Understanding International Milk Price Relationships

Glauco R. Carvalho – Researcher at Embrapa, Department of Agricultural Economics, Texas A&M University (PhD candidate)

David Bessler – Professor, Department of Agricultural Economics, Texas A&M University

Torsten Hemme - Managing Director, IFCN Dairy Network

Eva Schröer-Merker – Team Leader, Dairy Sector Analysis, IFCN Dairy Network

Selected Paper prepared for presentation at the Southern Agricultural Economics Association's 2015 Annual Meeting, Atlanta, Georgia, January 31-February 3, 2015

Understanding international milk price relationships

Abstract

Price studies have been extensively investigated in agricultural economics literature. In the grain market, it seems that more information is available in terms of price behavior and relationships across markets. In the dairy market, on the other hand, price information is more limited. There are studies related to milk price relationships, but none explore the short-run and long-run relationship between milk prices across countries. This analysis aims to fill this gap in the literature. Insights from this work, which may help private companies and policymakers on how milk prices behave across the world, are provided. Data are offered by the IFCN Dairy research network, located in Kiel, Germany, and includes monthly price data from the United States, Brazil, Germany, the Netherlands, Russia, South Africa, India, China, and New Zealand. A Vector Error Correction (VEC) model is used to summarize the long-run relationship among prices from these nine countries. Contemporaneous innovations are modeled as an acyclic graph using recently developed algorithms from the machine literature. Forecast error variance decompositions are also estimated to visualize the relationships among variables in the system. As for validation, out-of-sample forecasts from the estimated Vector Autoregression (VAR) and VEC models are performed and the latter performed better. This forecasting exercise also supports the imposition of a low number of cointegrating vectors, which coheres well with trace tests and information criteria. The United States, New Zealand, and the IFCN milk price play an important role in the international dairy market.

Key word: price, direct acyclic graph, error-correction.

JEL code: C32, C51, C52.

Introduction

Price studies have been extensively investigated in agricultural economics and economics literature. Policymakers, traders, economists, farmers, and private companies involved in the supply chain are periodically trying to build a better understanding of price behavior to support their decisions.

In the grain sector, more information is available because the commodities have a more developed future markets spread out across the world. Prices for wheat, soybean, and corn can be observed daily in different countries. Studies on price behavior and international relationships across markets are also more often applied to the grain market. Bessler, et al. (2003) used an error correction model and directed acyclic graphs to evaluate price dynamic in the international wheat market. Long-run relationships between future (and spot) prices of cocoa and coffee on the New York CSCE and London were also studied using cointegration analysis (Sohbet and Jumah, 1995).

In the dairy market, however, price information is more limited. Future markets are available in just few regions, and daily prices are rarely found. The dairy sector is historically one of the most regulated sectors on the agribusiness and government interventions in price and trade are commonly used. However, recommendations from the World Trade Organization (WTO) discourage policies that causes trade distortions, like subsidies, quota, and standard trade barriers as studied by different authors (Sharma, et al. (1996), Langley, et al. (2006), van Meijl and van Tongeren (2002), and Lips and Rieder (2005)). Nevertheless, milk price studies are more commonly applied to evaluate specific regional issue such as market power, price discrimination, and volatility.

The farm-retail price transmission process for whole milk and 2% milk in some US cities were studied in Capps Jr and Sherwell (2007). They found asymmetric price transmission and the elasticities were larger when the farm prices were increasing in comparison with the corresponding elasticities associated with falling farm prices. Similar results were found by Kinnucan and Forker (1987), which suggested that the retail prices are more sensitive to increases in farm prices than to decreases in farm prices. Price transmission from farm to retail was studied in Brazil as well, and the findings suggested that price transmission in most of the markets was asymmetric, with higher transmission rates for price increases (Aguiar and Santana, 2002).

In Russia, retail price linkage between different markets was studied under regulated and free market contexts using cointegration and impulse response analysis. The evidences suggested that spatially separated markets are efficiently linked by regional arbitrage and trade activities (Goodwin, et al., 1999). The correlation between the US and international dry milk prices was studied by Gould and Villarreal (2002). Their findings suggested that European and Oceania FOB non-fat dry milk (NFDM) prices moved together over the 1995-2001 period, with a correlation coefficient at 0.98. On the other hand, the correlation coefficients between NFDM prices in the US versus Europe/Oceania were quite low, 0.13 and 0.07, respectively. In case of whole milk powder (WMP), FOB prices in Europe and Oceania displayed again close relationship, with correlation coefficient of 0.948. However, WMP price in the US was negatively related to the international price and the correlation coefficient was relatively low, -0.25. One of the reasons for that is because the US is a minor participant of the international WMP trade.

Regardless of regional characteristics of the dairy market, the exports of milk products are growing fast over time. From 2000 to 2013, the global dairy exports increased at the annual rate of 3.5% according to Food and Agriculture Organization (FAO) statistics. In the case of cheese and WMP, the export expansion was even higher, reaching the rate of 5.1% and 3.6%, respectively. With such performance, studies focused on trade liberalization, and regional impacts of trade became numerous ((Langley, et al., 2006), (Sharma and Gulati, 2003), (Alston, et al., 2006), (Larivière and Meilke, 1999)). Because of that, studies dedicated to understanding the price relationships across countries are critical to the world dairy industry.

The international dairy market is one of the most protected in agribusiness, and the global trade in dairy products has been distorted for decades. Government interventions in price and trade are very common in both domestic and frontier policies (Meilke and Lariviére, 1999). Different economic environment and dairy policies, such as consumer protection, producer support, tariffs, quota, and exchange rate, play a role in the price relationship.

The law of one price (LOP) states that once prices are converted to a common currency, the same good has the same price in different countries. However, numerous reasons exist for the failure of LOP such as exchange rate risk, transportation costs, an institutional factor that affect price settings, non-tradable inputs, among others (Miljkovic, 1999). Therefore, since the international milk market may not be perfectly competitive, it deviates from the LOP assumption (Samuelson, 1952).

