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Components of farm milk price behavior in Brazil from 2005 to 2020

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ABSTRACT - The objective of this study was to assess behavior patterns in Brazilian farm milk prices. We employed a structural time series techniques model, the Unobserved Component Model (UCM), which is part of the family of State Space models, to assess the trend, seasonality, cyclical behavior, and impacts of exogenous regressors on aggregated farm milk price behavior in Brazil from January 2005 to December 2019. We tested five alternative models with different regressors using the monthly national average prices of milk paid to farmers. The fit of the models was assessed with Akaike information criterion and Bayesian information criterion. Predictions were assessed by the root mean squared error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). All models demonstrated a high degree of accuracy. Trends, seasonality, and two cycles were statistically significant, with the trend and long-period cycle contributing the most to price variation. Exogenous factors such as feed cost and international dairy product prices also had significant positive effects on the level of Brazil's farm milk prices. All models demonstrated a high degree of accuracy, which may indicate their usefulness for price forecasting and policy formulation.

Keywords: Brazil, dairy, price cycles, time series

1. Introduction

Price variability in the Brazilian dairy sector has increased since market deregulation in 1991, when the federal government ended the policy of price control at the farm and retail levels (Siqueira et al., 2010). The patterns of farm, wholesale, and retail prices also appear to have changed, creating additional challenges for management throughout the dairy supply chain (Chaves et al., 2022). Analysis of milk price behavioral patterns at the farm level would be helpful in setting public policies to mitigate volatility and risk on dairy supply chains. Only a limited number of studies have addressed this issue (Nicholson and Stephenson, 2014, 2015; Paura and Arhipova, 2016), especially for the Brazilian context (Viana et al., 2010; Santos et al., 2014; Alves et al., 2015).

Both cow milk production and dairy product consumption have grown rapidly in Brazil during the first two decades of the 21st century. Brazil is a tropical country, and the climatic conditions result in a marked seasonal milk production that is reflected in the farm-milk price behavior (Santos et al., 2014). Many commodities experience cycles in price and production with characteristic periods, amplitudes, and phases. Industries with significant delays on biological cycles or time required to build/expand plants have strong cycle dynamics suggesting that oscillations arise endogenously (Meadows, 1970; Sterman, 2000; Guimarães et al., 2009). In contrast, few studies have addressed the pattern of long-term oscillations in production and prices in the dairy industry

(Brockington et al., 1992; Nicholson and Stephenson, 2015). Identification of random shocks on time series of milk prices is also relevant to understand price behavior. The estimation of other exogenous variables is a topic of research in dairy price analysis (Paura and Arhipova, 2016), and the use of methods such as Holt-Winters may not be satisfactory to forecast the monthly milk production (Samohyl et al., 2001).

Despite the importance and acknowledgment of apparent cyclical behavior for commodity analysis (Davidsen et al., 1990; Jones et al., 2002; Conrad, 2004; Bragança and Bueno, 2010; Rooney et al., 2015), no formal analysis of farm milk prices in Brazil has been undertaken. Thus, our main objective was to assess behavior patterns in Brazilian farm milk prices, with particular emphasis on trends, seasonality price cycles, and other exogenous factors such as feed concentrate ration price, dairy product trade, and international dairy product prices.

2. Material and Methods

We used a type of time-series model, the Unobserved Component Model (UCM), which is part of the family of State Space models, to assess the Brazilian milk price behavior. The UCM is a flexible formulation that can include components such as trend, seasonal, cyclical, and exogenous regressors and disturbance terms. This technique can handle a wider range of problems than the time series analysis in the Box-Jenkins ARIMA system (Durbin and Koopman, 2012).

The UCM models represent trend, seasonal, cyclical components assuming that they follow stochastic processes (Harvey and Koopman, 2009). Thus, the UCM can be written as:

$$y_t = \tau_t + \gamma_t + \psi_t + \beta x_t + \varepsilon_t;\ \varepsilon_t \sim N(0, \sigma^2_\varepsilon) \quad (1)$$

in which y_t is the dependent variable (observed milk price) at time t; τ_t is the trend component; γ_t is the seasonal component; ψ_t is the cyclical component; β is a vector of fixed parameters; x_t is a vector of exogenous variables; and ε_t is the idiosyncratic error, with $t = 1, ..., T$. Trend was modeled as a random walk process as:

$$\tau_t = \mu_t \quad (2)$$

$$\mu_t = \mu_{t-1} + \alpha_{t-1} + \eta_t;\ \eta_t \sim N(0, \sigma^2_\eta) \quad (3)$$

$$\alpha_t = \alpha_{t-1} + \xi_t;\ \xi_t \sim N(0, \sigma^2_\xi) \quad (4)$$

in which μ_t is the local level, α_t is the local slope, and η_t and ξ_t are the errors.

