Price transmission and competition amid a series of crises: study of the Hungarian milk supply chain

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Zombor Berezvai
Corvinus University of Budapest, Budapest, Hungary and Hungarian Competition Authority, Budapest, Hungary, and
Márton Kónya
Hungarian Competition Authority, Budapest, Hungary

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Abstract

Purpose – A series of crises, such as the COVID-19 pandemic, the energy crisis, the Russian war against Ukraine and drought, have significantly impacted agricultural supply chains globally, resulting in high inflation. This paper examines price transmission amid these crises in the Hungarian milk supply chain.

Design/methodology/approach – This study employed asymmetric error correction models to analyse Hungarian milk supply chain data between 2019 and 2022.

Findings – The study's results suggest that milk processors have benefited from asymmetric price transmission. This phenomenon may be attributed to an imbalance between demand and supply, with high demand driven by government subsidies when supply chains are disrupted. Consequently, processors passed on cost increases without responding to demand fluctuations.

Research limitations/implications – The period under investigation encompassed multiple crises, making it challenging to determine the individual impacts of each crisis.

Originality/value – This study provides new evidence regarding price transmission in the context of crises affecting the demand and supply of dairy products in Hungary. The incorporation of the processing sector into the analysis enables a comprehensive investigation of all stages of the supply chain.

Keywords Milk, Price transmission, Supply chain, Inflation, Crisis

Paper type Research paper

1. Introduction

Several significant crises have impacted the world in the past few years. They began with the arrival of the COVID-19 pandemic in early 2020, followed by disrupted supply chains, an energy crisis in 2021, and, more recently, the Russian war against Ukraine and severe droughts in 2022. Hungary experienced unusually high inflation rates during this period, particularly regarding food and beverages. Annual food inflation exceeded 40%, while dairy inflation approached 80% at the end of 2022. This level of inflation is almost unprecedented; hence, it is an interesting question how these crises impacted competition across the supply chain and how different levels of the supply chain behaved and formulated their respective prices.

Price transmission in agricultural supply chains can differ substantially across countries and periods, and market shocks and reforms can influence the symmetry of the transmission process (Bakucs *et al.*, 2014). Asymmetries in the price transmission process can result in significant welfare losses (Yu and Gould, 2019). It is, therefore, imperative that public policies are implemented to eliminate these asymmetries. It is crucial to gain insight into price transmission in the context of the current multiple crises to develop effective public policies. In light of the projected increase in the likelihood of occurrences such as pandemics (Dodds,

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2019) and extreme weather conditions (IPCC, 2023), implementing effective public policies is likely to become increasingly important in the future.

This paper has two main objectives. First, the speed and symmetry of price transmission within the Hungarian milk supply chain during the 2019–2022 period will be analysed to get a better understanding of the effects of the multiple crises. Second, to identify whether any players had market power during this period. A further contribution of the paper is that as opposed to several papers investigating asymmetric price transmission in agricultural markets (e.g. Bakucs *et al.*, 2012; Rezitis, 2019), we are not merely studying farm and retail prices, but the whole supply chain with the inclusion of milk processors.

The paper's main contribution is to show that external factors can influence market power in the supply chain. Concretely, we found that the supply chain disruptions and limited supply combined with high demand due to government subsidies created a favourable environment for dairy processors and increased their market power in the supply chain. Processors were able to pass on cost increases while also taking advantage of high demand by raising prices. It indicates that improving competition in the processing sector and increasing the price competitiveness of substituting products, mainly plant-based dairy alternatives, can positively affect inflation that public policies should consider in similar situations.

The paper is structured as follows. Section 2 provides a review of existing literature. Section 3 summarises the data used. Section 4 introduces the methodology and the results, while Section 5 discusses the findings and its policy implications.

