. Palm oil is a versatile vegetable oil and, with a share of more than 30 % of global vegetable oil production, it is also the most produced vegetable oil (USDA 2014). Figure 5 shows that global production of palm oil almost doubled from 2000 to 2010. This trend further continued with an estimated production of about 56 million tonnes in 2013, with Indonesia and Malaysia being the two most important producers, with a



**Fig. 5** Global production and use of palm oil. Source: WWF



share of about 85 % (USDA 2014). Although this expansion is mainly driven by increased use of palm oil for cooking, and within the food industry in general, estimates show that about 9 % of global palm oil production will be used within the biodiesel industry by 2021 (FAO and OECD 2012). In addition, Sanders et al. (2014) pointed out that changes in health-related regulations and standards for food on “trans fats have led food companies to switch to using palm oil in production”.

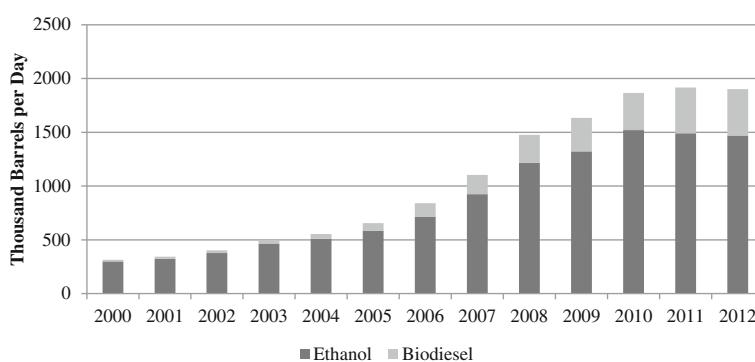
### Biofuel policies

Global production of biofuels has increased almost sixfold from 2000 to 2011, as can be seen in Fig. 6, while global crude oil production remained relatively flat, as can be seen in Fig. 7. The USA is by far the largest producer of ethanol, with a share of about 60 % of global production in 2011. In contrast, Europe is the major producer in the biodiesel sector, accounting for about 44 % of global production in 2011 (based on EIA data).

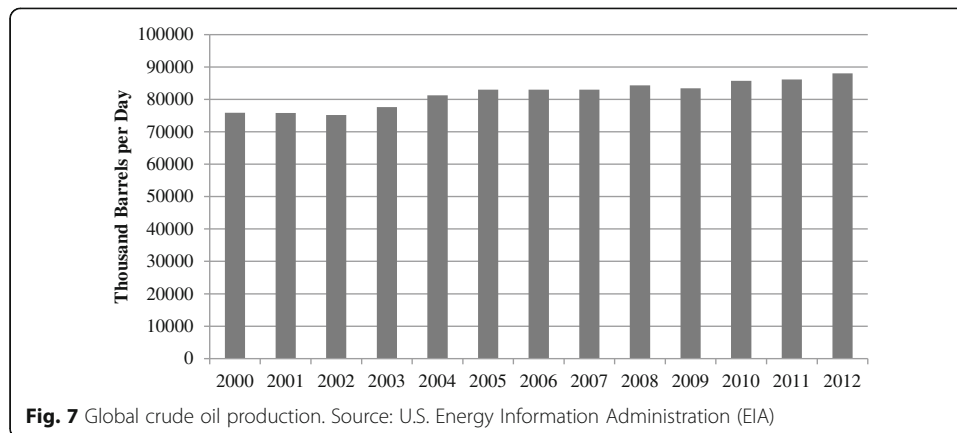
The expansion of biofuel production is mainly driven by policy decisions in the USA and the EU, as well as other countries, like Brazil. For example, in the USA, the Energy Policy Act of 2005 set targets for the amount of biofuel that producers need to mix with conventional fuels. These targets were further extended under Section 202 of the Energy Independence and Security Act of 2007, which sets a target of 36 million gallons of fuel from renewable sources by 2022.

In the EU, Directive 2009/28/EC of the European Parliament, and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources, states “a mandatory 10 % minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020”. More recent developments, like the proposal for a directive of the European Parliament, and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels, does not change this target, but addresses sustainability criteria for the production of biofuels.

The effects of these EU biofuel policies on palm oil were analysed by Gerasimchuk and Koh (2013). They concluded that, despite rapeseed being the main feedstock for biodiesel production within the EU, palm oil imports will increase by 40 % from 2012 to 2020, if no policy changes occur.



**Fig. 6** Global biofuel production. Source: U.S. Energy Information Administration (EIA)

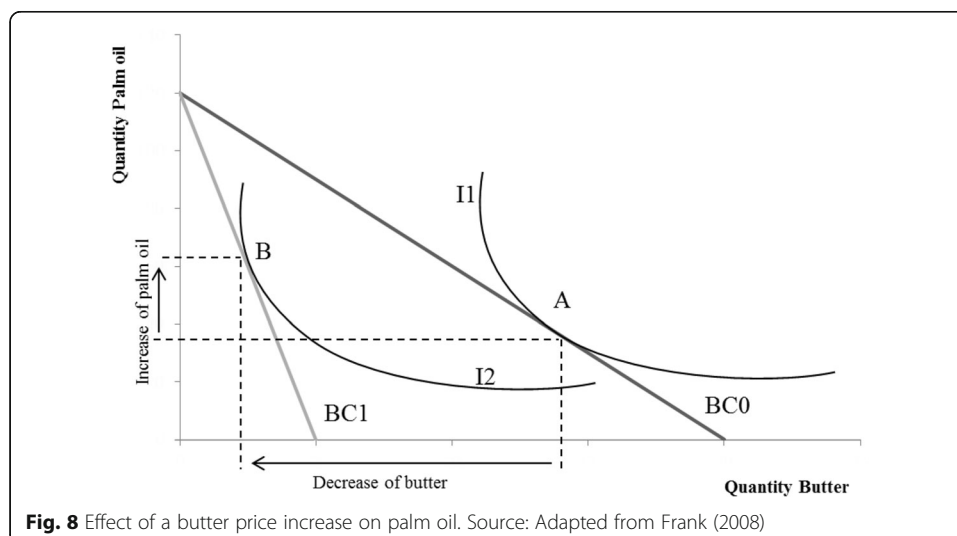


### Transmission effects between butter, palm oil and crude oil markets

Listori and Esposti (2012) mentioned a number of different types of price transmission effects involving agricultural commodity prices. In this paper, three of these are considered for the study of butter prices, namely spatial transmission, cross-commodity price transmission and transmission from non-agricultural to agricultural commodities.<sup>10</sup>

Firstly, spatial transmission effects between World and EU butter prices are analysed, given the recent greater market orientation of the CAP. The underlying economic justification for this analysis is spatial arbitrage (Listori and Esposti 2012). For the case of butter markets, this means that when World prices rises, arbitrageurs will start to buy butter in the EU and sell on the World market.<sup>11</sup> This will, in turn, increase EU prices.