The stochastic seasonal component γ_t can be modeled as:

$$\gamma_t = -\sum_{j=1}^{s-1} \gamma_{t-j} + \omega_t;\ \omega_t \sim N(0, \sigma^2_\omega) \quad (5)$$

However, because the estimated models would not converge with the inclusion of stochastic seasonal factors, we employed a deterministic form for the seasonal component (represented by monthly binary variables) with effect of sum zero, as follows:

$$\gamma_t = -\sum_{j=0}^{s-1} \gamma_{t-j} = 0 \quad (6)$$

The cyclical component ψ_t is a function of the frequency λ, in radians, and a unitless scaling variable ρ, termed the damping effect, $0 < \rho < 1$. Two equations are needed to express the cycle component:

$$\psi_t = \psi_{t-1}\, \rho.cos.\lambda + \psi'_{t-1}.\rho.sin.\lambda + \kappa_t;\ \kappa_t \sim N(0, \sigma^2_\omega) \quad (7)$$

$$\psi_t' = \psi_{t-1}\, \rho.sin.\lambda + \psi'_{t-1}.\rho.cos.\lambda + \kappa_t';\ \kappa_t' \sim N(0, \sigma^2_\omega) \quad (8)$$

The errors of all components ε_t, η_t, ξ_t, ω_t, κ_t, and κ_t' are assumed to be independent.

The exogenous variables (x_t) can be used to control for other factors that often are assumed to influence milk prices. Similar to Nicholson and Stephenson (2015), we tested the impact of selected exogenous variables, in part because industry analysts often attribute changes in domestic milk prices to factors such as concentrated feed ration prices, imports, and the international price of dairy products (milk powder). We, therefore, controlled for these factors to assess underlying trend, cyclical, and seasonal components of price behavior. These variables were included in five alternative model specifications: the first containing only the unobserved components; the second, the third, and the fourth testing the exogenous variables separately; and the last putting all unobserved and exogenous variables together. Model 1 describes the pattern of price behavior including only the trend, seasonal, cyclical, and random components. Model 2 tests to what extent the feed concentrate ration price affects farm milk prices. Model 3 evaluates whether the volume of Brazilian imports and exports affects the milk price paid to farmers. In particular, trade is usually considered an endogenous component of the supply/demand balance of the commodities supply chains. However, due to the small amount of equivalent fluid milk imported and exported relative to the total production, we assume in our formulation that these variables are exogenous components that would affect the processors' inventories and, consequently, internal prices. Model 4 includes international whole milk powder prices as an exogenous variable to test for the impact of international linkages on Brazilian milk prices. Model 5 incorporates all the exogenous variables to simultaneously control for their potential impacts. The models were estimated using maximum likelihood methods based on a Kalman Filter approach using the STATA/MP 14.0 software.

The monthly national average prices of milk paid to Brazilian dairy farmers from January 2005 to December 2019 were obtained from the Centro de Estudos Avançados em Economia Aplicada (CEPEA). The values are the nominal net price received by producers (without freight and taxes), expressed in Reals per liter (CEPEA, 2019). The ration price expressed in Reals per kilogram, using a weighted average of the wholesale prices lagged by two months of corn (60%) and soybean (40%) for deflated values from the Secretaria da Agricultura e do Abastecimento do Paraná. The quantities of monthly imports and exports were expressed in metric tons (MT) of fluid milk equivalent obtained from Embrapa Dairy Cattle and based on data from the Ministry of Economy. International product prices in dollars per MT were calculated as the three-month moving average of the whole milk powder prices from the European Union (EU) and Oceania.