It can be observed in the dairy economics literature, some studies related to milk price relationships, but none explore the short-run and long-run relationship between milk prices across countries and Direct Acyclic Graph (DAG), modeling innovations in contemporaneous time ((Glymour, et al., 1991), (Pearl, 2009)). This analysis aims to fill this gap on the literature. The study allows an evaluation of whether prices in important milk suppliers are connected, and how the causal structure is formed. Moreover, the study is able to provide insights on contemporaneous causal relationships among multiple markets, which may help private companies and policymakers.

A Vector Error Correction model is used to summarize the long-run relationship among prices in nine different markets: United States, Brazil, Germany, the Netherlands, Russia, South Africa, India, China, and New Zealand. The International Farm Comparison Network (IFCN) milk price is also included to represent the international price. Contemporaneous innovations are modeled as an acyclic graph using recently developed algorithms from the machine literature. Applications of DAGs in agricultural economics are not common and those studies can contribute considerably to the agricultural economics field.

Data and background

The data used in the study was offered by the International Farm Comparison Network (IFCN dairy), located in Kiel, Germany, and includes monthly averages of the price of milk over the period January 2006-December 2013. These prices are collected by a number of countries including the ones analyzed in this study: United States, Brazil, Germany, the Netherlands, Russia, South Africa, India, China, and New Zealand. In addition, the IFCN dairy has published a composed price based on milk powder prices (skim and whole milk powder), cheese, butter, and whey, that was incorporated into the analysis as a reference for the international price. Therefore, a total of ten markets were studied, which included nine countries and the composed price called IFCN world milk price indicator. The nine countries listed above corresponded to around 50% of the global cow milk production in 2012, according to FAO.

It is worth remembering that at least one country was selected on each continent. The choice of each country was based on a bundle of criteria such as importance in production, exports, location, and data availability. Because long time series are desired, but sometimes not available, the number of countries was also restricted due to loss in degrees of freedom. All milk prices were computed in national currency, and converted to US dollar due to high inflation rate in some places.

Table 1 reports the prices in US$/100 kg milk with 4% fat and 3.3% protein. A relatively high range between minimum and maximum price were observed and it reflects the strong fluctuation in commodities price during the period of 2007 to 2009. The average price was varying from 32 US dollars per 100 kg milk in India to 46 US dollars in China. The maximum milk price was observed in China and the minimum in Brazil. The milk price in China also suffered relatively more variations than in the other places, represented by the standard deviation statistics. Figure 1 shows the pattern of milk prices across countries. Overall, no seasonal fluctuation is observed as well as any convergence to the mean value. Those characteristics, however, will be formally tested later.

Table 1 - Descriptive statistics on milk price per country, 2006-2013.

Market	Mean (USD/100 kg milk)	Std.Dev.	Std.Dev. Rank	Min (USD/100 kg)	Max (USD/100 kg)
Germany	42.40	7.93	7	30.13	59.66
Netherlands	42.37	8.23	6	27.62	60.77
Russia	42.36	10.61	2	24.84	62.53
USA	40.30	7.46	8	26.93	52.59
Brazil	38.44	9.59	5	18.30	55.19
New Zealand	34.70	9.76	4	18.90	54.66
China	46.27	13.33	1	23.93	76.11
India	32.16	5.44	9	22.40	41.69
South Africa	37.78	5.35	10	25.86	45.65
IFCN milk price*	38.16	9.92	3	19.30	54.90

Note:* Weighted average of 3 IFCN world milk price indicators: SMP & butter (35%); Cheese & whey (45%); WMP (20%). Prices for SMP, butter, cheese, WMP: USDA (export FOB port for Oceania). Price for whey: ZMP, since May 2009 Süddeutsche Butter - und Käsebörse eV, Kempten (Germany, FOB ex-works). Exchange rates: Oanda.