Secondly, transmission between cross-commodity prices, in particular between butter and palm oil prices, is studied. This type of transmission is mainly driven by the substitutability of butter and palm oil, as both are sources of fat (Listori and Esposti 2012). Frank (2008) reported high cross-elasticity between butter and margarine which can be produced using palm oil. Given this, a priori, one would expect that an increase of butter prices will increase the demand for palm oil which will, in turn, increase palm oil prices, and vice versa (Frank 2008). Figure 8 illustrates this, where the initial budget



constraint is marked by BC0. The optimal initial bundle is marked by A. This is where the indifference curve I1 intercepts the budget constraint BC0 and represents the optimal choice of quantities for butter and palm oil. If the butter price rises, and palm oil prices remain constant, consumers will buy less butter, given their current income constraint. As a result, the budget constraint changes to BC1. The new optimal bundle now changes to point B, meaning the demand for butter decreases and the demand for palm oil increases, given the butter price increase.<sup>12</sup> Given this increased palm oil demand, palm oil prices should increase, implying transmission from butter to palm oil prices.

Thirdly, transmission from crude oil to butter and palm oil prices is considered in this paper. According to Nazlioglu et al. (2013), three linkages and explanations for this relationship can be found: (i) oil as production cost, (ii) biofuels, and (iii) co-movement with agricultural commodities, due to investment fund activity.<sup>13</sup>

Fertilizers are one of the major inputs into dairy farming, accounting for approximately 12.5 % of operating farm expenditure (DairyNZ 2013). Fertilizer production, in general, is considered a high, energy-intensive process as, for example, nitrogen-based fertilizers are made primarily from natural gas. This is confirmed by the studies of Baffes (2007) and Baffes (2011), in which high pass-through from energy indices, for example, crude oil to fertilizer indices, is found. In addition, processing milk to butter also requires significant energy input. This suggests that a direct relationship between butter and crude oil is to be expected. In addition, transportation costs for butter and dairy commodities are mainly influenced by oil costs, thus further strengthening the relationship between butter and crude oil. This argument was used to explain correlation effects between crude oil and agricultural commodities, and, in particular, butter, in the study of Huchet-Bourdon (2011).

Fertilizers are also major inputs for the production of palm oil (Mohd and Mohd 2009), providing a direct link between crude oil prices and palm oil prices. During periods of high prices for crude oil biofuel, and biodiesel in particular, have become alternative substitutes for crude oil. While the use of palm oil for biodiesel production is still relatively small, this new economic relationship might give rise to transmission effects between crude oil and palm oil. Despite these theoretical links, findings of previous studies investigating the relationship between crude oil and palm oil are contradictory. Yu et al. (2006) and Campiche et al. (2007) found that there was no co-integration relationship between crude oil and palm oil for data up to 2007. Weak dependence between the growth rates of palm oil and crude oil prices were found in a more recent study, using futures prices and extreme value theory (Chuangchid et al. 2012). However, Amna and Fatimah (2009) found that there was co-integration between oil and palm oil prices, for the period from 1983 to 2008.

## Methods

In this paper, a VAR<sup>14</sup> model is combined with a multivariate GARCH model. The VAR model identifies transmission in prices while the GARCH model is used to identify potential transmission in volatility. More precisely, the BEKK (named after Baba, Engle, Kroner and Kraft) parameterization by Engle and Kroner (1995) is used. The BEKK model accounts for transmission between own and cross volatility.

A comprehensive analysis of VAR models can be found in Lütkepohl (2010). At its simplest, a VAR is given by

$$y_t = v + \Phi_1 y_{t-1} + \dots + \Phi_p y_{t-p} + u_t \quad u_t \sim N(0, H_t) \quad (1)$$

where  $y_t$  is the  $k$  by 1 vector of returns at time  $t$ ,  $v$  is a  $k$  by 1 vector of intercept parameters and  $\Phi_l$ ,  $l = 1 \dots p$  are  $k$  by  $k$  matrices of coefficients corresponding to the lagged return vector  $y_{t-p}$ . The  $k$  by 1 residual vector  $u_t$  is normally distributed with conditional variance-covariance matrix  $H_t$ . Transmission in prices between markets is measured via the off-diagonal elements of the  $\Phi_l$  matrices. If  $H_t$  is constant, the model in Eq. 1 reduces to a simple VAR model.

The conditional variance-covariance matrix  $H_t$  follows a BEKK model which is, for example, described in Bauwens et al. (2006). In a BEKK (1,1) model,  $H_t$  is defined as

$$H_t = CC' + A' u_t u_t' A + G' H_{t-1} G \quad (2)$$

where  $C$  is a  $k$  by  $k$  lower triangular matrix of constants.  $A$  and  $G$  are  $k$  by  $k$  coefficient matrices. This parameterisation guarantees that  $H_t$  is positive definite. Similar to the VAR model, spillover effects of volatility from one market to another market are measured in the BEKK model over the off-diagonal elements of  $A$  and  $G$ .

Transmission in the conditional mean equation is tested via the off-diagonal elements  $\phi_{ij,l}$  of the parameter matrices  $\Phi_l$ ,  $l = 1 \dots p$ . If the Wald test suggests a rejection of the joint null hypothesis that  $\phi_{ij,l} = 0$  for all  $l = 1 \dots p$ , it is assumed that there is significant transmission from  $j$  to  $i$ . As presented in Serra et al. (2011), in the BEKK model, conditional variance of market  $i$  ( $h_{iit-1}$ ) may be affected by market  $j$ , directly by the lagged variance of market  $j$  ( $h_{jjt-1}$ ), indirectly by the conditional covariance between  $j$  and  $i$  ( $h_{ijt-1}$ ) and by market shocks in market  $j$  ( $u_{jt-1}$ ). If the parameters in  $G$  multiplying  $h_{ijt-1}$  are significant, it is said that there is direct volatility transmission from market  $j$  to market  $i$ . In the case where the parameters of the covariance  $h_{ijt-1}$  are significant, there is indirect transmission of volatility. Lastly, if the parameters in  $A$  multiplying  $u_{jt-1}$  are significant, there is transmission from market shocks in  $j$  to volatility in market  $i$ . Wald tests are used to test the significance of the parameters in  $A$  and  $G$ .