The fit and complexity of the model were assessed with Akaike information criterion (AIC) and Bayesian information criteria (BIC). Residuals were evaluated for normality using the Shapiro-Wilk test, Skewness, and Kurtosis, and for the White-noise process using Bartlett and Portmanteau test. Model prediction accuracy was assessed by the root-mean-square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). The original variables were transformed in natural logarithmic form (Ln) and because of the nature of the UCM, the time series do not need to be differenced to obtain a stationary form (Koopman and Ooms, 2012).

3. Results

The results of the five models have similar information regarding the components underlying milk price behavior (Table 1). The yearly average nominal milk price paid to farmers in Brazil increased R$0.93 per liter (194%), and the actual price (deflated by IGP-DI to dec-2019) R$0.36 per liter (34%) in the 2005-2019 period. The calculated geometric growth rate of the trend component was significant at 1% of probability and indicates that this component responds to 0.5% of increase in prices per month in nominal terms.

The seasonal pattern is also similar in all models. August and January have the highest and the lowest prices on average, respectively. The deterministic seasonal component indicates that December, January, February, and March have statistically similar prices, and the value is lower than the period from April to November (Table 2).

Two cyclical components are important to determine milk price behavior. All models indicate that milk price has one short-term cycle with a period of eight months and one long-term cycle with 30 months (Figure 1).

Table 1 - Unobserved Component Model assessment for Brazilian farm milk price from January 2005 to December 2019, with dependent variable expressed in the logarithmic form (Ln)

	Mode l		Model 2		Model 3		Model 4		Model 5	
	Coef.	P	Coef.	P	Coef.	P	Coef.	P	Coef.	P
Level	0.00048	0.000	0.00046	0.000	0.00048	0.000	0.00049	0.000	0.00046	0.000
Seasonality										
Jan	−0.0188	0.023	−0.0198	0.017	−0.0207	0.011	−0.0189	0.022	−0.0214	0.008
Feb	−0.0036	0.763	−0.0040	0.745	−0.0006	0.958	−0.0037	0.760	−0.0006	0.958
Mar	0.0190	0.191	0.0193	0.198	0.0220	0.115	0.0185	0.207	0.0230	0.114
Apr	0.0676	0.000	0.0696	0.000	0.0696	0.000	0.0666	0.000	0.0712	0.000
May	0.0994	0.000	0.1047	0.000	0.1005	0.000	0.0981	0.000	0.1042	0.000
Jun	0.1111	0.000	0.1181	0.000	0.1124	0.000	0.1096	0.000	0.1171	0.000
Jul	0.1197	0.000	0.1258	0.000	0.1203	0.000	0.1178	0.000	0.1238	0.000
Aug	0.1281	0.000	0.1315	0.000	0.1297	0.000	0.1267	0.000	0.1317	0.000
Sep	0.1065	0.000	0.1107	0.000	0.1063	0.000	0.1065	0.000	0.1105	0.000
Oct	0.0709	0.000	0.0747	0.000	0.0708	0.000	0.0719	0.000	0.0755	0.000
Nov	0.0292	0.000	0.0302	0.000	0.0291	0.000	0.0298	0.000	0.0310	0.000
Cycle 1										
Period (months)	8.3	0.49^{SE}	8.3	0.49^{SE}	8.2	0.49^{SE}	8.3	0.50^{SE}	8.3	0.51^{SE}
Frequency	0.7555	0.045^{SE}	0.7561	0.044^{SE}	0.7612	0.045^{SE}	0.7567	0.046^{SE}	0.7593	0.047^{SE}
Damping	0.9087	0.037^{SE}	0.9067	0.037^{SE}	0.9151	0.037^{SE}	0.9027	0.039^{SE}	0.9053	0.039^{SE}
Variance	0.0002	0.009	0.0002	0.007	0.0002	0.018	0.0002	0.009	0.0002	0.011
Cycle 2										
Period (months)	32.9	2.64^{SE}	32.7	2.71^{SE}	33.2	2.60^{SE}	31.3	3.31^{SE}	30.6	3.30^{SE}
Frequency	0.1908	0.015^{SE}	0.1922	0.02^{SE}	0.1893	0.01^{SE}	0.2003	0.02^{SE}	0.2054	0.02^{SE}
Damping	0.9850	0.011^{SE}	0.9842	0.01^{SE}	0.9853	0.01^{SE}	0.9816	0.01^{SE}	0.9811	0.01^{SE}
Variance	0.0002	0.025	0.0002	0.033	0.0002	0.025	0.0002	0.050	0.0001	0.087
Exogenous component										
Ration	-	-	0.0881	0.050	-	-	-	-	0.0660	0.137
Import	-	-	-	-	0.0230	0.001	-	-	0.0223	0.002
Export	-	-	-	-	−0.0004	0.929	-	-	-	-
International price	-	-	-	-	-	-	0.1556	0.051	0.1867	0.014
Model evaluation										
Observations	180	-	178	-	180	-	180	-	178	-
Wald Chi^2	9184.43	0.000	8394.15	0.000	9493.04	0.000	6199.61	0.000	5270.15	0.000
AIC	−664.63	-	−657.40	-	−670.96	-	−666.20	-	−667.53	-
BIC	−607.16	-	−596.95	-	−607.10	-	−605.53	-	−600.71	-
Residuals										
Shapiro-Wilk W test (norm.)	0.9802	0.012	0.9797	0.011	0.9770	0.004	0.9792	0.009	0.977	0.005
Skewness (0)	0.1318	0.456	0.2295	0.200	0.1562	0.378	0.1042	0.555	0.190	0.287
Kurtosis (3)	4.4414	0.004	4.4451	0.004	4.3699	0.006	4.445	0.004	4.517	0.003
Adj Chi^2	7.94	0.018	8.74	0.012	7.74	0.020	7.80	0.020	8.71	0.012
Bartlett's test	1.2412	0.091	1.1312	0.154	1.0038	0.266	1.2176	0.103	0.9627	0.312
Portmanteau test	48.227	0.174	43.5103	0.324	46.8347	0.2124	45.7268	0.246	42.7173	0.355
Prediction error										
RMSE	0.033	-	0.032	-	0.032	-	0.033	-	0.031	-
MAE	0.023	-	0.023	-	0.021	-	0.023	-	0.021	-
MAPE	2.572	-	2.567	-	2.437	-	2.583	-	2.454	-

