Analysis of Dairy Product Price Transmission in Hungary: A Nonlinear ARDL Model

Marwa Ben Abdallah 1,*, Maria Fekete Farkas 2 and Zoltan Lakner 3

1 Doctoral School of Management and Business Administration, Szent István University, 2100 Gödöllő, Hungary
2 Faculty of Economics and Social Science, Szent István University, 2100 Gödöllő, Hungary; Farkasne.Fekete.Maria@gtk.szie.hu
3 Department of Food Economics, Faculty of Food Science, Szent István University, 2100 Gödöllő, Hungary; lakner.zoltan@etk.szie.hu
* Correspondence: Marwa.Ben.Abdallah@phd.uni-szie.hu; Tel.: +36-7021-285-16

Received: 14 May 2020; Accepted: 7 June 2020; Published: 9 June 2020

Abstract: This paper addresses the assessment of the price transmission of dairy products in Hungary. Monthly prices are used in testing the hypothesis of asymmetric price transmission between farmers and retailers. The magnitude of short- and long-run asymmetric transmission between price levels is measured through a nonlinear autoregressive distributed model (NARDL). The cointegration of variables is validated through bounds test of the NARDL model. The estimated NARDL model proves the existence of long- and short-run asymmetric relationships between producer milk price and most retailer dairy product prices. Furthermore, the model confirms the presence of a significantly positive long-run price asymmetry for butter, buttercream, sour cream, and Trappista cheese. The positive long-run price transmission asymmetry results could be explained by the strong market power of milk processors, which are granted through their concentrations and the absence of competitiveness in the market. The short-run asymmetry of price transmission could be explained by implementing some policy interventions, such as the milk quotas, which limit milk production. Analyzing the asymmetric relationship between the producer milk price and the retailer dairy product prices could give a clear vision of the dairy sector and how prices move between market actors, highlighting the retailers’ purchasing power feature, and its role in determining the market price interaction.

Keywords: dairy sector; asymmetric transmission; NARDL; Hungary

1. Introduction

The Hungarian milk sector enjoys an important position, compared with other neighboring countries in the European Union (EU) area. Due to the high genetic performance of livestock, and production specification of qualified farmers, Hungary could supply a high quality of milk [1]. The magnitude and the quickness that price variations follow during their transmission, from one level of commodity supply chain to the other level, could entail an important policy for the general welfare and dynamic of markets, which describes the market power and consumer search costs [2]. The demand and supply elasticity, as well as the demand curve, frame the magnitude of price change transmission [3]. The agro-food supply chain, such as in the dairy sector, is always one of the main subjects which should be examined. With its different levels, the importance of different actors of the supply chain lies not only in the feeding population but also in both its social and economic aspects. Instability in the economic environment has severely affected not only supply–demand equilibrium, global trade, and domestic transactions, but also food price levels. Food prices have witnessed many fluctuations; these shifts are the main concern of considerable research, and create the investigation of price transmission along the food supply chain.
Prices do not represent only the simple link between different market actors (farmers, producers, processors, retailers, and consumers), they also reflect the market dynamics and the price adaptability policy used. To investigate the relationship between prices, a cointegration approach is developed. Cointegration models are useful tools, which serve to examine the asymmetric price transmission between variables. There are two different types of asymmetric price transmission; vertical and horizontal. The vertical price transmission consists of exploring the relationship between different prices on different levels of the same commodity supply chain [4,5]. A vertical price transmission is useful to evaluate the efficiency of different integrated actors in a market. Determining the magnitude of price change transmission between market actors could serve as a significant policy indicator to determine welfare allocation and how much of the market is competitive and sustainable [6]. When price shocks occur at one level of the market chain in a competitive market, the other levels respond by the same magnitude, which reflects the market efficiency and confirms the price equilibrium between all actors [7]. While horizontal (also called spatial), price transmission evaluates the relationship between the same level of prices. It could be established between two different commodities in the same country [8]. An important number of existing researches examine horizontal price transmission [9]. Spatial price transmission was investigated between Serbia and a group of countries (i.e., Hungary, Germany, United Kingdom, Spain, Denmark, and USA) for pork prices, and revealed that pork price shock in Spain, followed by Hungary, had the highest effect on pork price in Serbia [10]. A spatial price transmission was established, analyzing the dairy sector in 20 countries within Europe. It highlights the existence of positive effects of the milk volume traded between Europe and the negative effect of the geographic interval on price transmission of milk price in Europe [11].

Different econometric models of asymmetric price transmission have been determined, to figure out the pattern of relationship between prices. Different studies are elaborated on, to provide an empirical literature review on econometric models and types used in investigating asymmetric price transmission researches. Surveys have been set up. A survey of 40 papers, which is mainly in the agricultural field, was published by Meyer and Von Cramon-Taubadel [12]. They categorized price asymmetry based on three criteria; the magnitude of response, the sign (positive or negative), and the direction (vertical or spatial).