## Data

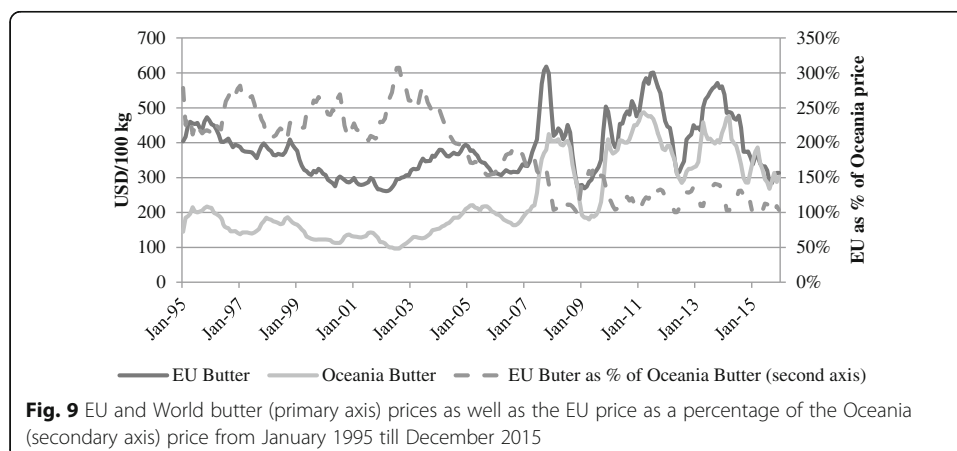
Butter, crude oil and crude palm oil prices from January 1995 to December 2015 are used in the following analysis. Due to data availability,<sup>15</sup> monthly data from January 1995 to December 2005 (132 observations) are used to test transmission effects before the full implementation of the CAP Luxembourg agreement, while bi-weekly data from January 2006 to December 2015 (260 observations) are used to test for transmission post implementation of the agreement. For butter, a representative EU and a World price series are considered. The EU prices are weekly Dutch Dairy Board wholesale prices, as published by Agra Europe. They have been converted to monthly and bi-weekly data by simply averaging weekly prices. The World butter prices are reported by the USDA.<sup>16</sup> These consist of FOB (Free on Board) wholesale Oceania export prices which can be considered as proxy World prices.<sup>17</sup> Crude oil prices are Europe Brent FOB prices and were obtained from the U.S. Energy Information Administration (EIA).<sup>18</sup> Lastly, two sources for palm oil prices are considered. For the first period, from January 1995 to December 2005, monthly prices from the World Bank<sup>19</sup> are used. For

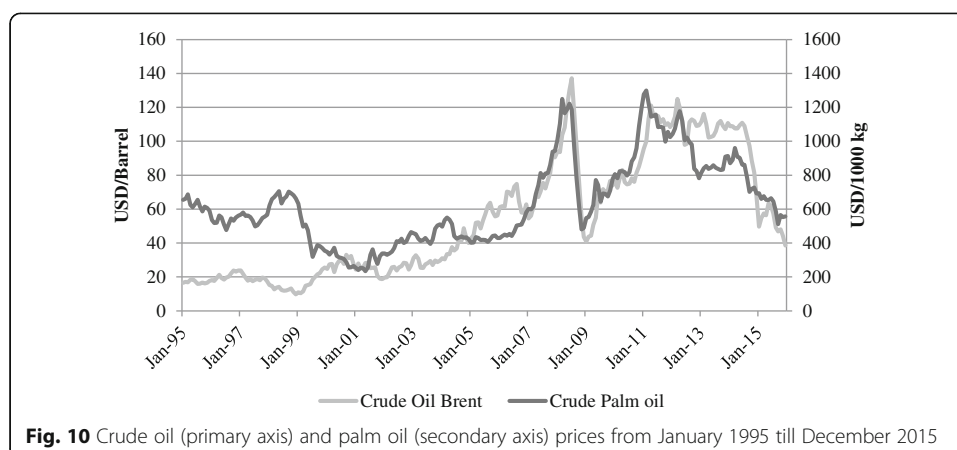
the second period, from January 2006 to December 2015, palm oil prices are sourced from the Malaysian Palm Oil Board.<sup>20</sup> In particular, crude palm oil prices CIF (Carriage, Insurance, Freight inclusive) at Rotterdam are used. The EU butter price has been converted to US dollar (USD) equivalents using currency exchange rates from the central Bank of Ireland,<sup>21</sup> as all other series are in USD.

Figure 9 shows the EU and World monthly butter prices in USD from January 1995 to December 2015. The World price is below the EU price, emphasizing the competitiveness of the New Zealand dairy sector (International Dairy Federation 2013). From 1995 to about 2005, it can be observed that the EU price is more than twice the Oceania price. This can be seen in Fig. 9, where the EU price, as a percentage of the Oceania price, is plotted on the secondary  $y$  axis. After 2005, the difference between the EU and Oceania price decreases and almost disappears by the end of 2015. However, while there is a gap between the EU and Oceania price for almost the whole period, one can see that both prices tend to move generally in the same direction.

Figure 10 shows the crude oil and palm oil prices for the same period, with palm oil on the secondary  $y$  axis. The common peak of crude oil and palm oil prices at the end of 2008, followed by the sharp fall at the beginning of 2009, seems to be the most striking feature of both series. After the trough in 2009, both prices recovered again to peaks at the beginning of 2011. After this, the crude oil price remained relatively stable within a corridor of about 100 to 120 USD per barrel until the recent sharp fall to about 40 USD per barrel at the end of 2015.