AIC - Akaike's information criterion; BIC - Bayesian information criterion; RMSE - root-mean square error; MAE - mean absolute error; MAPE - mean absolute percentage error; SE - standard error.

Table 2 - Deterministic seasonal component of the milk price estimated by Model 1 and expressed in Reals per liter

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasonal component	0.981	0.996	1.019	1.069	1.104	1.117	1.127	1.136	1.112	1.073	1.029	1.00

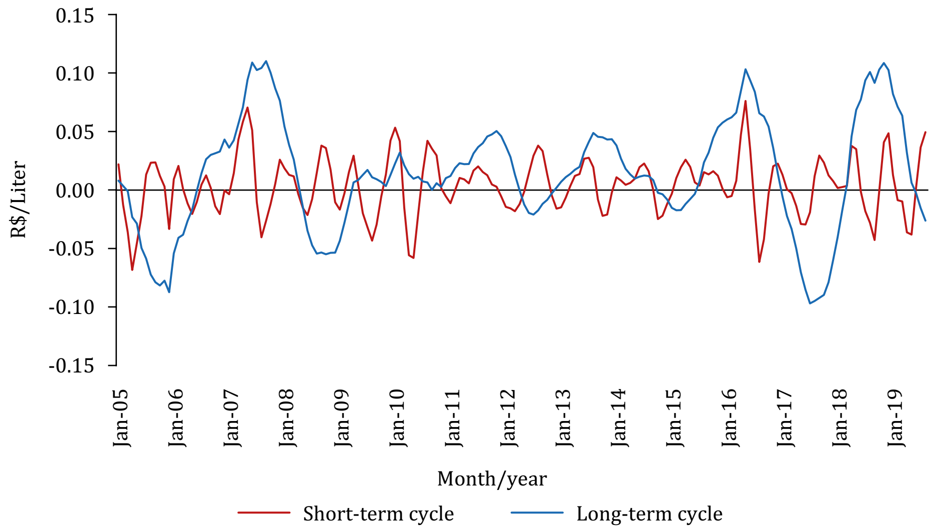

Figure 1 - Cycle component of the Brazilian milk price paid to farmers from January 2005 to December 2019.