Frey and Manera [13] classified the econometric models of asymmetric prices in categories; the first class represents the autoregressive distributed lag (ARDL) model [14], the partial adjustment model (PAM) [15], the error correction model (ECM) [16,17], the regime switching model (RSM) [18], and their multivariate extensions. Different methods have been run to assess asymmetric price transmission along dairy supply chains of different countries. In 2014, using the error correction model, the milk market was analyzed to evaluate the asymmetric price transmission between the producer (farmer) and retailer [19]. The threshold error correction models have been used to detect an asymmetric price transmission between three milk products (i.e., butter, cheese, and raw milk) in the U.S. [20]. Three price stages (i.e., producer, wholesale, and retail) of Slovakian milk products were analyzed using the error correction models. The results revealed the existence of asymmetric price transmission in both the short and long run [21]. The nonlinear panel ARDL was applied by Meyer et al. [22] to test the asymmetric relationship between food and oil prices in the short and long run. The Hungarian dairy sector is distinguished by specific characteristics which create a distinct interest in examining its price transmission. The dairy industry market is oligopsonistic, where buyers have the power to reduce the seller price and to catch larger market share. Hungary is an importer of dairy products and exporter of raw milk with low added value. For this reason, the government tries to enhance the production of raw milk for processing inside Hungary; however, the milk production and processing owned by foreigners are dominant, which leads to a more concentrated industry. To account for the price transmission of milk and dairy products, the NARDL model is employed. It has the advantage of combining the short-run dynamic process and the long-run asymmetric cointegration, which help to not have biased results.
To achieve our research objective, five sections are illustrated in the rest of the paper. Section 2 describes the dairy sector characteristics in Hungary and the different regulations adopted by the government to protect the sector and their consequences. In Section 3, we explain the methodology and the different tests used, before estimating the model. The results and their interpretations are analyzed in Section 4. The discussion is displayed in Section 5, and finally our conclusion is presented in Section 6.

2. The Dairy Sector in Hungary

Hungary plays an important role in milk production and has a distinguished place among other EU states. Different regulation systems have been applied to the Hungarian dairy sector which have led to results, especially after 2004, where Hungary joined the EU area.

Milk and milk processing are considered a principal agro-food sector, among other sectors. The Hungarian dairy sector plays a major role in the Central European region, and it represents an essential income source for farmers [23]. Despite the increase of the Hungarian raw milk price, it is still considered low, compared with other EU countries [1]. Two main agricultural policies were applied to regulate the dairy market; the price support and the milk quota systems. The milk quota system was applied from 1984 to 2015 by the European Union (EU), as a tool to control the milk production [24]. It is considered one of the main efficient systems that was employed to regulate the milk markets of all EU members [25], especially after creating financial problems due to the excess production of butter and milk powder [1]. After the abolition of the milk quota in 2015, the Hungarian milk sector witnessed a difficult situation. The price of milk has decreased by approximately 28–30%, in addition to the high cost of milk production, which seriously harmed farmers by creating a great revenue loss [26]. Besides the decrease of dairy cow numbers, between 2010 and 2015, the milk production was in an expanding movement, which was followed by rapid price fall [27]. The Hungarian milk producers have benefited by the price support before 2004. This played an important role in expanding the milk production. Thus, it reached 2,100,000 tons in 2004. After the abolishment of the price aid, milk production witnessed a decrease of 15% in 2006 to reach 1,800,000 tons, which was accompanied by an increase in the exported milk quantity to Italy, leading to price reduction of raw milk [23]. Despite this, the Hungarian dairy sector is among those sectors that receive the highest support, and the milk cost is still considered to be high for farmers, which is explained by the high input price for livestock, and some macroeconomic indicators adopted, such as the Tax Law [1]. From 1995 till the beginning of the 21st century, milk processors were owned by, and concentrated on, foreign companies, which weakened the position of farmers; they had low bargaining power, and strengthened the processor position to manipulate the market power [23]. A deep change occurred after the purchase of the foreign milk processor companies by Hungarian investors, following which two main firms were born; the first one is the Alfoldi Milk cooperative, which purchased Parlamat in 2003 and Friesland in 2016, with a market share of 20% in 2013. The second group is the Sole Mizo group, with a market share of 31.7% [28].

Figure 1 displays the fluctuations of milk and milk product prices in Hungarian forint (HUF). The prices of dairy products are processor prices. Cheese, butter, and butter cream vacillated, especially the processor butter price between 2011 and 2017. Between 2004 and 2011, all prices, except Trappista cheese, oscillated. After 2011, they followed an increasing trend which ended at a peak in January 2014. We classified dairy products in two scales to figure out the price change clearly, due to the large price discrepancy between these two categories (products with a long shelf life, and others with a shorter shelf life).
were developed to investigate the relationship between cointegrated vectors. However, α refers to the natural logarithm of the producer price of raw milk: 

\[ \ln y_t = \alpha_0 + \alpha_1^+ \ln PPRM_t^+ + \alpha_2^- \ln PPRM_t^- + \varepsilon_t \] (1)

where \( \ln y_t \) refers to the natural logarithm of the dairy products, which is to be analyzed; \( \alpha = (\alpha_0, \alpha_1^+, \alpha_2^-) \) is a cointegrating vector or the vector of long-run parameters to be estimated. From Equations (2) and (3), \( \ln PPRM_t^+ \) and \( \ln PPRM_t^- \) are partial sums of positive and negative changes in \( \ln PPRM_t \) which designs the natural logarithm of the producer price of raw milk:

\[ \ln PPRM_t^+ = \sum_{i=1}^{t} \Delta \ln PPRM_{i+1} = \sum_{i=1}^{t} \max (\Delta \ln PPRM_i, 0) \] (2)

\[ \ln PPRM_t^- = \sum_{i=1}^{t} \Delta \ln PPRM_{i-1} = \sum_{i=1}^{t} \min (\Delta \ln PPRM_i, 0) \] (3)

From the above specification, \( \alpha_1 \) denotes the magnitude of the long-run relationship between positive shocks in raw milk price and milk products. However, \( \alpha_2 \) captures the long-run relationship between negative shocks in raw milk price and milk products.