Table 1 provides descriptive statistics of the log returns  $y_t = \log(P_t/P_{t-1})$ , where  $P_t$  is the price at time  $t$ . Using log returns is a common practice in studies of this nature. One can see that the mean of the monthly EU butter and palm oil returns have a negative sign for the period from 1995 to 2005. This indicates that these prices were dropping over this period. The means of the Oceania and crude oil series, on the other hand, are positive, indicating that these price series seemed to rise over the period from 1995 to 2005. It can also be seen that the crude oil series has the largest standard deviation of 8.8 %, while the EU butter series has the lowest standard deviation of 2.7 %. This indicates that the EU butter price seems to be the least variable series during this period. This is also true for the second period from 2006 to 2015, although the standard deviation of the bi-weekly returns from all series is much more aligned than for the first period. For the second period, only crude oil shows a negative mean, which is





largely a result of the recent price drop for oil, from more than 100 USD to about 40 USD. All series, with the exception of the EU butter and crude oil series for the first period, exhibit excess kurtosis, implying that returns have heavier tails than a normal distribution.

Table 1 also shows correlations between all series. In the first period, all correlations, with the exception of the correlation between the palm oil and crude oil series, are

**Table 1** Descriptive statistics of log returns from January 1995 till December 2015

1995–2005 (monthly log returns)				
Statistic	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
Mean	−0.20 %	0.25 %	−0.32 %	0.93 %
Std	2.71 %	4.32 %	6.61 %	8.84 %
Skewness	0.42	1.21	−0.01	−0.20
Excess kurtosis	0.06	6.82	2.08	−0.08
2006–2015 (biweekly log returns)				
Statistic	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
Mean	0.00 %	0.18 %	0.10 %	−0.19 %
Std	3.78 %	4.18 %	4.33 %	5.48 %
Skewness	−0.09	0.04	−0.70	−0.61
Excess kurtosis	2.49	2.19	2.08	1.82
1995–2005 (monthly log returns)				
	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
EU butter	1	0.33*	0.27*	0.05
Oceania butter		1	0.10	0.11
Crude palm oil			1	−0.14
Crude oil Brent				1
2006–2015 (biweekly log returns)				
	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
EU butter	1	0.39*	0.20*	0.31*
Oceania butter		1	0.19*	0.14**
Crude palm oil			1	0.39*
Crude oil Brent				1

The symbols \* and \*\* denote significance at the 5 and 10 % confidence level, respectively

positive. However, only the correlation between both butter series, and the correlation between the EU butter series and palm oil series, are significant. For the second period, all correlations are positive and significant. This implies that, in general, the series tend to move together but it does not mean that transmission between all series should be expected as, for example, other common factors, like general economic conditions, can cause these co-movements.

Table 2 shows the results of selected statistical tests. The results for the augmented Dickey Fuller test imply that all log return series are stationary in both periods. The Jarque-Bera tests confirm the assumption, given the excess kurtosis, that all series, with the exception of the EU butter series in the first period, are not normal at the 5 % confidence level. The rejections of the null hypothesis by the Ljung-Box tests suggest that there is significant autocorrelation in all series, with the exception of the crude oil series for the first period. Lastly, the results of the Ljung-Box tests for the squared returns, along with the results of the Engle-ARCH test for the first period test, imply that there are no ARCH effects in the log returns, with the exception of the crude oil series<sup>22</sup> at the 5 % confidence level. In combination this implies that a simple VAR model is appropriate to model the returns in the first period. In contrast, both of these tests for the second period reject the null hypothesis at the 1 % confidence level, for all series. This indicates that the standard deviations of all series are not constant over time and that the series have ARCH effects in the second period.

## Results and discussion

In light of the preliminary analysis for the first period, a simple VAR model is used as both butter log returns show no signs of ARCH effects for this period (see Table 2). For the second period, a VAR-BEKK model, as described in the “Methods” section, is applied as there are strong ARCH effects in the log returns of all series (see Table 2). All models are implemented in Matlab,<sup>23</sup> with the VAR

**Table 2** Statistical properties of log returns from January 1995 till December 2015

	1995–2005 (monthly)			
	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
Augmented Dickey Fuller test	−7.6*	−8.77*	−4.55*	−11.08*
Jarque-Bera test	3.58	248.63*	19.10*	0.97*
Ljung-Box test	25.14*	43.54*	42.16*	7.65
Ljung-Box test squared returns	8.62	2.14	22.21**	24.09*
Engle test	10.46	7.21	17.18	24.90*
	2006–2015 (biweekly)			
	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
Augmented Dickey Fuller test	−8.03*	−6.90*	−10.34*	−10.20*
Jarque-Bera test	61.02*	46.75*	62.27*	47.50*
Ljung-Box test	148.74*	130.21*	65.50*	67.32*
Ljung-Box test squared returns	44.42*	42.65*	94.6*	85.58*
Engle test	40.61*	27.46*	65.22*	50.28*

The symbols \* and \*\* denotes rejection of the null hypothesis at the 1 and 5 % confidence level, respectively. The augmented Dickey Fuller test was performed with automated lag selection based on the Hannan Quinn (HQ) criterion. The Ljung-Box and Engle tests were performed with 10 lags



models estimated via ordinary least squares, and the VAR-BEKK via quasi maximum likelihood estimation. Model stability tests indicate that the VAR parameters are stable over time. In contrast, the initial likelihood function was flat and thus difficult to optimize. To address this issue, a simulated annealing algorithm was used.<sup>24</sup>

The parameters are estimated by quasi maximum likelihood (QML) estimation, which result in consistent parameter estimates even if the underlying series are not normal (Bauwens et al. 2006). The optimal lag length of all VAR processes is determined by the Hannan Quinn criterion (HQ) (Hannan and Quinn 1979). In particular, the HQ criterion suggests a lag length of two for the first period (1995 to 2005) and a lag length of one for the second period (2006 to 2015).<sup>25</sup> The HQ criterion also suggests a BEKK(1,1) model.<sup>26</sup> As argued in Lütkepohl (2010), the HQ criterion is consistent and selects the real lag length, with probability of 1 as the sample size goes to infinity. In addition, parameters are constrained to zero, if including the parameter does not improve the HQ criterion. This procedure is described in Lütkepohl (2010).