2. Literature review

2.1 Price transmission in the milk supply chain

Asymmetric price transmission analyses focus on the pricing dynamics between the various levels of the supply chain. Price transmission is said to be asymmetric if the timing and the magnitude of pass-through of price increases and decreases are different. Most papers argue that asymmetric price transmission indicates uncompetitive market structures (McCorriston *et al.*, 2001; Fałkowski, 2010; Bakucs *et al.*, 2012; Yu and Gould, 2019; Antonioli and Santeramo, 2022), proposing that if companies have market power, they will transmit margin-squeezing price changes faster and more entirely than margin-stretching price changes. There are some alternative explanations for asymmetric price transmission summarised by Meyer and von Cramon-Taubadel (2004) and Vavra and Goodwin (2005), such as the presence of menu costs, uncertainty about the permanent nature of the price shock, risk of spoiling products and state subsidies that are particularly relevant for dairy products (Kinnucan and Forker, 1987). A meta-analysis conducted by Bakucs *et al.* (2014) indicated that asymmetric price transmission is more likely to ensue if the farm structure is more fragmented or there is a higher level of government support and more regulation on retail prices. A recent overview of price transmission can be found in von Cramon-Taubadel and Goodwin (2021).

In the case of the milk supply chain, Bakucs *et al.* (2012) analysed the Polish and the Hungarian milk supply chains using vector error correction models. They found asymmetric and symmetric price transmission in Poland and Hungary, respectively. Kharin *et al.* (2017) investigated the Slovak milk supply chain after eliminating milk quotas in the European Union. They found that farm and processor price transmission is symmetric, likely due to the strengthening of the producer organisations. Rezitis (2019) analysed the Finnish dairy supply chain and found asymmetric price transmission for several products using nonlinear autoregressive distributed lag models. The asymmetries can be caused by the substantial market power of the retailers. Yu and Gould (2019) studied 18 United States metropolitan areas to identify the connection between market power (measured by the price-cost margin) and asymmetric price transmission. Price transmission was investigated using distributed lag and error correction models. The principal conclusion of the paper is that elevated market power is associated with larger asymmetric price transmission, which also results in significant welfare losses. Hillen (2021) used error correction models to examine the Swiss dairy and cheese supply chains. Her findings indicate that the different levels of the supply chains are only weakly related to each other; price pass-through is relatively slow but mainly symmetric. Bor and Tuncay (2021) investigated the Turkish milk supply chain and found asymmetric price transmission and significant market power on the retailer side between 2003 and 2016. Their analysis shows that positive deviations in price spreads take about nine months to adjust, while negative deviations take about two months. In an Italian milk supply chain study, Antonioli and Santeramo (2022) examined the impact of two major reforms that led to increased market liberalisation between 2000 and 2016. They employed error correction models to assess the effect of market liberalisation on price adjustments. They found that it resulted in more efficient price adjustments, but the market reacted more slowly to external shocks. Rose and Paparas (2023) found that the British milk supply chain exhibits long-term symmetry with farm prices Granger causing retail prices.

2.2 Price transmission during crises and shocks

There is an extensive literature on the impact of recent external crises on food supply chains. By reviewing these papers, we can gain insight into how these crises have disrupted and shaped supply chains, thereby, into the processes that could have elevated the market power of some supply chain members while decreasing that of others.

Many aspects of the disruptions caused by COVID-19 have been examined. Gray (2020) deals primarily with transportation in Canadian agriculture during the first months of the pandemic. He uses statistical records to investigate the role of transportation in disrupting food supply chains. Enumerating the various modes of transport, he explains that most modes of transportation are less and less labour-intensive, require relatively little human-to-human interaction, and, as such, are not disrupted by social distancing. The dramatic fall in non-food transportation has also led to excess free capacities for moving food, which can offset any temporary shortages. These remarks apply to marine shipping, trains, and trucks as well. This early article also anticipates the widespread use of home delivery once associated “learning costs” are sunk.