The dairy supply chain is particularly characterized by two main periods, which are the collectivization and the privatization. Before 1990, it was owned by the state, known as collectivization, as the state was the sole owner of the dairy processing. The second period constitutes the privatization, from 1990, of dairy processing [29].

3. Materials and Methods

to investigate the relationship between prices, cointegration models were used. Different models were developed to investigate the relationship between cointegrated vectors.

In this study, we used monthly data of 189 observations in Hungary. The period of the study ranged between January 2004, which synchronizes with Hungary joining the EU, and September 2019. Data were collected from the Research Institute of Agricultural Economics; market price information system. These data are available on the website. A NARDL model was a suitable model to estimate simultaneously long- and short-run nonlinear relationships, in a cointegration frame, between time series. We estimated a set of equations, where the dependent variable for each equation was the retail price of one dairy product, and the independent variable was the producer price of raw milk.

NARDL Model

NARDL presents an extended nonlinear model from the linear ARDL, which was developed by Pesaran and Shin [30] and Pesaran et al. [31].

The explicative variable was the farmer price of raw milk. To capture both the long- and short-run asymmetries effect of food price on macroeconomic variables, we applied the nonlinear ARDL model developed by Shin et al. [32]. First, we developed the following asymmetric long-run equation

\[ \ln y_t = \alpha_0 + \alpha_1^+ \ln PPRM_t^+ + \alpha_2^- \ln PPRM_t^- + \varepsilon_t \] (1)

where \( \ln y_t \) refers to the natural logarithm of the dairy products, which is to be analyzed; \( \alpha = (\alpha_0, \alpha_1^+, \alpha_2^-) \) is a cointegrating vector or the vector of long-run parameters to be estimated. From Equations (2) and (3), \( \ln PPRM_t^+ \) and \( \ln PPRM_t^- \) are partial sums of positive and negative changes in \( \ln PPRM_t \) which designs the natural logarithm of the producer price of raw milk:

\[ \ln PPRM_t^+ = \sum_{i=1}^{t} \Delta \ln PPRM_{i+1} = \sum_{i=1}^{t} \max (\Delta \ln PPRM_i, 0) \] (2)

\[ \ln PPRM_t^- = \sum_{i=1}^{t} \Delta \ln PPRM_{i-1} = \sum_{i=1}^{t} \min (\Delta \ln PPRM_i, 0) \] (3)

Figure 1. Prices of milk products in Hungary (in HUF). Source: Research Institute of Agricultural Economics [28].
Based on Shin et al. [32], and adding the asymmetric long-run relationship expressed in Equation (1) with linear ARDL form as proposed by Pesaran and Shin [30] and Pesaran et al. [31], we obtained the NARDL model as expressed in Equation (4).

\[
\text{ln}y_t = \beta_0 + \beta_1 \text{ln}y_{t-1} + \beta_2^+ \text{lnPPRM}^{+t-1} + \beta_2^- \text{lnPPRM}^{-t-1} + \sum_{i=1}^p \omega_1 \Delta y_{t-1} + \sum_{i=0}^q \omega_2 \Delta \text{lnPPRM}^{\pm t} + \sum_{i=1}^m \omega_3 \Delta \text{lnPPRM}^t + \epsilon_t
\]  

where \( \beta_2^+ = -\frac{\beta_1}{\alpha_1} \) and \( \beta_2^- = -\frac{\beta_1}{\alpha_2} \). \( p, q \) and \( m \) are lag orders of dependent and independent variables; \( \epsilon_t \) is the error term of the NARDL model; \( \sum_{i=1}^p \omega_1, \sum_{i=0}^q \omega_2 \) and \( \sum_{i=1}^m \omega_3 \) are coefficients of short run asymmetric cointegration models; \( \sum_{i=0}^q \omega_2 \) and \( \sum_{i=1}^p \omega_3 \) are the positive and negative coefficients, respectively, of the exogenous variable; \( \sum_{i=1}^p \omega_1 \) are coefficients of lagged dependent variables.

First, unit root tests were employed. The empirical methods applied in this study first included unit root tests (i.e., Phillips–Perron (PP) [33] and Zivot–Andrews (ZA) [34]) to test the stationarity properties of the variables under consideration. Second, a bound test was applied, testing the existence of the nonlinear cointegration between variables, and the third step was estimating NARDL model and model robustness.

The recent nonlinear autoregressive distributed lag (NARDL) model proposed by Shin et al. [32] was used for detecting both long- and short-run asymmetric price transmission between the producer price of raw milk (PPRM) and the retailer price of different dairy products.

Compared to the other methods of asymmetric cointegration approaches, NARDL is distinguished by many advantages. It does not require that all variables should have the same integration order, however it allows variables to be integrated and non-integrated I(0) and I(1), but not I(2). The NARDL model permits us to determine asymmetries and cointegration dynamics, even with small samples. With the NARDL model, short and long nonlinear asymmetric relationships are determined simultaneously.