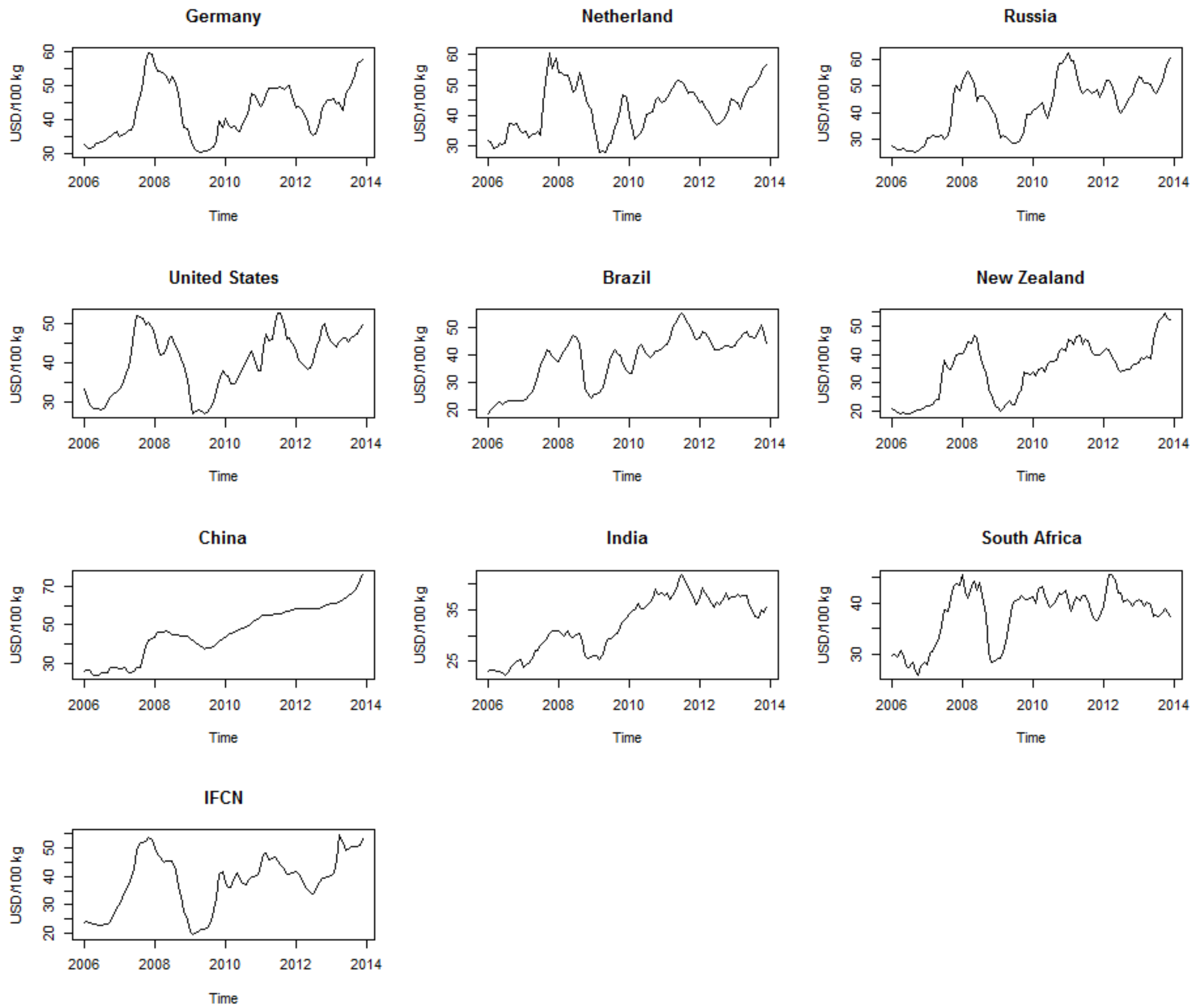

Figure 1 – Milk prices in USD/100 kg: monthly data from Jan-2006 to Dec-2013

Method and Empirical Results

The method applied to study the international milk price relationship was twofold. First, the Vector Error Correction (VEC) was used for estimating, forecasting and testing long-run relations. Second, Direct Acyclic Graphs were implemented for understanding relationships in contemporaneous time. The steps performed to achieve the objective followed standard procedures, which include testing for stationarity cointegrating vectors, lag length selection, exclusion restrictions, weak exogeneity, and out-of-sample forecasts. The impulse response analysis and forecast error variance decomposition were also estimated to identify reactions to shocks, and relationships among variables in the system.

The error correction model and cointegration analysis follow Johansen (1991) and Johansen and Juselius (1992, 1994). The existence of long-run equilibrium relationships among non-stationary variables implies cointegration. Cointegration has been applied to a range of studies, such as market power, international trade, and price relationship. The CATS in RATS program was used for all estimation and hypothesis testing (Hansen and Juselius, 1995).

Let $\mathbf{Z}_t$ represent the vector of milk prices p for the ten markets under consideration, such that,

$$Z_t = \begin{bmatrix} Z_{1t} \\ Z_{2t} \\ Z_{3t} \\ Z_{4t} \\ . \\ . \\ . \\ Z_{10t} \end{bmatrix}$$

where the subscripts 1 to 10 represent, respectively, Germany, Netherlands, Russia, US, Brazil, New Zealand, China, India, South Africa, and IFCN world milk price indicator. The error correction representation is modeled as following:

$$\Delta Z_t = \sum_{i=1}^{k-1} \Gamma_i \Delta Z_{t-i} + \Pi Z_{t-1} + \mu + \varepsilon_t,\ t = 1, \dots, T. \quad (1)$$

The cointegration hypothesis is defined as a reduced rank of the Π-matrix

$$H_1(r)\colon \Pi = \alpha\beta', \quad (2)$$

and the number of cointegrating vectors r is determined. There are three cases of interest in considering the equation 2 (Tsay, 2005): (a) if rank(Π)=0, then it implies that Z_t is not cointegrated and therefore, no long-run information is observed. The appropriate model in this case would be a VAR in first difference; (b) if rank(Π)=p, then it implies that Z_t contains no unit roots; that is, Z_t is stationary in levels (I(0)) and a VAR in levels would be an appropriate model; and (c) if 0< rank(Π)=r<p, then Z_t is cointegrated with r linearly independent cointegrating vectors. Moreover, there exist matrices α and β, with p x r dimension, such that Π=αβ' and rank(α)=rank(β)=r. In the case of this study, the third model was found to be the appropriate approach.

Test for stationarity

For a better understanding of each time series, the test for stationarity was performed using both the Augmented Dickey-Fuller and the Likelihood Ratio Test. The former has the null hypothesis defined as non-stationarity of the series while the latter assumes the opposite. Regardless of the test considered in the study, the ten time series analyzed were pretty much non-stationary as can be noticed in Table 2. Following the ADF test, all p-values were above 10%, but the Netherlands. Basically, at 90% confidence level the test failed to reject the null hypothesis of nonstationarity. According to the Likelihood test, however, all ten series were non-stationary with a very high significance level. As pointed out in Tsay (2005), when modelling non-stationary times series jointly, the cointegration may be found. The Error Correction Model (ECMs) is an alternative approach to VAR when the series are non-stationary. Moreover, ECMs are a theoretically-driven approach useful for estimating both short-term and long-term effects of one time series on another.

Table 2. Test of stationarity

Markets	Augmented Dickey-Fuller (k=2) Null of Non-stationarity (p-value)	Likelihood Ratio Test Null of Stationarity (p-value)
Germany	-2.69 (0.29)	39.39 (0.00)
Netherlands	-3.32 (0.07)	39.74 (0.00)
Russia	-2.85 (0.23)	39.43 (0.00)
U.S.	-2.30 (0.45)	40.72 (0.00)
Brazil	-3.12 (0.11)	39.74 (0.00)
New Zealand	-2.41 (0.41)	38.41 (0.00)
China	-2.85 (0.23)	40.97 (0.00)
India	-1.77 (0.67)	41.24 (0.00)
South Africa	-2.92 (0.20)	40.34 (0.00)
IFCN price	-2.15 (0.51)	38.18 (0.00)

Lag-order and seasonal component

One of the weaknesses of the Johansen approach is that it is sensitive to the lag length. So, the lag length should be determined in a systematic manner based on the existent metrics. Moreover, the selected lag length should work in such a way that residuals of the VAR model are not correlated. The dynamic behavior of the series in terms of lag length and monthly seasonal pattern was explored using the Schwarz loss (SL) metric (Schwarz, 1978) and the Hanna and Quinn's (HQ) metric (Hannan and Quinn, 1979) to possible lags of 1, 2, …, 5. In addition, a seasonal component was tested with and inclusion or exclusion of the monthly indicator variables (dummies).