Diagnostic tests of the residuals from the VAR and VAR-BEKK models are presented in Table 3. The Ljung-Box (LB) test and the Engle test for the standardized residuals of each series indicate that both models are appropriate and that there is no evidence of autocorrelation or ARCH effects in the residuals. This is further confirmed by the Hosking Multivariate Portmanteau (HM) and Lagrange Multiplier (LM) tests, which can be seen as the multivariate generalization of the former tests.

**Table 3** Diagnostic tests for the residuals of the VAR model (1995 to 2005) and VAR-BEKK model (2006 to 2015)

1995–2005 (monthly) VAR model				
Statistic	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
Ljung-Box test	7.77***	4.69***	14.36***	8.67***
Ljung-Box test squared returns	10.55***	6.53***	15.76***	16.76**
Engle test	7.87***	11.46***	13.84***	16.27**
Multivariate tests				
Hosking test				146.29***
Hosking test squared returns				996.09***
Lagrange multiplier test				1107.5*
2006–2015 (biweekly) VAR-BEKK model				
Statistic	EU butter	Oceania butter	Crude palm oil	Crude oil Brent
Ljung-Box test	11.80***	16.49**	8.29***	5.80***
Ljung-Box test squared returns	5.49***	13.95***	10.51***	10.03***
Engle test	5.03***	12.34***	10.20***	9.54***
Multivariate tests				
Hosking test				171.93***
Hosking test squared returns				1039.2***
Lagrange multiplier test				1030.7***

The symbols \*, \*\* and \*\*\* denote acceptance of the null hypothesis at the 1, 5 and 10 % confidence level, respectively, for the residual diagnostic tests. The residual diagnostic tests were performed with 10 lags

### Price transmission effects

To analyse price transmission effects, tests of the significance of the coefficients of the parameter matrices  $\Phi_l$  from the VAR model in Eq. 1 were performed and are reported in Table 4, for both periods.<sup>27</sup>

From Table 4, it can be seen that for the EU butter series for the first period, past returns with one and two lags significantly affect current EU butter returns, at the 1 % confidence level. EU returns are not affected by any of the other series in this period. This is different for the second period, as EU returns are now affected by its own past returns and also by past Oceania butter returns, at the 1 % confidence level. This might be an indication that the CAP successfully isolated EU butter prices from developments of World markets historically, but not in more recent times. The Oceania series, on the other hand, is significantly impacted by its own past returns and past EU returns in both periods, at least at the 5 % confidence level. In addition, Table 4 suggests that there is significant price transmission from crude oil prices to Oceania butter prices in the latter period at the 10 % confidence level, which contrasts with the case for EU butter prices. This effect might be explained by the stronger reliance of World prices on transportation costs compared to EU prices.

The palm oil series not only shows transmission from its own past returns in the first period but also shows transmission from crude oil returns in the second period, at the 1 % confidence level. It shows no transmission from either of the butter series. The price transmission effect from crude oil to palm oil in the second period may indicate the role of crude oil as an important input for palm oil transportation and production.<sup>28</sup> In addition, crude oil prices might impact palm oil prices because of the use of

**Table 4** Coefficients of the VAR processes for the first period (1995 to 2005) and second period (2006 to 2015)

1995–2005									
Lag 1									
	Constant	EU butter	Oceania butter	Crude palm oil	Crude oil Brent	Lag 2			
EU butter	x	0.4110*	x	x	x	–0.1466***	x	x	x
Oceania butter	x	0.220**	0.3788*	x	x	0.2648	x	x	x
Crude palm oil	x	x	x	0.3447*	x	x	x	–0.3899*	x
Crude oil Brent	x	x	x	x	x	x	–0.3313	x	x
2006–2015									
Lag 1									
	Constant	EU butter	Oceania butter	Crude palm oil	Crude oil Brent				
EU butter	x	0.5782*	0.1469*	x	x				
Oceania butter	x	0.1883*	0.3510*	x	0.0904***				
Crude palm oil	x	x	x	0.3274*	0.1778*				
Crude oil Brent	x	x	x	x	0.4210*				

The symbols \*, \*\* and \*\*\* denote rejection of the null hypothesis that the corresponding parameter equals 0 at the 1, 5 and 10 % confidence level, respectively. The symbol x denotes a zero constraint

palm oil for biodiesel production. Lastly, the crude oil series shows no significant price transmission effects, even from itself, in the first period. This is consistent with the results in Table 2, which suggest that crude oil log returns show no signs of autocorrelation. For the second period, the crude oil series only shows significant transmission from own past returns at the 1 % confidence level. Overall, the finding that crude oil is not affected by any of the other series is to be expected, given the size and importance of crude oil compared to the other markets.

### Volatility transmission effects

Volatility transmission is tested via Wald tests on the coefficients of the parameter matrices A and G from the BEKK model in Eq. 2 and reported in Table 5. In particular, Wald tests of the form  $a_{ij} = 0$  and  $b_{ij} = 0$  are performed. As mentioned for the first period, a simple VAR model is appropriate (see Table 3). This implies that the assumption of a constant volatility is valid and, as a consequence, there are no volatility transmission effects reported for the first period.<sup>29</sup>

The Wald tests in Table 5 suggest that all diagonal elements of the coefficient matrix G from Eq. 2 are significant at the 1 % confidence level. This suggests that all series exhibit transmission from own past volatility. In addition, from matrix A, we see that there is strong evidence that market shocks (volatility) from the Oceania butter series transmit to volatility of the EU butter series ( $a_{2,1}$ ) at the 1 % confidence level.<sup>30</sup> EU butter market shocks transmit to palm oil volatility ( $a_{1,3}$ ) at the 1 % confidence level. In addition, there is evidence that crude oil market shocks transmit to the volatility of the Oceania butter series ( $a_{4,2}$ ), and palm oil series ( $a_{4,3}$ ), at the 5 % confidence level.