4. Results

Prior to the implementation of the NARDL model, unit root tests were applied to our time series data to detect their stationarity and their integration order. Data should be not integrated I(0) and/or integrated at first order I(1) and not integrated at second order I(2), which is required by the model. To avoid I(2) variables, two different unit root tests, with and without structural break, were used. PP and ZA tests were used to verify the integration order of our data.

Table 1 presents the descriptive statistics of 10 variables. Monthly prices from January 2004 to September 2019 are statistically summarized. Data were collected from the Research Institute of Agricultural Economics. Raw milk and milk product prices were measured by HUF/kg (i.e., raw cow milk, butter, butter cream, cottage cheese, sour cream, natural yogurt, fruit yogurt, kefir, Trappista cheese, and processed cheese). The words between parentheses designate the prices of dairy products, which are displayed in the paper below. Trappista cheese is a semi-hard cheese derived from cow milk. Kefir is a sour fermented milk beverage. Cottage cheese is a creamy fresh cheese. Prices of two types of yogurts, the natural and with fruit, were analyzed. For unit root tests, the optimal lag number used was based on Schwartz information criteria (SIC).
Table 1. Statistics of dairy product prices (in HUF/kg).

|       | Min   | Max   | Mean  | Standard Deviation |
|-------|-------|-------|-------|-------------------|
| Butter (BU) | 856.20 | 1885.40 | 1260.40 | 278.94 |
| Sour cream (SCREAM) | 268.10 | 499.90 | 360.70 | 59.66 |
| Natural yogurt (YOGNAT) | 209.20 | 390.60 | 303.20 | 45.86 |
| Fruit yogurt (YOGFRUIT) | 229.80 | 427.70 | 359.40 | 34.22 |
| KEFIR | 1.98 | 2.43 | 2.35 | 0.28 |
| Processed cheese (PCHESSE) | 916.00 | 1195.90 | 1051.40 | 141.65 |
| Raw milk (PPRM) | 54.99 | 105.33 | 77.81 | 13.39 |

Table 2 provides the results of Phillips–Perron (PP) and Zivot–Andrews (ZA) tests used by this paper. A and L are the first differences and natural log operators, respectively. Superscripts *, **, and *** represent the significance at 10%, 5%, and 1% levels, respectively. The column of dates refers to the structural break dates suggested by ZA tests.

Table 2. Root tests without, and with, a structural break.

|       | PP Statistics | ZA Statistics | Break Point | PP Statistics | ZA Statistics | PP Statistics |
|-------|---------------|---------------|-------------|---------------|---------------|---------------|
| Intercepts | Intercept | Intercept and Trend |             | Intercept | Intercept and Trend |             |
| LPPRM | -1.36 ** | -4.21 | 12/2014 | -2.00 | -3.37 | 10/2012 |
| LBU | -0.26 * | -3.67 | 10/2014 | -2.51 | -3.45 | 08/2016 |
| LBCREAM | -1.84 ** | -4.41 | 01/2015 | -2.35 | -3.33 | 10/2007 |
| LCCHEESE | -1.88 ** | -3.83 | 01/2015 | -2.72 | -3.47 | 03/2017 |
| LSCREAM | -0.28 | -5.01 ** | 11/2006 | -2.25 | -3.28 | 10/2007 |
| LYOGNAT | -1.71 ** | -7.33 *** | 07/2015 | -3.82 ** | -3.82 | 12/2011 |
| LYOGFRUIT | -3.30 ** | -4.81 ** | 04/2015 | -2.07 | -2.58 | 11/2007 |
| LTCHEESE | -1.98 | -4.43 | 08/2014 | -2.97 | -3.82 | 03/2018 |
| LPCHEESE | -2.82 * | -3.76 | 08/2007 | -3.60 | -3.30 | 12/2007 |

We began the data examination by conducting a unit root test for the variables at level, by including the constant and time trend, and including only constant at first difference, using PP and ZA tests, as illustrated in Table 2. The PP test results confirm that all variables are stationary after applying the first difference, indicating that the variables are I(1), but it also highlights that the series LYOGNAT and LPCHEESE do not contain the unit root at level and first difference with constant, and LBCREAM and LYOGFRUIT are stationary at level and first difference for constant and trend. Moreover, the findings of the ZA test, which have a break point, justify the fact that all variables are stationary at first difference, and thus all variables are I(1), except LYOGNAT and LYOGFRUIT are prevented from unit root at level and first difference with constant.

Table 3 provides bounds testing results for nonlinear cointegration. It displays the nonlinear cointegration test results, between the raw milk price and each milk product price. It tests the null hypothesis of a linear cointegration of the variables. Findings are significant at 1% significance level; and for natural yogurt, the significance level is 5%, which confirms the evidence of a nonlinear cointegration among variables. It justifies the use of the NARDL approach. Thus, the nonlinear model,
NARDL is appropriate to estimate the model. The optimal lag number used in our model is based on Schwartz information criteria (SIC). There is an evidence of cointegration when the nonlinear form is specified, since the F-statistic is greater than the upper critical bound at 5% and 1%. The superscripts **, and *** represent the significance at 5%, and 1% levels, respectively.