The estimated spectral density showed that the cyclical components are composed of two distinct random components that mostly did not overlap each other. The short-term cycle was tightly distributed (damping 0.90) at a lower frequency peak (0.2), and the long-term was more smoothly distributed (damping 0.98) at a higher frequency (0.8) (Figure 2). Both cycles had a small variance and were statistically significant at 10% of probability.

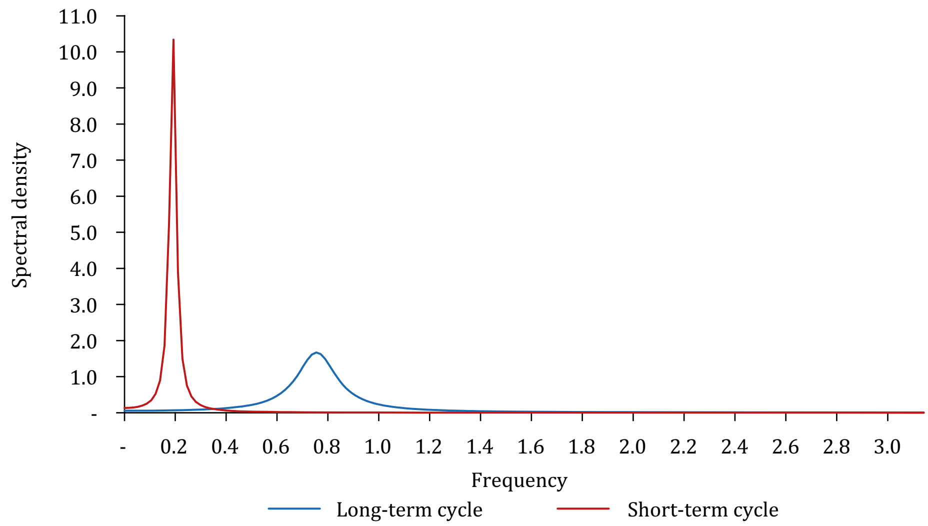

Figure 2 - Spectral density of the Brazilian milk price paid to farmers from January 2005 to December 2019.

Three exogenous variables were tested separately (models 2, 3, and 4) and in combination (model 5). In the inclusion of exogenous variables, ration price, imports/exports, and international price did not significantly change the estimated cycle periods of eight and 30 months, the seasonal pattern, nor the trend of farm price. The amplitude of the short-term cycle ranged from R$0.04 to R$0.14 and the long-term from R$0.15 to R$0.30 per liter during the period of analysis (Figures 3A, 3B, and 3C).

Figure 3 - Level component (A), short-term cycle component (B), and long-term cycle component (C) of the five models.

As expected, the effect of ration price on milk farm price was positive and significant at 5% of probability in Model 2. The increase of 10% in ration price increased farm milk price by 0.8%. The impact of imports and exports on milk prices were tested in Model 3, and we found a positive and small impact of imports on farm prices. An increase in imports of powder milk of 10% was associated with an increase of 0.2% in the domestic prices paid to farmers; this relationship is further discussed below. The effect of international prices of milk powder on domestic farm prices was statistically significant in models 4 and 5. An increase of 10% on global powder prices measured at Oceania and Europe was associated with an increase in the price paid to Brazilian farmers by 1.5% in model 4 and 1.8% in model 5.

The five models have similar AIC and BIC values indicating similar fit and complexity. The Shapiro-Wilk test indicates that the residuals are normally distributed in models 1 and 2 but not in models 3, 4, and 5 due to kurtosis and not to skewness. In all models, the observed skewness value, close to zero, and the P-value (>0.2) indicate that the hypothesis of normality distribution of the residuals cannot be rejected. However, the kurtosis above 4 and P-value indicate that the normality hypothesis is rejected. The combined statistic of normality (Adjusted χ^2) indicates that the hypothesis of normality cannot be rejected. Bartlett's test indicates that models 2, 3, 4, and 5 have the residuals not different from the white noise process at 10% level of probability, and the P-value of model 1 is 0.091. The Portmanteau test for white noise confirms that for all models, the residual is a random process. More specifically, the residuals all have means not different from zero, finite variance, and no intertemporal correlation. The models generally track well with actual values and the prediction capacity is similar between models with a MAPE for one-step-ahead prediction ranging from 2.4% to 2.6%.