Both criteria, SL and HQ, disagreed about the local minimum for the lag length determination as in Table 3. The Schwartz metric indicated lag of order 1 while the Hanna and Quinn's metric suggested order 2. As for the seasonal component, the metrics found no seasonal behavior. For the remaining part of this study, a two lags ECM without seasonal component is considered. The order two was suggested by Hannan and Quinn's metrics because the Schwarz loss may have a tendency to under-fit since it places greater penalty on large parameterization in comparison with other metrics (Geweke and Meese, 1981). Moreover, Hannan and Quinn's may perform better than Schwarz loss when the sample size is small, or the series are non-stationary (Wang and Bessler, 2009).

Another issue observed in the series was the existence of multiple break points, which was tested using the Bai-Perron procedure (Bai and Perron, 2003). Break point was found in China (2008:11) and the Netherlands (2008:07). However, the small sample size does not allow the estimation of the model in the second period due to low degree of freedom. This finding will be left for future research, whenever more data points will be available.

Table 3. Loss metrics (SL and HQ) on lag length and seasonal indicator variables from VARs on milk prices from 10 markets: monthly data, 2006-2013

Lag Length	With Seasonal Dummy Variables		Without Seasonal Dummy Variables	
k=	SL	HQ's Φ	SL	HQ's Φ
1	15.74*	12.13	12.89*	11.08
2	16.96	**11.71***	13.92	**10.48***
3	18.95	12.06	16.24	11.16
4	20.53	12.00	18.43	11.71
5	22.34	12.16	20.85	12.48

Cointegration analysis

Even though most of the time series data from the ten markets are non-stationary, they may share one or more stationary relationships in such a way that a linear combination of prices in level may be stationary. To identify the number of cointegrating vectors, the trace test and the information criteria were used. The trace test results are described in Table 4 and suggested the existence of two cointegrating vectors no matter the inclusion/exclusion of a constant within the cointegrating space. However, the likelihood test for exclusion restriction was performed and the output was very significant. Therefore, the constant was considered in the cointegrating space for appropriate specification.

The trace test was conducted sequentially following Johansen (1992), which starts testing for zero cointegrating vectors (r=0) with constant in the cointegrating space. The null hypothesis state the market in that row is not in the cointegrated space. Therefore, once the null hypothesis is rejected, we move on to test r=0 without constant. By rejecting the null hypothesis again, the test moves to r less than or equal to 1 with constant, and so forth. The procedure continues until the first fail to reject result appears, which happened at $r \leq 2$. This finding suggested two cointegrating vectors with the constant within the cointegrating space as reported in Table 4.

Another criterion used to identify the number of cointegrating vectors was the loss metrics and both SL and HQ indicated 1 cointegrating vector (Table 5). Therefore, the methods applied in the study suggested low number of cointegrating vectors, regardless the difference between both approaches trace test and loss metrics.

Table 4. Trace Tests on order of cointegration among milk prices from 10 world market: 2006-2013

H_0: Rank	Trace*	C (5%)*	D (lag2)	Trace	C (5%)	D (lag2)
r = 0	293.905	244.560	R	283.101	232.600	R
r ≤ 1	210.217	203.340	R	202.065	192.304	R
r ≤ 2	160.220	165.732	**F#**	152.688	155.748	**F#**
r ≤ 3	113.252	132.004	F	105.787	123.039	F
r ≤ 4	69.110	101.838	F	62.769	93.918	F
r ≤ 5	43.652	75.737	F	37.621	68.681	F
r ≤ 6	25.826	53.423	F	19.890	47.208	F
r ≤ 7	14.865	34.795	F	8.982	29.376	F
r ≤ 8	7.793	19.993	F	2.067	15.340	F
r ≤ 9	1.989	9.133	F	0.034	3.841	F

Note: * Associated with a constant within the cointegrating vectors. D=Decision of rejection (R) or fail to reject (F)

Table 5. SL and HQ criteria on order of cointegration among milk prices from 10 world market: 2006-2013

Cointegrating vectord	Criteria*		Test for autocorrelation (p-value)	
r	SC	HQ	LM(1)	LM(4)
<u>1</u>	**<u>11.417</u>**	**<u>9.482</u>**	**<u>0.09</u>**	**<u>0.21</u>**
2	11.756	9.530	0.01	0.18
3	12.029	9.546	0.00	0.17
4	12.236	9.527	0.00	0.11
5	12.545	9.642	0.01	0.08
6	12.839	9.775	0.00	0.08

Note: * Model associated with a constant within the cointegrating vectors.

As for validation and model selection, the out-of-sample forecasts were performed contrasting the ECM with the VAR model. The 10-steps ahead forecast exercise was conducted for the ECM considering all possible numbers of cointegrating vectors from 0 to 10, where the 10 cointegrating vectors represent the unrestricted VAR model. The ECM performed better than the VAR, which agrees with the idea that if the series are non-stationary the levels VAR models are not the appropriate approach for modelling the series. Moreover, the ECM with low number of cointegrating vectors forecasted better than the ECM with high number of cointegrating vectors. Basically, for each of the ten series the root mean squared error (RMSE) was small for the number of contintegrating vectors varying between 0 and 2.

As for specification, both the trace test and the dynamic forecast for 10-steps ahead indicated two cointegrating vector while the HQ criterion indicates 1 cointegrating vector. The former was select under the argument that the model should be chosen based on it's out-of-sample forecast, and in this case the ECM with two cointegrating vectors forecasted better. Table 6 reports the ECM and VAR RMSE for the out-of-sample forecasts considering 1, 5 and 10-steps ahead.