**Table 5** Coefficients of the BEKK(1,1) process for the second period (2006 to 2015)

2006–2015				
Parameter matrix C (Eq. 2)				
	EU butter ( $c_{1,j}$ )	Oceania butter ( $c_{2,j}$ )	Crude palm oil ( $c_{3,j}$ )	Crude oil Brent ( $c_{4,j}$ )
EU butter ( $c_{1,j}$ )	0.0015			
Oceania butter ( $c_{2,j}$ )	−0.0049	0.0097		
Crude palm oil ( $c_{3,j}$ )	0.0007	0.0014	0.0021	
Crude oil Brent ( $c_{4,j}$ )	−0.0006	0.0024	−0.0041	0.0001
Parameter matrix A (Eq. 2)				
	EU butter ( $a_{1,j}$ )	Oceania butter ( $a_{2,j}$ )	Crude palm oil ( $a_{3,j}$ )	Crude oil Brent ( $a_{4,j}$ )
EU butter ( $a_{1,j}$ )	0.0380	−0.0097	0.2470*	0.1483
Oceania butter ( $a_{2,j}$ )	−0.1863*	0.0633	−0.0380	−0.1082
Crude palm oil ( $a_{3,j}$ )	0.0620	−0.0848	−0.0134	0.1318
Crude oil Brent ( $a_{4,j}$ )	0.0074	0.1108**	−0.0995**	0.2255**
Parameter matrix G (Eq. 2)				
	EU butter ( $g_{1,j}$ )	Oceania butter ( $g_{2,j}$ )	Crude palm oil ( $g_{3,j}$ )	Crude oil Brent ( $g_{4,j}$ )
EU butter ( $g_{1,j}$ )	0.9671*	0.0426	0.0434	−0.0153
Oceania butter ( $g_{2,j}$ )	0.0184	0.9299*	−0.0218	0.0010
Crude palm oil ( $g_{3,j}$ )	−0.0253	0.0412	0.9615*	−0.0053
Crude oil Brent ( $g_{4,j}$ )	0.0022	−0.0417	0.0323	0.9532*

Coefficients of the parameter matrices C, A and G. Note that C is a triangular matrix. The symbols \*, \*\* and \*\*\* denote rejection of the null hypothesis that the corresponding parameter equals 0 at the 1 or 5 % confidence level

Lastly, crude oil volatility is only affected by its own market shocks ( $a_{4,4}$ ) at the 5 % confidence level. Also, the constant terms in matrix  $G$  are found to be of no significance, implying that the conditional variances are mainly driven by the coefficients in matrix  $A$  and  $G$ .

To further investigate the volatility effects, inferences are drawn from the nonlinear parameter functions in Table 6, as in Serra et al. (2011). The results in Table 6 confirm the finding of the Wald tests in Table 5 that all series exhibit transmission from own lagged volatilities. Table 6 also reports significant transmission effects from market shocks from the Oceania series ( $u_2$ ) to the volatility of the EU butter series ( $h_{11}$ ), at the 1 % confidence level. This was also suggested by the Wald tests in Table 5. Volatility of the EU butter series ( $h_{11}$ ) is further affected by the covariance between the EU and Oceania butter series ( $h_{12}$ ), and covariance between the EU butter and palm oil series ( $h_{13}$ ), at the 5 % confidence level. In general, the finding of transmission effects from Oceania to EU butter prices is consistent with O'Connor and Keane (2011) who, as stated above, assumed that EU and World prices would be more aligned in the future. Volatility of the Oceania butter series ( $h_{22}$ ), on the other hand, is affected by crude oil market shocks ( $u_4$ ) at the 5 % confidence level. There are no direct transmission effects from the palm oil series to the volatility of either of the butter series.

Crude oil market shocks ( $u_4$ ) also transmit to the volatility of the palm oil series ( $h_{33}$ ) at the 1 % confidence level. Simultaneous market shocks of the crude oil market and EU butter market ( $u_1u_4$ ) also transmit to the volatility of the palm oil series ( $h_{33}$ ) at the 5 % confidence level. In addition, there are direct transmission effects from EU butter market shocks ( $u_1$ ) to volatility of the palm oil series ( $h_{33}$ ) at the 1 % confidence level. Lastly, there are indirect transmission effects to the volatility of the palm oil series ( $h_{33}$ ) from the covariance between the EU butter series and palm oil series ( $h_{13}$ ) at the 5 % confidence level, and from the covariance between the crude oil and palm oil series ( $h_{34}$ ) at the 1 % confidence level.

**Table 6** Conditional variance equations for EU butter, palm oil and crude oil prices

$$\begin{aligned}
 h_{11t} &= 2.23e-06 + \mathbf{0.935^*}h_{11t-1} + 3.37e-04h_{22t-1} + 6.41e-04h_{33t-1} + 4.87e-06h_{44t-1} + \mathbf{0.036^{**}}h_{12t-1} - 0.049^*h_{13t-1} + 0.004h_{14t-1} \\
 &\quad - 9.29e-04h_{23t-1} + 8.10e-05h_{24t-1} - 1.12e-04h_{34t-1} + 0.001u_{1t-1}^2 + \mathbf{0.035^*}u_{2t-1}^2 + 0.004u_{3t-1}^2 + 5.44e-05u_{4t-1}^2 \\
 &\quad - 0.014u_{1t-1}u_{2t-1} + 0.005u_{1t-1}u_{3t-1} + 5.60e-04u_{1t-1}u_{4t-1} - 0.023u_{2t-1}u_{3t-1} - 0.003u_{2t-1}u_{4t-1} + 9.15e-04u_{3t-1}u_{4t-1} \\
 \\
 h_{22t} &= 1.18e-04 + 0.002h_{11t-1} + \mathbf{0.865^*}h_{22t-1} + 0.002h_{33t-1} + 0.002h_{44t-1} + 0.079h_{12t-1} + 0.004h_{13t-1} - 0.004h_{14t-1} + 0.077h_{23t-1} \\
 &\quad - 0.078h_{24t-1} - 0.003h_{34t-1} + 9.35e-05u_{1t-1}^2 + 0.004u_{2t-1}^2 + 0.007u_{3t-1}^2 + 0.012u_{4t-1}^2 - 0.001u_{1t-1}u_{2t-1} + 0.002u_{1t-1}u_{3t-1} \\
 &\quad - 0.002u_{1t-1}u_{4t-1} - 0.011u_{2t-1}u_{3t-1} + 0.014u_{2t-1}u_{4t-1} - 0.019u_{3t-1}u_{4t-1} \\
 \\
 h_{33t} &= 7.15e-06 + 0.002h_{11t-1} + 4.76e-04h_{22t-1} + \mathbf{0.925^*}h_{33t-1} + 0.001h_{44t-1} - 0.002h_{12t-1} + \mathbf{0.083^{**}}h_{13t-1} + 0.003h_{14t-1} \\
 &\quad - 0.042h_{23t-1} - 0.001h_{24t-1} + \mathbf{0.062^*}h_{34t-1} + \mathbf{0.061^*}u_{1t-1}^2 + 0.001u_{2t-1}^2 + 1.79e-04u_{3t-1}^2 + \mathbf{0.010^*}u_{4t-1}^2 - 0.019u_{1t-1}u_{2t-1} \\
 &\quad - 0.007u_{1t-1}u_{3t-1} - \mathbf{0.049^{**}}u_{1t-1}u_{4t-1} + 0.001u_{2t-1}u_{3t-1} + 0.008u_{2t-1}u_{4t-1} + 0.003u_{3t-1}u_{4t-1} \\
 \\
 h_{44t} &= 2.23e-05 + 2.35e-04h_{11t-1} + 1.02e-06h_{22t-1} + 2.79e-05h_{33t-1} + \mathbf{0.909^*}h_{44t-1} - 3.09e-05h_{12t-1} + 1.62e-04h_{13t-1} \\
 &\quad - 0.029h_{14t-1} - 1.07e-05h_{23t-1} + 0.002h_{24t-1} - 0.010h_{34t-1} + 0.022u_{1t-1}^2 + 0.012u_{2t-1}^2 + \mathbf{0.017^{**}}u_{3t-1}^2 + \mathbf{0.051^*}u_{4t-1}^2 \\
 &\quad - 0.032u_{1t-1}u_{2t-1} + 0.039u_{1t-1}u_{3t-1} + 0.067^{**}u_{1t-1}u_{4t-1} - 0.029u_{2t-1}u_{3t-1} - 0.049u_{2t-1}u_{4t-1} + \mathbf{0.059^*}u_{3t-1}u_{4t-1}
 \end{aligned}$$