Table 3. Results for the NARDL models.

| Cointegration Hypothesis                  | F Statistic |
|------------------------------------------|-------------|
| F (LBU/PPRM*, PPRM−)                    | 6.74 ***    |
| F (LBCREAM/PPRM*, PPRM−)                | 12.40 ***   |
| F (LCCHEESE/PPRM*, PPRM−)               | 5.87 ***    |
| F (LScream/PPRM*, PPRM−)                | 7.78 ***    |
| F (LYOGNAT/PPRM*, PPRM−)                | 2.56 **     |
| F (LYOGFRUIT/PPRM*, PPRM−)              | 7.16 ***    |
| F (LKEFIR/PPRM*, PPRM−)                 | 6.65 ***    |
| F (LTCHEESE/PPRM*, PPRM−)               | 17.02 ***   |
| F (LPCHEESE/PPRM*, PPRM−)               | 5.34 ***    |

The estimation of the model presented in Equation (4) is summarized in Tables 4 and 5. They provide all parameters of the model and the diagnosis tests for model robustness. To assess the model, ARCH, for autoregressive conditional heteroskedasticity, and LM, for error autocorrelation, tests were used to check the residuals of the model estimation. Short-run coefficients were estimated (i.e., the constant, the lagged exogenous variables, the positive and the negative effect of raw milk price). The model permitted us to upraise the milk product price’s dynamic, and its return to the positive and negative changes in raw milk price. The short-run findings point out the significance of all lagged dependent variables, which justifies the persistence of the milk product prices in Hungary. According to ARCH testing for the autoregressive conditional heteroskedasticity of the error term, we fail to reject the null hypothesis, which means that residual variance is constant over time. Furthermore, the serial correlation LM test confirms the absence of autocorrelation in the residuals. In the appendix, Figures 2–10 show how much the model coefficients are stable by the estimated model, and lie within the 5% significance line for cumulative sum (CUSUM).
Table 4. Estimation results (dependent variable: LPPRM).

| Variable  | Coefficient | Variable  | Coefficient | Variable  | Coefficient | Variable  | Coefficient |
|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|
| C         | 0.45 ***    | C         | 1.03 ***    | C         | 0.27 ***    | C         | 0.34 ***    |
| LBU_{t-1} | -0.15 ***   | LBCREAM_{t-1} | -0.36 ***  | LKEFIR_{t-1} | -0.11 ***  | LSCREAM_{t-1} | -0.14 ***  |
| LPPRM_{t-1}^+ | 0.11 ***   | LPPRM_{t-1}^+ | 0.14 ***   | LPPRM_{t-1}^+ | 0.06 ***   | LPPRM_{t-1}^+ | 0.09 ***   |
| LPPRM_{t-1}^- | 0.07 ***   | LPPRM_{t-1}^- | 0.08 **    | LPPRM_{t-1}^- | 0.08 ***   | LPPRM_{t-1}^- | 0.06 ***   |
| \Delta LBU_{t-1} | 0.13 *     | \Delta LBCREAM_{t-1} | -0.39 ***  | \Delta LKEFIR_{t-1} | -0.21 ***  | \Delta LSCREAM_{t-1} | -0.07     |
| \Delta LBU_{t-2} | 0.13 *     | \Delta LBCREAM_{t-2} | -0.16 **   | \Delta LKEFIR_{t-2} | 0.00       | \Delta LSCREAM_{t-2} | 0.15 **    |
| \Delta LPPRM_{t-1}^+ | 0.69 ***   | \Delta LPPRM_{t-1}^+ | -0.19      | \Delta LPPRM_{t-1}^+ | 0.30 **    | \Delta LPPRM_{t-1}^+ | 0.62 ***   |
| \Delta LPPRM_{t-2}^+ | -0.36 **   | \Delta LPPRM_{t-2}^- | 0.61 *     | \Delta LPPRM_{t-2}^- | 0.44 ***   | \Delta LPPRM_{t-2}^- | 0.53 ***   |
| LM        | 3.65 (0.37) | LM        | 0.50 (0.60) | LM        | 3.51 (0.53) | LM        | 7.01 (0.27) |
| ARCH (4)  | 5.48 (0.24) | ARCH (2)  | 2.09 (0.35) | ARCH (2)  | 0.92 (0.62) | ARCH (4)  | 7.25 (0.12) |

**Long run coefficients**

| LPPRM_{t-1}^+ | 0.74 ***   | LPPRM_{t-1}^+ | 0.39 ***   | LPPRM_{t-1}^+ | 0.57 ***   | LPPRM_{t-1}^+ | 0.65 ***   |
| LPPRM_{t-1}^- | 0.48 ***   | LPPRM_{t-1}^- | 0.24 ***   | LPPRM_{t-1}^- | 0.76 ***   | LPPRM_{t-1}^- | 0.48 ***   |
| F stat      | 15.68 ***  | F stat      | 13.97 ***  | F stat      | 16.06 ***  | F stat      | 8.96 ***   |

Superscripts *, **, and *** represent the significance at 10%, 5%, and 1% levels, respectively.
Table 5. NARDL estimation results (dependent variable: LPPRM) (cont).