Table 6. Root Mean Squared Forecast Error on Out-Of-Sample Forecast from an Error Correction Model (ECM) and a Levels Vector Autoregression (VAR) on milk price in ten markets: from 2006:1 to 2013:12

Forecast (Steps ahead)	RMSE		RMSE		Number
	ECM	VAR	ECM	VAR	Observations
	Germany		New Zealand		
1	1.84	1.93	2.52	2.61	44
5	6.41	8.29	7.08	9.00	40
10	7.88	12.35	9.35	11.76	35
	The Netherlands		China		
1	1.84	2.61	0.81	0.99	44
5	6.69	8.93	3.57	4.74	40
10	8.52	11.98	5.55	8.11	35
	Russia		India		
1	2.85	3.10	1.11	1.30	44
5	10.19	11.12	2.96	4.42	40
10	10.40	12.19	2.86	6.24	35
	United States		South Africa		
1	1.91	2.19	1.72	2.25	44
5	7.53	9.72	5.23	8.04	40
10	7.72	11.68	5.52	8.78	35
	Brazil		IFCN milk price		
1	1.81	1.99	2.41	2.58	44
5	6.77	8.83	8.52	11.45	40
10	6.07	10.74	10.10	14.75	35

Forecast error variance decomposition and Impulse Response Function

Table 7 contains the forecast error variance decompositions at horizon 0, 1, 12, and 24 months. The decompositions are helpful in visualizing the relationships among variables in the system. The US price variation is explained by itself in contemporaneous time (100%). However, IFCN milk price innovation explains 21.16% of the US price at 12-month horizon, while New Zealand explains about 9.15% of the US price. At 24-month horizon, the US price variation is explained by innovations from the US price itself (47.18%), New Zealand (12.43%), and IFCN milk price (23.24%).

At the contemporaneous time, only five countries are not affected by innovation in third markets: Russia, US, New Zealand, China, and India. The result suggested that price variation in each of these markets depends only on innovation on that specific market in contemporaneous time. A more detailed analysis on this issue will be explored later using Direct Acyclic Graph. As for uncertainty in the long-term horizon (12 and 24 months), the New Zealand market is the most independent, and approximately 70% of the changes in New Zealand prices are explained by innovation on its own market. A possible explanation for that is the fact that New Zealand is the main dairy export, and therefore, has strong influence in its own market as well as in the international market.

The US, India, IFCN and China markets are also relatively more independent. As for price relationship, those countries are considered exogenous, which means that their milk prices do not respond to price shocks in other countries. Germany and the Netherlands, on the other hand, are strongly affected by shocks in other places. The Germany market is very sensitive to innovations in Russia market in the short-term. This relationship may reflect the fact that those countries are closely connected in trade since Russia is the main market of the Germany dairy products. For the long-term, however, the Germany market responds more to innovations in the US market (the main cow milk producer) and New Zealand market (the main exporter).

Understanding price behavior in a group of countries also requires knowledge of how some countries respond to shocks in other countries or in their own market. The impulse response function (IRF) provides an overview of the dynamic patterns of responses across the entire VEC system. Basically, the IRF shows how each series responds to a one-time-only shock in every series, including their own shocks. Figure 2 illustrates that New Zealand, IFCN, and US are the main dairy markets; that is, shocks in those markets spread out responses across the world. These results are meaningful since New Zealand is the main dairy exporter, IFCN is the international price reference and the US is the biggest producer in terms of cow milk. Brazil and the Netherlands also play some role on the price transmission. The reason for that might be related to the volume of milk produced and the size of the dairy market in Brazil such that excess supply/demand affect prices in other places. The Netherlands is an important dairy export country in the EU, which may explain the impact in prices in other countries.

Table 7. Forecast error variance decompositions on milk price from ten markets, 2006-2013

Market	Horizon	Germany	Netherlands	Russia	USA	Brazil	New Zealand	China	India	South Africa	IFCN milk price
Germany	0	85.27	0.00	14.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1	51.40	2.28	19.08	10.38	3.24	5.35	5.40	0.20	0.56	2.11
	12	1.02	3.21	3.79	36.67	12.68	38.54	1.20	0.21	0.39	2.20
	24	1.02	3.21	3.79	36.67	12.68	38.54	0.96	0.16	0.25	2.74
Netherlands	0	0.00	95.44	0.00	0.00	0.00	0.00	4.56	0.00	0.00	0.00
	1	0.04	75.51	1.67	0.52	3.81	0.02	13.44	1.34	1.63	2.01
	12	4.63	22.18	1.07	8.28	33.69	15.48	2.43	1.15	0.83	10.26
	24	4.60	20.29	0.81	8.23	33.66	18.39	1.21	0.67	0.53	11.61
Russia	0	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1	2.19	4.58	88.13	0.17	0.48	2.00	2.08	0.10	0.24	0.03
	12	11.45	11.35	32.27	10.18	0.98	22.97	8.78	0.59	0.08	1.35
	24	12.06	10.75	30.44	10.49	0.57	25.35	7.98	0.49	0.05	1.82
USA	0	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
	1	0.06	0.00	0.04	94.01	0.01	1.21	0.04	0.57	2.12	1.93
	12	0.40	1.68	2.11	50.53	6.34	9.15	2.80	3.75	2.09	21.16
	24	0.51	0.95	1.98	47.18	6.32	12.43	1.87	3.92	1.60	23.24
Brazil	0	0.00	0.00	0.00	0.00	82.86	0.00	0.00	17.14	0.00	0.00
	1	0.52	0.00	0.48	0.36	83.44	1.02	1.45	11.10	0.89	0.74
	12	0.28	3.44	8.17	1.80	35.47	24.29	2.21	15.20	4.53	4.61
	24	0.40	4.99	7.30	2.88	29.98	29.90	0.99	13.63	4.08	5.86

(continued)