Coluccia *et al.* (2021) describe how the COVID-19 pandemic transpired in 2020 in Italy. In discussing demand-side phenomena, they show that while non-food sales dropped dramatically, food sales slightly increased after lockdown measures. Small local shops performed better among retailers, partially because customers avoided longer journeys to supermarkets to comply with security measures. Export of agricultural products increased slightly, though compared on a year-to-year basis, there was a clear negative trend, of which dairy and milk constituted a 5% year-over-year decrease in March. So far as food prices go, the authors show that compared to the previous year, food prices grew by around 2%; however, the price of dairy and milk decreased by 10%. In discussing supply-side effects, they make the same remarks as Gray (2020), attributing minor damage to transportation. They identify the most significant supply-side difficulties as ones originating from absenteeism due to illness, quarantine, or refusal to work in unsafe conditions. They mention the absence of a foreign temporary workforce due to border closures. Thus, they conclude that the production phase suffered the most disturbances, not transportation.

Wang and Shimokawa (2022) survey the difference made by the perishability of a product in determining its resilience against supply chain shocks. They employ a fixed effect model to examine the effects of two Chinese provincial blockades on cabbage as a perishable and potato as a non-perishable agricultural product. The blockade of Hubei is particularly noteworthy since it had a longer duration than that of Shijiazhuang and is also an economically more isolated area. They consistently find that cabbage is more vulnerable to the disruption of supply chains. The authors are lauding the efforts of the government to stabilise the price of these products through the distribution of reserve supplies and price regulations. However, they also note that the government did not discriminate sufficiently according to perishability, which is made clear by the higher volatility of cabbage prices in the area. Overall, they surmise that perishable products are much more precarious during disturbed supply chains.

COVID-19 afflicted all economic agents in food supply chains, but not uniformly. Bhandari and Ravishankar (2020) examine the Indian dairy industry and conclude that while both farmers and processors tried to adjust to the changes by converting surplus milk to products with longer shelf-life, providing delivery service instead of retailers, etc., farmers have lower chances at adaptation since they cannot adjust the composition of their supply as quickly as processing firms. Thus, processing firms strengthened their positions relative to farmers. Wang *et al.* (2020) come to similar conclusions when drawing parallels between the dairy industry in China and the United States. They highlight that in China, many processing firms convert their milk into storable powder forms, while farmers cannot transform surplus milk into easily storable form. For the United States, they mentioned that farmers who had long-term selling contracts with their processors could sell their surplus to processors as the terms of the contract dictated. However, even so, farmers were at least as afflicted by unsold surpluses as processors. They also show that, on average, smaller farms had to dump more of their surplus than larger ones. They mention that as a somewhat more labour-intensive level of the dairy industry, processing firms saw more difficulties emerging from labour absenteeism. Acosta *et al.* (2021) survey the effect of COVID-19 on the dairy industry globally. They find that while processing firms had to adjust packaging, distribution, mode of processing, etc., most processing plants could adjust to social distancing and return to full capacity. Meanwhile, farmers could do little about the oversupply of milk, and even though farmgate prices rebounded in time, many smallholders had to exit the market. Their paper forecasted mergers and overall consolidation of the farming sector, where many smallholders exited.

Similar themes are discussed in the paper of Verma *et al.* (2024), who focus on the Indian livestock industry during COVID-19. They find that shocks originated downstream of the supply chain due to lost demand. They highlight the position of animal feed suppliers, who faced running at partial capacity due to international panic hoarding and a general lack of raw materials on the one hand and a deficit of product demand on the other. They also note that inaccurate perceptions of consumption patterns caused further supply disturbances downstream. They call, above all, for an efficient infrastructure of storage facilities and an information-based network of such facilities to avoid waste during periods of disturbances and the resulting transitions in production and distribution processes.

Regarding pricing and allocation aspects, Akber and Paltasingh (2022) provide crucial insights regarding the effect of COVID-19 on the Indian economy. They observed the price convergence of 22 essential food items before and after lockdown measures and found that prior to lockdown, the law of one price was generally observable. However, convergence was weak following lockdown measures. Alongside the disruption of supply chains, they attribute these failures of the market mechanism to a lack of enforcement against black market activities and what they call unlawful hoarding. The paper demonstrates the difference made in an economy's allocational capacity by heavily disrupted supply chains.