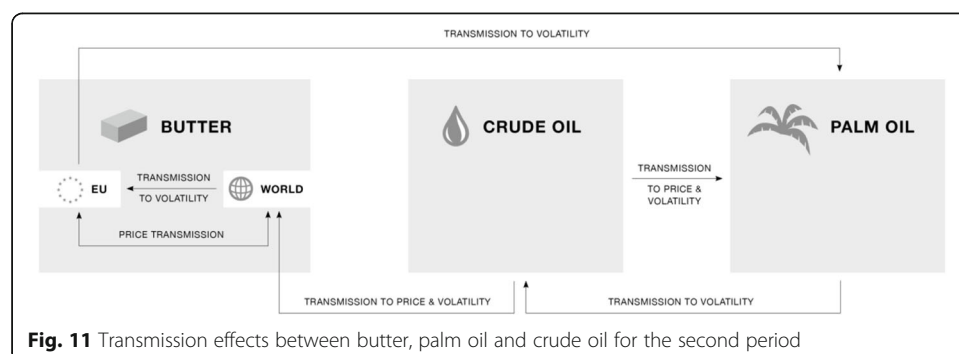
$i, j = 1, 2, 3, 4$  stands for EU butter, Oceania, palm oil and crude oil series, respectively. The symbols \*, \*\* and \*\*\* denote rejection of the null hypothesis that the corresponding parameters equals 0 at the 1, 5 or 10 % confidence level, respectively. Significant parameters are also in bold

The volatility of the crude oil series ( $h_{44}$ ) is affected by own market shocks ( $u_4$ ) at the 1 % confidence level. Table 6 further suggests transmission from palm oil market shocks ( $u_3$ ) to volatility of the crude oil series ( $h_{44}$ ) at the 5 % confidence level. However, given that this finding contrasts with the results in Table 5, it might be considered somewhat weak. Nonetheless, it might be an indication that the link between palm oil and crude oil markets is strengthening due to growing biofuel production. This assumption is also shared by Bakhat and Würzburg (2013) who found palm oil prices Granger causing crude oil prices. Transmission from wheat and barley markets to West Texas Intermediate (WTI) crude oil volatility as well as from the barley market to Brent volatility is found in Mensi et al. (2014). Although the authors argue that cereals and crude oil markets are more interrelated, they do not provide explanations for this. Besides this direct volatility transmission effect, the crude oil volatility ( $h_{44}$ ) is also affected by simultaneous market shocks of the crude oil market and palm oil market at the 1 % confidence level ( $u_3u_4$ ) and simultaneous market shocks of the crude oil market and EU butter market at the 5 % confidence level ( $u_1u_4$ ).

## Conclusions

In this paper, price and volatility transmission effects between EU and World butter prices as well as palm oil and crude oil prices were analysed. For this, a VAR model was applied to monthly data from January 1995 to December 2005 in order to analyse price transmission effects pre-2006, while a VAR-BEKK model was applied to bi-weekly data from January 2006 to December 2015, in order to analyse both price and volatility transmission effects post-2006. The main findings are summarized in Fig. 11 and as follows:

- There are no significant price transmission effects from World butter prices to EU butter prices or vice versa prior to 2006. For the period post this date, there are significant bidirectional price transmission effects between EU and World butter prices. In addition, there is significant transmission from World butter market shocks to EU butter volatility.
- There is evidence of volatility transmission effects from EU butter market shocks to palm oil volatility.
- There is evidence that crude oil prices transmit to Oceania butter and palm oil prices. Also, there is evidence that crude oil market shocks transmit to Oceania butter and palm oil volatility. In addition, there is weak evidence that palm oil market shocks transmit to crude oil volatility.



**Fig. 11** Transmission effects between butter, palm oil and crude oil for the second period

The issues addressed in this paper fit the growing interest in the literature regarding the linkages between oil and agricultural commodities. The results help to explain which factors drive butter prices and butter price volatility, which in turn may help to develop appropriate risk management tools in the dairy industry. As the dairy futures markets, which have recently developed in the EU, remain illiquid, as they are still thinly traded, cross hedging may provide a promising avenue to manage price risk. Unfortunately, these cross-hedging opportunities between well-established palm oil derivatives markets and dairy markets may not be effective, given the results in this paper, which reports no transmission effects from palm oil to butter. On the other hand, this result weakens the fear that “Under very high prices, demand may retreat and dairy ingredients can be replaced by cheaper substitutes in food manufacturing” which is stated by FAO and OECD (2011a). However, the finding of transmission from EU butter market shocks to palm oil volatility shows that there is some relationship in these markets. This relationship might be enforced, for example, considering that Unilever is the largest importer of palm oil impacting 8 % of global production<sup>31</sup> and also the largest producer of margarine.<sup>32</sup>

The identified transmission effects between World and EU butter prices suggests that dairy prices are driven by a common factor, thus suggesting that hedging EU butter prices with those of more established US dairy derivatives markets should be explored. It also confirms the achievement of the aim of greater market orientation of the EU dairy industry as posited by the recent changes in the CAP. For the EU supply chain, this finding implies that they need to deal with higher levels of volatility, similar to those associated with World prices. For policy makers and modellers, there is a need to consider World prices when considering EU prices.