| Variable | Coefficient | Variable | Coefficient | Variable | Coefficient | Variable | Coefficient | Variable | Coefficient |
|----------|-------------|----------|-------------|----------|-------------|----------|-------------|----------|-------------|
| Cottage Cheese | Trappista Cheese | Processed Cheese | Natural Yogurt | Yogurt Fruit | | | | | |
| C | 0.25 *** | C | 0.98 *** | C | 0.47 *** | C | 0.15 ** | C | 0.56 *** |
| LCCHEESE\(_{t-1}\) | -0.09 *** | LTCHEESE\(_{t-1}\) | -0.33 *** | LPCHEESE\(_{t-1}\) | -0.16 *** | LYOGNAT\(_{t-1}\) | -0.06 ** | LYOFRUIT\(_{t-1}\) | -0.22 *** |
| LPPRM\(_{t-1}\) | 0.05 *** | LPPRM\(_{t-1}\) | 0.20 *** | LPPRM\(_{t-1}\) | 0.04 ** | LPPRM\(_{t-1}\) | 0.02 | LPPRM\(_{t-1}\) | 0.09 *** |
| ΔLCCHEESE\(_{t-2}\) | 0.00 | ΔLTCHEESE\(_{t-2}\) | 0.24 *** | ΔLPCHEESE\(_{t-2}\) | -0.21 *** | ΔLYOGNAT\(_{t-1}\) | -0.11 | ΔLYOFRUIT\(_{t-1}\) | -0.21 *** |
| ΔLPPRM\(_{t-2}\) | 0.70 *** | ΔLPPRM\(_{t-2}\) | 0.74 *** | ΔLPPRM\(_{t-2}\) | 0.21 | ΔLPPRM\(_{t-2}\) | 0.35 * | ΔLPPRM\(_{t-2}\) | 0.37 |
| LM | 10.48 (0.23) | LM | 0.50 (0.60) | LM | 1.47 (0.43) | LM | 2.88 (0.33) | LM | 2.66 (0.35) |
| ARCH (5) | 7.81 (0.16) | ARCH (1) | 9.51 (0.00) | ARCH (1) | 6.06 (0.01) | ARCH (1) | 4.25 (0.03) | ARCH (1) | 18.32 (0.00) |
| F stat | 3.39 * | F stat | 4.11 ** | F stat | 0.27 (0.59) | F stat | 4.77 ** | F stat | 0.14 (0.70) |

Superscripts *, **, and *** represent the significance at 10%, 5%, and 1% levels, respectively.
The estimation of the model presented in Equation (4) is summarized in Tables 4 and 5. They provide all parameters of the model and the diagnostic tests for model robustness. To assess the short-run coefficients were estimated tests were used to check the residuals of the model estimation. Furthermore, the serial correlation LM test confirms the absence of autocorrelation in the error term, we fail to reject the null hypothesis, which means that residual variance is constant over time. Additionally, the ARCH testing for the autoregressive conditional heteroskedasticity of the residuals. In the appendix, Figures 2–10 show how much the model coefficients are stable by the time. Furthermore, the serial correlation LM test confirms the absence of autocorrelation in the error term, we fail to reject the null hypothesis, which means that residual variance is constant over time. Additionally, the ARCH testing for the autoregressive conditional heteroskedasticity of the residuals. In the appendix, Figures 2–10 show how much the model coefficients are stable by the time. Furthermore, the serial correlation LM test confirms the absence of autocorrelation in the error term, we fail to reject the null hypothesis, which means that residual variance is constant over time. Additionally, the ARCH testing for the autoregressive conditional heteroskedasticity of the residuals. In the appendix, Figures 2–10 show how much the model coefficients are stable by the time. Furthermore, the serial correlation LM test confirms the absence of autocorrelation in the error term, we fail to reject the null hypothesis, which means that residual variance is constant over time. Additionally, the ARCH testing for the autoregressive conditional heteroskedasticity of the residuals. In the appendix, Figures 2–10 show how much the model coefficients are stable by the time. Furthermore, the serial correlation LM test confirms the absence of autocorrelation in the error term, we fail to reject the null hypothesis, which means that residual variance is constant over time.

Figure 2. Cumulative sum (CUSUM) test of butter.

Figure 3. CUSUM test of kefir.

Figure 4. CUSUM test of butter cream.

Figure 5. CUSUM test of cottage cheese.

Figure 6. CUSUM test of fruit yogurt.

Figure 7. CUSUM test of natural yogurt.
5. Discussion

The estimate of the long-run coefficients for all price pairs and the positive and negative shocks of the raw milk price (LPPRM_{t-1}^+, LPPRM_{t-1}^-) positively affect, with different magnitudes, the different dairy product prices. All long-run coefficients are significant at 1%. The existence of a long-run asymmetric relationship between raw milk and all examined dairy product prices is confirmed, except for in processed cheese and fruit yogurt, which means that a response of the exogenous variables, milk products, from a positive shock of raw milk price is different from the negative shock. Wald test, the long-run asymmetry test, is significant for all variables, except processed cheese and fruit yogurt.

The response of some retailer prices of the examined dairy products (i.e., butter, butter cream, sour cream, and Trappista cheese) for positive shocks of raw milk price are transmitted higher than negative shocks, indicating an increase in the surplus between the processor dairy product prices and the raw milk prices. A negative shock of the raw milk price affects kefir, natural yogurt, and cottage cheese prices to a higher extent than positive shocks, i.e., the retailer prices adjust more rapidly to price fall on the farmer level.

Butter price registers the highest long-run coefficients ($\alpha^+_1 = 0.74$ and $\alpha^-_1 = 0.48$), which means that a 1% increase in the farm price of raw milk leads to a 74% increase in the processor price of butter, while a decrease of 1% increases the cottage cheese price by 48%.

In the short run, the significance of the coefficients means that all examined dairy products are affected by their past price information, and their lagged prices are significant, which indicates the persistence of the past price on the actual price. The short-run asymmetric transmission may have occurred due to the adjustment costs, such as the packaging costs. The changing (menu cost) price, as well, may lead to asymmetric readjustment of prices, such as the cost caused by printing new product catalogues and prices.