4. Discussion

From a systems perspective, the behavior of milk price paid to farmers is dynamically determined by supply and demand balance and can be affected by exogenous variables of socioeconomic and environmental nature. Previous studies indicated that models with endogenous herd structure and the underlying delays are relevant to understand the magnitudes of the short- and long-term milk price oscillations (Munshi and Parikh, 1994; Bhattacharya et al., 2016; Simões et al., 2019). Our methodological approach did not include endogenous components, but we recognize the importance of tracking the causality of supply and demand balance, when observing, for instance, the significant upward trend of milk price found in the fifteen years of analysis. We also did not test the impact of exogenous shocks on the demand side, but previous studies indicate that *per capita* income is relevant to domestic dairy market in Brazil. The income elasticity of dairy products ranges from 0.4 to 1.5 depending on the type of products and income level (Carvalho et al., 2008; Carvalho, 2011), and according to Silva Filho et al. (2019), variations of 1.0% in the growth rate of national gross domestic product (GDP) led to positive variations in the growth rate of formal milk collection in the order of 1.3%, and this increase can change the price levels in the long-term. In the period of analysis, the actual *per capita* income increased 35% in Brazil (IBGE, 2022), which can be related to the upward trend observed. Differences in the growing rate of nominal and real price highlights the relevance of the inflationary effects in the Brazilian economy and, farm management decisions about milk production are also related to inflation on production costs, especially feed prices (Wolf, 2010).

A significant seasonal component in the milk price behavior was identified, consistent with the pattern observed by Alves et al. (2015) and Santos et al. (2014). In tropical countries like Brazil, the seasonality observed in prices reflects the milk production seasonality pattern based on nutrients and availability of forage (pasture) production. During autumn and winter (April to September), which are the coldest and driest months, milk production is lower, and prices are higher. From October to March (spring and summer), the hottest and rainiest months, the reverse is observed. This seasonality differs in temperate climate countries like the US, in which calving are strategically concentrated in more profitable periods of the year (Oltenacu et al., 1989; Washington et al., 2002; Ferreira et al., 2020). Reducing milk production seasonality would benefit dairy processors and, at least theoretically, would reduce milk price oscillations at the farm level. Modification on milk production systems with enhanced feed strategies and switching from pasture-based to confinement systems with investments in compost-bedded pack barns is an example of how farmers are addressing seasonality (Marcondes et al., 2020; Pinheiro et al., 2021), but the impact of the increased milk production remains an issue due to its potential of price reduction (Simões et al., 2019). However, understanding the significant seasonal price component can be useful to farmers and processors to formulate more profitable strategies of seasonal production.

We identified the presence of two cyclical patterns in the milk price time series with duration of eight and 30 months. The underlying explanation of the specific values for these cycles—particularly that of 8 months' duration—is not as straightforward as for the trend and seasonal components. However, understanding the cycle frequency and amplitude can facilitate the analysis of a commodity price behavior. Most of the commodities show cycle patterns in prices because of the feedback loops in the causal structure of the supply chains and because of the presence of the stocks and material and information delays (Meadows, 1970; Rosen et al., 1994). The oscillatory behavior can also be initiated through producer responses to price or production shocks (Tomek and Kaiser, 2014), for example as tested in our models with the variables feed cost, imports/exports, and international price. Understanding the amplitude of the cycle component in actual price can be useful to design and support decision- and policy-makers in forecasting prices and contribute to further understand the sources and responses to the large-amplitude price cycles (Nicholson and Stephenson, 2014).

The presence and the high level of stocks across supply chains are an important source of delays and oscillation on prices from consumers to farmers (Lee et al., 1997; Adnan and Özelkan, 2019). In Brazil, there are no government-held stocks of milk and dairy products, and current stocks held by major dairy companies are considered operating stocks only to meet short-term demand (USDA-FAS, 2018). The milk supply model of Bozic et al. (2012) indicated that long-term price changes come from changes in herd structure, while short-term price volatility arises based on cow productivity. Although more investigation is needed, we can hypothesize that the long-term oscillatory behavior pattern of milk price in Brazil could be driven partially by the dairy herd aging-chain and the farmers' decision about holding or sending heifers and cows to slaughter (Brockington et al., 1992; Bragança and Bueno, 2010). The short-term cycle is probably influenced by the 12-month seasonal pattern but also by the feed strategy of farmers and the milk production system response.