Lastly, the finding that World butter and palm oil prices and volatility are affected by crude oil prices highlights the important role of oil as an input factor to agriculture. It also shows that the link between agricultural commodity markets and crude oil markets is getting stronger. This dependence may have unwanted consequences for food production, especially in the case of palm oil, where rising oil prices may lead to increased demand for biodiesel, which, in turn, may lead to an increased use of palm oil for biodiesel production, and thus reduce the supply of palm oil for food production. This is highlighted by FAO and OECD (2011b) for the analogous case of ethanol and crops. Finally, for investors, the benefits of diversification in spreading risks to different commodity markets may be less effective given the dependence of the agricultural commodities, analysed in this paper, to crude oil. This is also pointed out in Nazlioglu et al. (2013), who say that investors interested in one commodity market must consider risk transmission between other markets.

## Endnotes

<sup>1</sup>[http://ec.europa.eu/agriculture/milk/milk-package/index\\_en.htm](http://ec.europa.eu/agriculture/milk/milk-package/index_en.htm)

<sup>2</sup>The analysis in this paper is not considered a formal test of the LOP as co-integration analysis would be the preferred choice for such an analysis. For examples, see O'Connor (2006), Yu et al. (2006), or Acosta et al. (2014).

<sup>3</sup>The terms ‘spillover effects’ and ‘transmission effects’ are used interchangeably throughout this study.

<sup>4</sup>It should be noted that with the exception of the US dairy futures markets, other dairy futures markets are still very much at the embryonic stage, while markets for palm oil are well established.

<sup>5</sup>It should be noted that these periods only approximate the periods before and after the Luxembourg 2003 agreement, as this agreement was implemented over a number of years.

<sup>6</sup>For an introduction to the BEKK model, see Engle and Kroner (1995).

<sup>7</sup>This is not modelled and taken as given.

<sup>8</sup>This is also taken as given.

<sup>9</sup>Intervention prices actually paid for butter were € 2.22/kg in December 2013, compared to € 2.95/kg in December 2000.

<sup>10</sup>Transmission along the supply chain (vertical transmission), or between future and spot prices, is also mentioned in Listori and Esposti (2012).

<sup>11</sup>It should be noted that the price difference must be large enough to account for transportation and other costs.

<sup>12</sup>It should be noted that only the total effect of a butter price increase is described here. This effect can also be separated into income and substitution effects (Frank, 2008).

<sup>13</sup>Beside these potential relationships, endogenous supply response shocks or climate shocks also play an important role in the determination of dairy prices.

<sup>14</sup>A Vector-Error-Correction (VECM) model was tested, but no co-integration relationship was found.

<sup>15</sup>In particular, no bi-weekly palm oil prices could be sourced before 2006.

<sup>16</sup><http://www.ams.usda.gov/AMSV1.0/>

<sup>17</sup>Oceania prices have also been used as global proxy in Acosta et al. (2014) and O'Connor and Keane (2011).

<sup>18</sup><http://www.eia.gov/>

<sup>19</sup><http://databank.worldbank.org>

<sup>20</sup><http://bepi.mpob.gov.my/>

<sup>21</sup><http://www.centralbank.ie/polstats/stats/exrates/Pages/default.aspx>

<sup>22</sup>The results of the Ljung-Box test for the squared returns of the palm oil series show that the null hypothesis can only be rejected at the 5 % confidence level.

<sup>23</sup>The Econometrics toolbox available at <http://www.spatial-econometrics.com/> and the MFE Financial Econometrics Toolbox available at [http://www.kevinsheppard.com/wiki/MFE\\_Toolbox](http://www.kevinsheppard.com/wiki/MFE_Toolbox) were used.

<sup>24</sup>In particular, the implementation of Joachim Vandekerckhove is used (<http://www.mathworks.de/matlabcentral/fileexchange/10548-general-simulated-annealing-algorithm/content/anneal.m>).

<sup>25</sup>A lag length of two for the first period is also suggested by the AIC criterion (Akaike, 1973), while the Schwarz criterion (Schwarz, 1978) suggests a lag length of one. For the second period, all three criteria coincide and suggest a lag length of one.

<sup>26</sup>This coincides with the AIC and Schwarz criterion, which also suggest one lag.

<sup>27</sup>In addition, a dummy variable for the abolishment of the EU milk quota in April 2015 were added but found to be of no significance.

<sup>28</sup>As palm oil prices FOB at Rotterdam are used, transportation costs may be a significant factor in explaining this result.



<sup>29</sup>A VAR-BEKK model was also applied to the first period. The off-diagonal elements of the parameter matrices  $A$  and  $G$  were not found to be significant based on Wald tests. This also implies that there were no volatility transmission effects in the first period, which is consistent to the use of the VAR model. These additional results are available from the authors on request.

<sup>30</sup>The direction of transmission effects in Table 5 is always from the series in the row to the series in the column.

<sup>31</sup><https://www.unilever.com/sustainable-living/the-sustainable-living-plan/reducing-environmental-impact/sustainable-sourcing/transforming-the-palm-oil-industry/> (Accessed 18 June 2016)

<sup>32</sup><http://www.wsj.com/articles/unilever-profit-falls-after-year-earlier-gains-1453188371> (Accessed 18 June 2016)

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#### Authors' contributions

DB performed the statistical analysis, interpreted the results and drafted the manuscript. DO conceived the research idea. DO and AT participated in the interpretation of the statistical results and edited the manuscript. All authors read and approved the final manuscript.

#### Competing interests

The authors declare that they have no competing interests.

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