Market	Horizon	Germany	Netherlands	Russia	USA	Brazil	New Zealand	China	India	South Africa	IFCN milk price
New Zealand	0	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
	1	0.51	0.37	2.39	1.54	2.43	91.46	0.56	0.06	0.56	0.12
	12	0.72	6.34	2.21	2.20	7.40	71.43	3.99	0.37	1.37	3.97
	24	0.94	7.53	1.64	2.90	6.71	69.05	4.86	0.35	1.21	4.81
China	0	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
	1	0.35	14.11	0.01	0.23	0.04	0.35	84.36	0.33	0.14	0.06
	12	2.18	21.08	0.14	8.49	1.10	14.89	49.75	0.73	0.03	1.61
	24	2.42	20.77	0.12	9.15	1.34	18.26	45.00	0.53	0.02	2.40
India	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00
	1	1.95	0.31	0.01	0.43	0.65	1.86	0.09	93.19	0.76	0.76
	12	7.85	0.86	0.51	4.07	1.03	24.05	0.02	54.01	1.98	5.63
	24	8.05	1.03	0.45	4.24	1.08	26.45	0.01	50.21	2.04	6.43
South Africa	0	0.00	0.00	0.00	0.00	13.19	0.00	0.00	16.08	70.73	0.00
	1	0.82	0.52	0.19	0.04	17.01	1.51	0.00	14.44	65.08	0.38
	12	2.53	1.40	1.79	1.24	14.26	16.92	0.15	11.40	47.13	3.17
	24	2.70	1.93	1.74	1.58	13.53	19.74	0.08	10.88	43.98	3.85
IFCN milk price	0	0.00	0.00	0.00	0.00	0.00	7.20	0.00	0.00	0.00	92.80
	1	0.49	0.33	0.31	0.02	0.33	22.19	0.01	0.00	0.27	76.04
	12	2.93	0.11	0.87	0.08	3.35	39.15	0.12	0.11	0.25	53.03
	24	3.07	0.13	0.79	0.17	3.28	41.35	0.07	0.12	0.27	50.76

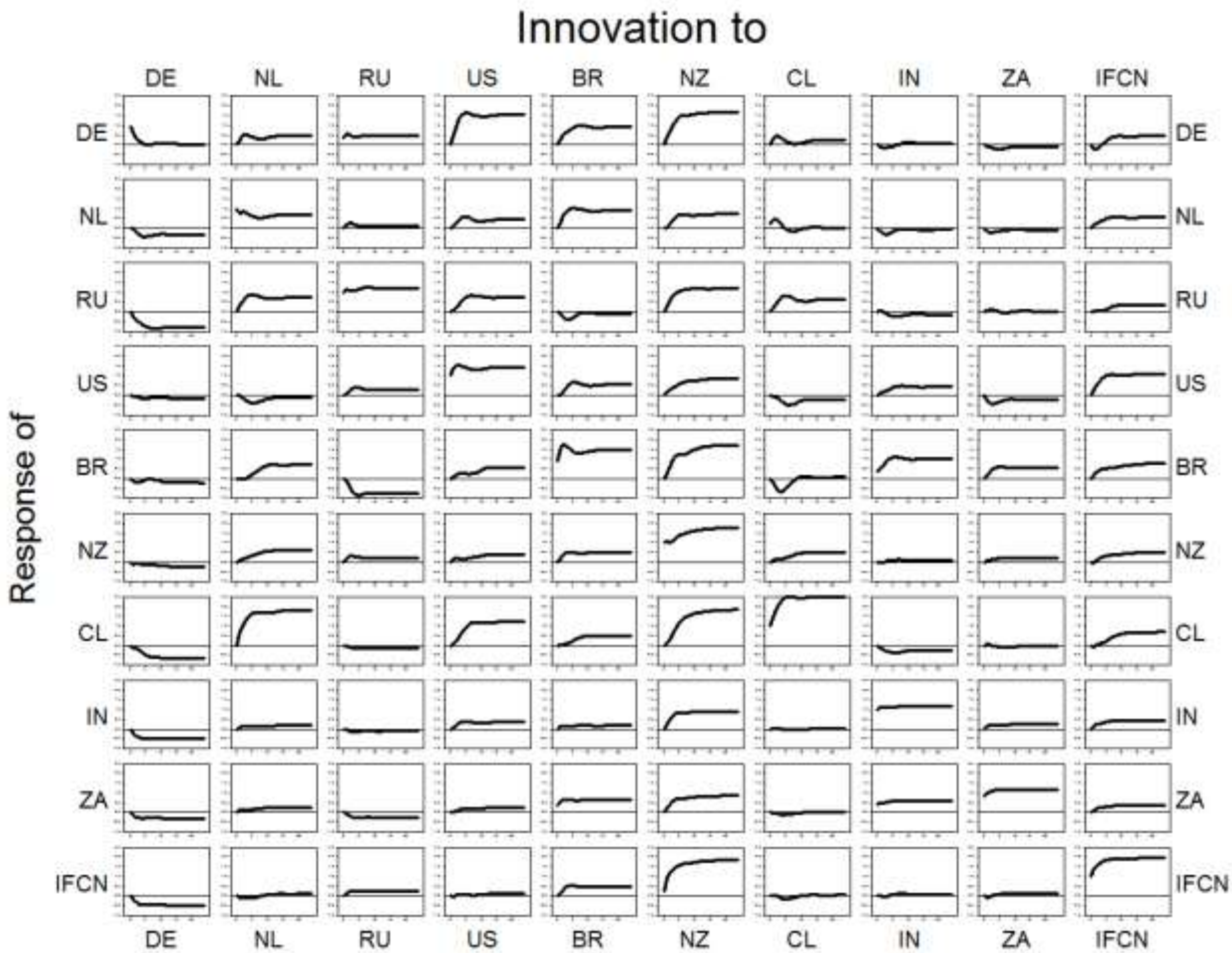

Figure 2. Impulse response on milk price from ten markets, 2006-2013

Note: DE: Germany; NL: Netherlands; RU: Russia; US: United States; BR: Brazil; NZ: New Zealand; CL: China; IN: India; ZA: South Africa;

Direct Acyclic Graphics

A graph is a picture that summarizes information dependence and independence among a group of variables. The vertices of a graph correspond to variables and the edges denote a relationship that may exist between variables. A direct graph represents the causal flow among the set of variables and it has a single arrowhead on the edge. A bi-directed edge will be observed in some applications, which denotes the existence of unobserved common causes, also called confounders (Pearl, 2009).