Positive effects are registered for both negative and positive shocks of the raw milk price. For milk products with shorter shelf life (i.e., cottage cheese, kefir, and natural yogurt), the negative shock of the raw milk price has a greater effect than the positive shock. However, for longer shelf life dairy products, a positive shock of raw milk price has a greater effect than a negative shock. In the short run, an increase of the raw milk price led to an increase of 11.3% in the butter price, 14.4% in butter cream, and 11.7% in sour cream. However, for longer shelf life dairy products, a positive shock of raw milk price has a greater effect than a negative shock. In the short run, an increase of the raw milk price led to an increase of 11.3% in the butter price, 14.4% in butter cream, and 11.7% in sour cream.
cream, 6% in kefir, 9% in sour cream, 0.5% in cottage cheese, 20% in Trappista cheese, 4% in processed
cheese, 2% in natural yogurt, and 9% in fruit yogurt. The asymmetric transmission of both positive
and negative shocks, which is manifested, could be explained by the imperfect market competition.
Thus, the dairy retailers are largely concentrated, which grants them to exercise a market power. These
results point out that processors benefit from an advantage over producers of raw milk, because their
margin increases regardless of the type of shocks (positive or negative), which could be explained by
the strong market power of processors. Furthermore, the negative asymmetric relationship highlighted
for shorter shelf life dairy products (i.e., kefir, natural yogurt, and cottage cheese), is in agreement with
the evidence that the dairies are performing to achieve the farmer profit maximization.

6. Conclusions

This study was elaborated to examine the asymmetric price transmission between raw milk price
and different dairy product prices. The work aimed to assess dairy product responses whenever a
positive or negative change occurs in raw milk. Our findings confirm the existence of an asymmetric
price transmission between milk and dairy products, except processed cheese and fruit yogurt, with
different magnitudes and speed. The positive response of the milk processors to a positive or a negative
shock of the raw milk price reveals that processors have more advantages, compared to the farmers
(producers), since whenever negative or positive shocks happen at the farmer level, processor prices
respond positively. The processor’s dairy products have a strong market power, and as we have
previously mentioned before, more than 50% of the dairy market share is owned by two big companies.
The asymmetric price transmission is confirmed in our study. Similar results were found by Acosta
and Valdez [6], in their investigation of the dairy sector in Panama, and Rezitis [35], who confirmed
the existence of an asymmetric price transmission in the Finnish dairy supply chain; an asymmetric
relationship was detected between the producer and the consumer. Different impacts were registered
in our study that highlight the importance of different kinds of dairy products (i.e., highly perishable
and less perishable). This study was limited to the dairy sector in Hungary, however, it could be
applied to other commodities in other countries. Also, for some characteristics related to the specificity
of the area, such as the criteria of LFA (less favored area) and non-LFA areas, where the production cost
differs from mountain areas to non-hilly areas, the particularity of milk production capacity and policy
intervention could be taken into consideration. Further studies could be established, considering the
agricultural policy variables.

Author Contributions: Conceptualization: M.B.A. and M.F.F.; methodology: M.B.A.; software: M.B.A.; validation:
M.B.A., M.F.F., and Z.L.; formal analysis: M.B.A.; investigation: M.B.A.; resources: M.F.F.; data curation: M.F.F.;
writing—original draft preparation: M.B.A.; writing—review and editing: M.B.A, M.F.F, and Z.L.; visualization:
M.B.A.; supervision: M.F.F and Z.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

References
1. Vöneki, É.; Mándi-Nagy, D.; Stark, A. Prospects for the European Union and Hungarian dairy sectors after
the abolition of the milk quota system. Stud. Agric. Econ. 2015, 117, 1–9. [CrossRef]
2. Acosta, A.; Ihle, R.; Von Cramon-Taubadel, S. Combining market structure and econometric methods for
pricetransmission analysis. Food Secur. 2019, 11, 941–951. [CrossRef]
3. Bronnnmann, J.; Bittmann, T. Asymmetric adjustment of retail cod and herring prices in Germany: A NARDL
approach. Mar. Policy 2019, 106, 103513. [CrossRef]
4. Grau, A.; Hockmann, H. Market power in the German dairy value chain. Agribusiness 2017, 34, 93–111.
[CrossRef]
5. Fousekis, P.; Katrakilidis, C.; Trachanas, E. Vertical price transmission in the US beef sector: Evidence from
the nonlinear ARDL model. Econ. Model. 2016, 52, 499–506. [CrossRef]
6. Acosta, A.; Valdés, A. Vertical price transmission of milk prices: Are small dairy producers efficiently integrated into markets? *Agribusiness* **2014**, *30*, 56–63. [CrossRef]

7. Serra, T.; Goodwin, B.K. Price transmission and asymmetric adjustment in the Spanish dairy sector. *Appl. Econ.* **2003**, *35*, 1889–1899. [CrossRef]

8. Dong, X.; Brown, C.; Waldron, S.; Zhang, J. Asymmetric price transmission in the Chinese pork and pig market. *Br. Food J.* **2018**, *120*, 120–132. [CrossRef]

9. Bakucs, Z.; Brümmer, B.; Von Cramon-Taubadel, S.; Fertő, I. Wheat market integration between Hungary and Germany. *Appl. Econ. Lett.* **2011**, *19*, 785–788. [CrossRef]

10. Jeremić, M.; Zekić, S.; Matkovski, B.; Kleut, Ž. Spatial price transmission in pork market in Serbia. *Custos E Agronegocio* **2019**, *15*, 328–346.