We found a small but significant effect of the ration price on Brazilian milk prices similar to Nicholson and Stephenson (2015), who identified feed prices as an important determinant of the overall level of US milk prices. The elasticity value of farm milk price changes to feed costs is small compared with countries with higher levels of concentrate feeding (Nicholson and Stephenson, 2015), but still suggests the importance of cost control to farmers, given that the increase in feed costs does not appear to be fully transmitted to the price of the milk sold to processors. This is important in the Brazilian context because milk production is experiencing changes in the main production areas of the country with more intensive systems in genetics and feed strategies, resulting in higher dependency on corn and soybean prices to produce concentrate rations (Balcão et al., 2017; Telles et al., 2020; Lima et al., 2021).

A positive and small relationship between imports of powder milk and domestic prices paid to farmers was observed in our models. A negative elasticity in this case would be expected once higher imports could cause higher domestic supply and lower prices. Despite the limitation of the models tested, we can hypothesize that the unexpected elasticity indicates a non-causal relationship between the two variables, but that the outcomes are associated. According to official databases, imports were on average 4.1% (min 1.4% and max 8.1%) and exports 1.5% (min 0.3% and max 4.6%) of the total milk production in equivalent fluid milk in the period of analysis, indicating that the long-term market dynamics are influenced more by the domestic supply-demand balance (EMBRAPA, 2021). This finding suggests that supply-chain decision makers do not strongly adjust their domestic milk price expectations based on the amount of milk imported.

The price movements observed in the main global dairy markets (Oceania and Europe) can affect the price levels and, thus, expectations in Brazil. Costa et al. (2020) found that shocks on international dairy markets, particularly in New Zealand, US, and Uruguay, can be transmitted to the Brazilian dairy supply chain, modifying the farm price behavior in the main production areas of the country. Uruguay and Argentina are the main commercial partner of Brazil of dairy products. Market evidence indicate that when the relative milk price (international/domestic) is high, these Mercosur countries export more of their milk outside the region and reduce the availability of milk to Brazilian companies. When the relative price is lower, the Brazilian market becomes more attractive to these countries, and when international prices are high, it is more expensive to import milk, and processors tend to pay relative higher prices to Brazilian dairy farmers (Lima Filho, 2017).

5. Conclusions

Our analyses suggest that price trends, seasonality, cyclical patterns, and selected exogenous variables have been important components of farm milk price behavior in Brazil since 2005. These findings are consistent with a body of previous research on milk and commodity prices for other geographies and periods. The model assessment suggests a reasonably accurate means of forecasting future milk prices in Brazil, at least over relatively short time horizons. The predictable patterns of seasonality suggest the degree to which incentive programs might be developed to reduce it. The longer- (30 months) and shorter-term (eight months) cycles in farm milk prices have an amplitude up to R$0.30 per liter, indicating this as a major source of price variability. Our analyses also suggest that exogenous factors such as ration price and international price can have statistically significant impacts on farm milk prices, but these are of generally smaller magnitude than endogenous responses to production incentives. In addition, our analyses pre-date the onset of the Covid-19 pandemic and more recent global supply chain disruptions, both of which may have altered seasonality, price cycles, and the impact of exogenous variables.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: A.R.P. Simões, C.F. Nicholson and G.R. Carvalho. Data curation: A.R.P. Simões and C.F. Nicholson. Formal analysis: A.R.P. Simões and C.F. Nicholson. Funding acquisition: A.R.P. Simões and C.F. Nicholson. Investigation: A.R.P. Simões, C.F. Nicholson and G.R. Carvalho. Methodology: A.R.P. Simões and C.F. Nicholson. Resources: C.F. Nicholson and G.R. Carvalho. Supervision: C.F. Nicholson. Validation: A.R.P. Simões and C.F. Nicholson. Visualization: A.R.P. Simões and C.F. Nicholson. Writing – original draft: A.R.P. Simões and C.F. Nicholson. Writing – review & editing: A.R.P. Simões, C.F. Nicholson and G.R. Carvalho.

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