Direct Acyclic Graph emerged from artificial intelligence and computer science literature with the goal of helping researchers deal with inconsistence between the statistical theory and observational data. As one of the emerging tools, DAGs have gained significant popularity in recent years (Pearl, 2009). The main idea behind DAGs is to represent causal relationships among a set of observational variables using an arrow graph or picture. Lines with arrowheads are used to indicate causal flows between variables such that X → Y means that X causes Y. Lines without arrowhead, say W − Z, indicates that W and Z are connected, but the causal flow is unknown. The relationships between those variables are based on the correlation or partial correlation of the innovations. The PC algorithm, described in Spirtes and Glymour (1991) uses Fisher's z statistic to test whether conditional correlations are significantly different from zero (Wang and Bessler, 2006). Beginning with a complete undirected graph, the algorithm removes edges based on zero correlation or partial correlations. Double headed edges in the output of PC algorithm indicate that the adjacent variables have an omitted common cause.

The PC algorithm assumes the distribution of each variable is normal. The normality of each variable was tested using both Jarque-Bera and Shapiro-Wilks tests as discussed in Judge, et al. (1988) and described in Jarque and Bera (1987), and Shapiro and Wilk (1965) Based on Shapiro-Wilks five out of ten variables were normally distributed, while Jarque-Bera indicated six normally distributed variables. However, as pointed out in TETRAD V manual, the PC algorithm often succeed even when the assumption did not strictly hold. Another critical issue is that the PC algorithm may make mistakes related with edge inclusion/exclusion and edge direction when dealing with small sample size. A correction in term of level of significance is recommended and an alpha value of 0.20 was used for the sample size of 96 observations as mentioned in Wang and Bessler (2006) and Spirtes, et al. (2000).

As for applications, the TETRAD V described in Spirtes, Glymour and Scheines (2000) was used. The diagram described in Figure 3 represents the relationships among variables in the system at contemporaneous time. In many cases the prices variation are determined almost solely by their own innovations at contemporaneous time, which include countries like US, New Zealand, China, Russia, and India.

The IFCN milk price, on the other hand, is caused by New Zealand since the IFCN price considers in its calculation the export free on board prices from Oceania for SMP, butter, cheese, WMP. Another causal relationship indicated that Russia causes Germany. Russia is a big importer from EU, and a very important trading partner for Germany, so the causal relationship of the two countries is very plausible. The contemporaneous relationship between China and the Netherlands, with the former causing the latter, may be supported by trade. China is a big importer and the Netherlands has long geared up to export through giant dairy companies.

Less clear, however, are the contemporaneous correlations among Brazil, South Africa, and India in such a way that both Brazil and India cause South Africa and India causes Brazil. South Africa and Brazil have some common partners in trade. Both countries have exported dairy to Angola, Sudan, Nigeria, among others. Moreover, historically Brazil and South Africa have imported dairy products from countries like Argentina and Uruguay. Some dairy products from Brazil are also shipped to South Africa, which may help for understanding the causal relationship between them. However, the presence of India in this causal structure is tricky, and difficult to explain. It is known that both Brazil and India dairy sector is composed by numerous small family farmers, with high share of milk production sold without industrial transformation. In additional, the low production per cow is common in both markets.

Nevertheless, the causal relationship between these three countries is very strong regardless the model specification. Even when the specification was based on a VAR or ECM with different lag lengths the causal relationships between these countries were similar. Further investigation for understanding the milk price relationships between these markets will be left for future studies.

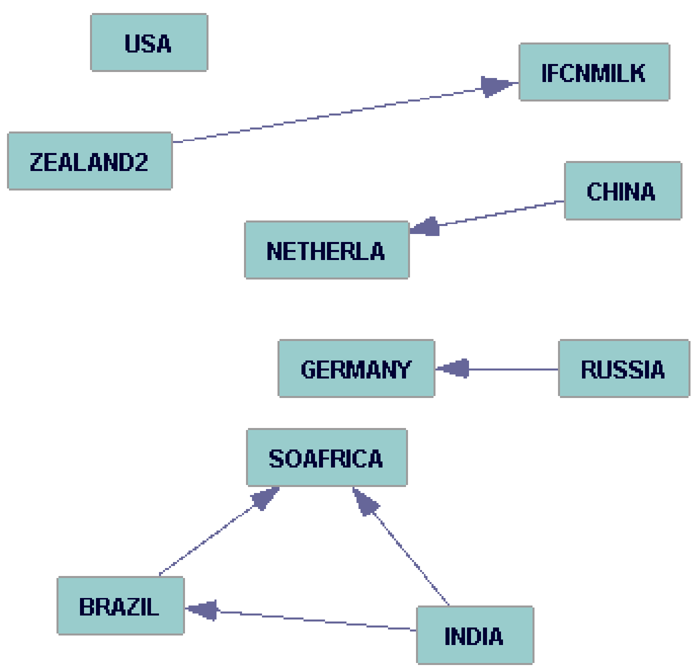

Figure 3. Graphical pattern from PC algorithm (20% significance) on innovations from two-lag ECM

Conclusions

The main objective of this study was to understand the milk price relationship across countries and provide insights of dependence and independency in different time horizon. Not many studies have been conducted with similar goals to explore the short-run and long-run relationships between milk prices. The results from this research were meaningful and may help private companies and policymakers on their decisions. The ECM with two lags was found to be the appropriate model for understanding the international milk price relationships. Moreover, a low number of cointegrating vectors was identified between those markets. In terms of forecasts, the ECM with two cointegrating vectors performed better than the VAR model.