11. Bakucs, Z.; Benedek, Z.; Fertő, I. Spatial price transmission and trade in the European dairy sector. *Agri On-line Pap. Econ. Inform.* **2019**, *11*, 13–20. [CrossRef]

12. Meyer, J.; von Cramon-Taubadel, S. Asymmetric price transmission: A survey. *J. Agric. Econ.* **2004**, *55*, 581–611. [CrossRef]

13. Frey, G.; Manera, M. Econometric models of asymmetric price transmission. *J. Econ. Surv.* **2007**, *21*, 349–415. [CrossRef]

14. Kharin, S. Vertical price transmission along the dairy supply chain in Russia. *Stud. Agric. Econ.* **2015**, *117*, 80–85. [CrossRef]

15. Ahn, D.H.; Boudoukh, J.; Richardson, M.; Whitelaw, R.F. Partial adjustment or stale prices? Implications from stock index and futures return autocorrelations. *Rev. Financ. Stud.* **2002**, *15*, 655–689. [CrossRef]

16. Fernández-Amador, O.; Baumgartner, J.; Crespo-Cuaresma, J. Milking the prices: The role of asymmetries in the price transmission mechanism for milk products in Austria. In *WIFO Working Papers* **378**; WIFO: Wien, Austria, 2010.

17. Rezitis, A.N.; Tsionas, M.G. Modeling asymmetric price transmission in the European food market. *Econ. Model.* **2019**, *76*, 216–230. [CrossRef]

18. Davies, A. Testing for international equity market integration using regime switching cointegration techniques. *Rev. Financ. Econ.* **2006**, *15*, 305–321. [CrossRef]

19. Bor, Ö.; Ismihan, M.; Bayaner, A. Asymmetry in farm-retail price transmission in the Turkish fluid milk market. *New Medit* **2014**, *13*, 2–8.

20. Awokuse, T.O.; Wang, X. Threshold effects and asymmetric price adjustments in US dairy markets. *Can. J. Agric. Econ. Rev. Can.* **2009**, *57*, 269–286. [CrossRef]

21. Wéldesenbet, T. Asymmetric price transmission in the Slovak liquid milk market. *Agric. Econ.* **2013**, *59*, 512–524. [CrossRef]

22. Meyer, D.F.; Sanusi, K.A.; Hassan, A. Analysis of the asymmetric impacts of oil prices on food prices in oil-exporting developing countries. *J. Int. Stud.* **2018**, *11*, 82–94. [CrossRef] [PubMed]

23. Hockmann, H.; Vöneki, É. Collusion in the Hungarian market for raw milk. *Outlook Agric.* **2009**, *38*, 39–45. [CrossRef]

24. Buleca, J.; Kováč, V.; Šubová, N. Milk production related to price of raw cow’s milk in selected European countries. *Potravin. Slovensk J. Food Sci.* **2018**, *12*, 798–805. [CrossRef]

25. Vargova, L.; Rajcaniova, M. Spatial price transmission of milk prices among the Visegrad countries. *Visegr. J. Bioecon. Sustain. Dev.* **2017**, *6*, 79–83. [CrossRef]

26. Szucs, I.; Szollosi, L. Problems of the Hungarian dairy sector in connection with the abolition of the milk quota system. *Rocz. Nauk. StowarzyszeniaEkon. Rol. I Agrobiz.* **2015**, *17*, 379–385.

27. Kovacs, K.; Pandey, R. Hungarian Dairy And Beef Production Sector Technical Efficiency Comparsion Using DEA. *Apabstract Appl. Stud. Agribus. Commer.* **2017**, *11*, 131–140. [CrossRef]

28. Research Institute of Agricultural Economics. Market Price and Information System.URL. 2019. Available online: https://pairaki.gov.hu/web_public/general/home.do (accessed on 1 October 2019).

29. Bruszt, L.; Karas, D. Diverging developmental strategies beyond “lead sectors” in the EU’s periphery: The politics of developmental alliances in the Hungarian and Polish dairy sectors. *Rev. Int. Political Econ.* **2019**, *1–21*, (this special issue, published online 7 August 2019). [CrossRef]

30. Pesaran, M.H.; Shin, Y. An autoregressive distributed-lag modelling approach to cointegration analysis. *Econom. Soc. Monogr.* **1998**, *31*, 371–413.
31. Pesaran, M.H.; Shin, Y.; Smith, R.J. Bounds testing approaches to the analysis of level relationships. *J. Appl. Econom.* 2001, 16, 289–326. [CrossRef]
32. Shin, Y.; Yu, B.; Greenwood-Nimmo, M. Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in Honor of Peter Schmidt 2014*; Springer: New York, NY, USA, 2014; pp. 281–314.
33. Phillips, P.C.; Perron, P. Testing for a unit root in time series regression. *Biometrika* 1988, 75, 335–346. [CrossRef]
34. Zivot, E.; Andrews, D.W. Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *J. Bus. Econ.* 2002, 20, 25–44. [CrossRef]
35. Rezitis, A.N. Investigating price transmission in the Finnish dairy sector: An asymmetric NARDL approach. *Empir. Econ.* 2019, 57, 861–900. [CrossRef]