The US, India, IFCN and China markets are relatively more independent and their milk prices do not respond much to shocks in prices in other countries. The findings also suggested that New Zealand, IFCN, and the US are the main dairy markets and shocks in their prices will spread out responses across the world.

As for contemporaneous relationship, Russia, US, New Zealand, China, and India are exogenous and price variation in each country depends only on innovation on that specific market. The causal relationships that arise from the DAG analysis suggest that trade plays an important role to understand the contemporaneous relationships. New Zealand, China, and Russia cause IFCN milk price, the Netherlands, and Germany respectively. Finally, Brazil causes South Africa and India causes both Brazil and South Africa. The role of India is not clear but the connection between these three countries was strong even considering different model specifications. This finding will be left for future investigations.

References

Aguiar, D.R.D., and J.A. Santana. 2002. "Asymmetry in farm to retail price transmission: Evidence from Brazil." *Agribusiness* 18:37-48.

Alston, J.M., J.V. Balagtas, H. Brunke, and D.A. Sumner. 2006. "Supply and demand for commodity components: implications of free trade versus the AUSFTA for the US dairy industry*." *Australian Journal of Agricultural and Resource Economics* 50:131-152.

Bai, J., and P. Perron. 2003. "Computation and analysis of multiple structural change models." *Journal of Applied Econometrics* 18:1-22.

Bessler, D.A., J. Yang, and M. Wongcharupan. 2003. "Price Dynamics in the International Wheat Market: Modeling with Error Correction and Directed Acyclic Graphs." *Journal of Regional Science* 43:1-33.

Capps Jr, O., and P. Sherwell. 2007. "Alternative approaches in detecting asymmetry in farm-retail price transmission of fluid milk." *Agribusiness* 23:313-331.

Geweke, J., and R. Meese. 1981. "Estimating Regression Models of Finite but Unknown Order." *International Economic Review* 22:55-70.

Glymour, C., P. Spirtes, and R. Scheines. 1991. "Causal inference." *Erkenntnis* 35:151-189.

Goodwin, B.K., T.J. Grennes, and C. McCurdy. 1999. "Spatial price dynamics and integration in russian food markets." *The Journal of Policy Reform* 3:157-193.

Gould, B.W., and H.J. Villarreal. 2002. *A descriptive analysis of recent trends in the international market for dry milk products*: Babcock Institute for International Dairy Research and Development, University of Wisconsin.

Hannan, E.J., and B.G. Quinn. 1979. "The Determination of the Order of an Autoregression." *Journal of the Royal Statistical Society. Series B (Methodological)* 41:190-195.

Hansen, H., and K. Juselius. 1995. *CATS in RATS: Cointegration Analysis of Time Series;[user's Manual}*: Estima.

Jarque, C.M., and A.K. Bera. 1987. "A Test for Normality of Observations and Regression Residuals." *International Statistical Review / Revue Internationale de Statistique* 55:163-172.

Judge, G.G., R.C. Hill, W. Griffiths, H. Lutkepohl, and T.-C. Lee. 1988. *Introduction to the Theory and Practice of Econometrics*. Second edition ed: Wiley.

Kinnucan, H.W., and O.D. Forker. 1987. "Asymmetry in Farm-Retail Price Transmission for Major Dairy Products." *American Journal of Agricultural Economics* 69:285-292.

Langley, S.V., A. Somwaru, and M.A. Normile. 2006. "Trade liberalization in international dairy markets: estimated impacts." U. S. Department of Agriculture, Economic Research Service.

Larivière, S., and K. Meilke. 1999. "An assessment of partial dairy trade liberalization on the U.S., EU-15 and Canada." *Canadian journal of agricultural economics* 47:59-73.

Lips, M., and P. Rieder. 2005. "Abolition of Raw Milk Quota in the European Union: A CGE Analysis at the Member Country Level." *Journal of Agricultural Economics* 56:1-17.

Meilke, K., and S. Lariviére. 1999. *The problems and pitfalls in modeling international dairy trade liberalization*. Ontario: IATRC.

Miljkovic, D. 1999. "The Law of One Price in International Trade: A Critical Review." *Review of Agricultural Economics* 21:126-139.

Pearl, J. 2009. *Causality*: Cambridge University Press.

Samuelson, P.A. 1952. "Spatial Price Equilibrium and Linear Programming." *The American Economic Review* 42:283-303.

Schwarz, G. 1978. "Estimating the Dimension of a Model." *The Annals of Statistics* 6:461-464.

Shapiro, S.S., and M.B. Wilk. 1965. "An Analysis of Variance Test for Normality (Complete Samples)." *Biometrika* 52:591-611.

Sharma, R., P. Konandreas, and J. Greenfield. 1996. "An overview of assessments of the impact of the Uruguay Round on agricultural prices and incomes." *Food Policy* 21:351-363.

Sharma, V.P., and A. Gulati. "Trade liberalization, market reforms and competitiveness of Indian dairy sector." International Food Policy Research Institute (IFPRI).

Sohbet, K., and A. Jumah. 1995. "Cointegration and Commodity Arbitrage." *Agribusiness (1986-1998)* 11:235.

Spirtes, P., and C. Glymour. 1991. "An Algorithm for Fast Recovery of Sparse Causal Graphs." *Social Science Computer Review* 9:62-72.

Spirtes, P., C.N. Glymour, and R. Scheines. 2000. *Causation, prediction, and search*: MIT press.

Tsay, R.S. 2005. *Analysis of financial time series*. 2nd edition ed. Hoboken, N.J.: John Wiley & Sons.

van Meijl, H., and F. van Tongeren. 2002. "The Agenda 2000 CAP reform, world prices and GATT–WTO export constraints." *European Review of Agricultural Economics* 29:445-470.

Wang, Z., and D.A. Bessler. 2009. "Finite sample performance of the model selection approach in co-integration analysis." *Journal of Statistical Computation and Simulation* 79:349-360.

---. 2006. "Price and quantity endogeneity in demand analysis: evidence from directed acyclic graphs." *Agricultural economics* 34:87-95.