Amin *et al.* (2024) compared the impact of the Great Recession in 2008 and the COVID-19 pandemic on agricultural commodity prices. They found that milk prices recovered first among all food commodities from the impact of the pandemic, but milk prices fluctuated more during COVID-19 than during the Great Recession. Furthermore, milk prices were largely independent of other commodity prices, reinforcing that it is a separate market with other driving forces besides other (plant- or animal-based) commodities.

The Russo-Ukrainian war is the other major event that disrupted supply chains and global food security. Zhang *et al.* (2023) estimate that 12% of the total calories traded worldwide in 2023 is affected by the ongoing war, chiefly in the form of grain. They enumerate how this conflict can influence various countries. Countries where rice is the staple cereal naturally have high resilience to the crisis, unlike many wheat-preferring African countries. The authors deem it unlikely that the rest of the world's grain-producing countries will be able to close the gap created by the fall of Ukrainian grain exports. The disruption of Black Sea trade may lead to increased shipping costs through other, longer trade routes. The paper suggests diversification of crop cultivation instead of industrial-scale monocultures and emphasises the need to free up exports of food and fertilisers.

3. Data

Price transmission in the Hungarian dairy market between January 2019 and December 2022 was investigated using weekly price data. The price data used in this analysis were collected by the Hungarian Competition Authority. The supply chain includes dairy farms, milk processors, and retailers. A distinctive feature of this paper is that data have been collected at each stage of the supply chain.

The pricing dynamics of dairy farms are characterised by the average weekly price of raw milk sold by a sample of 12 significant farming firms. The CR10 index for farms producing raw milk is 27–29%, which renders our sample less representative of this stage. Nevertheless, the observed raw milk prices are closely aligned with the monthly prices published by the Institute of Agricultural Economics (https://www.aki.gov.hu/en/market-price-information-system-mpis/). For this study, we have utilised the weekly average wholesale and retail prices of fresh milk with 2.8% and 1.5% fat content reported by the nine most significant processing companies and 14 most significant retailers. The revenue-based CR10 index for milk processors in Hungary is 86–87%, while the CR10 index for grocery retailers is 80–83%. Therefore, it can be reasonably assumed that the sample encompasses these stages of the supply chain in terms of market weight, confirming the accuracy of the data used in this study.

We have followed the methodology of previous studies (e.g. Bakucs *et al.*, 2012; Kharin *et al.*, 2017) and have adjusted the data for the general price increase by deflating it using the consumer price index (CPI). Since CPI data are reported monthly, we assumed that weekly rates are uniform within the month, i.e. weekly CPI was calculated as $CPI_{week} = \sqrt[n]{CPI_{month}}$, where n is the number of weeks in the month (four or five, depending on the month).

As Bakucs *et al.* (2012) argued, including the general inflation of prices may introduce a common factor which may generate biases towards a cointegration relationship. The deflated price series are presented in Figure 1, with a visible upward trend after late 2021 for all three prices. The deflated prices have been transformed using the natural logarithm as per the methodology employed by Bakucs *et al.* (2012) and Antonioli *et al.* (2019).

4. Methodology and empirical results

There are several types of econometric models to analyse the price transmission mechanism. Frey and Manera (2007) provide a methodological framework. The first step is to determine whether time series are stationary or not. The suitable methodology depends on the results of the unit root tests. If the series contain stochastic trends (i.e. they are not stationary), cointegration should be tested, and error correction models should be constructed.

Stationarity of the price series was tested using the Augmented Dickey–Fuller test without drift or linear trend, which failed to reject non-stationarity at a 5% significance level (Table 1), indicating that all the three time series are integrated in order 1.

The Johansen test confirmed the existence of pairwise cointegration between the price series (Table 2). The asymmetric cointegration tests proposed by Enders and Siklos (2001) indicate that the null hypothesis of equal speed and magnitude of adjustment below and above the threshold cannot be rejected (see the Appendix for details). Consequently, the introduction of a threshold cointegration model was not required.

Granger-causality tests indicate that there is a causal relationship from farmers to processors ($p = 0.036$) and from retailers to processors ($p < 0.001$). Exogenous farm and retail prices can be caused by international trade. Farmers can readily sell raw milk abroad,

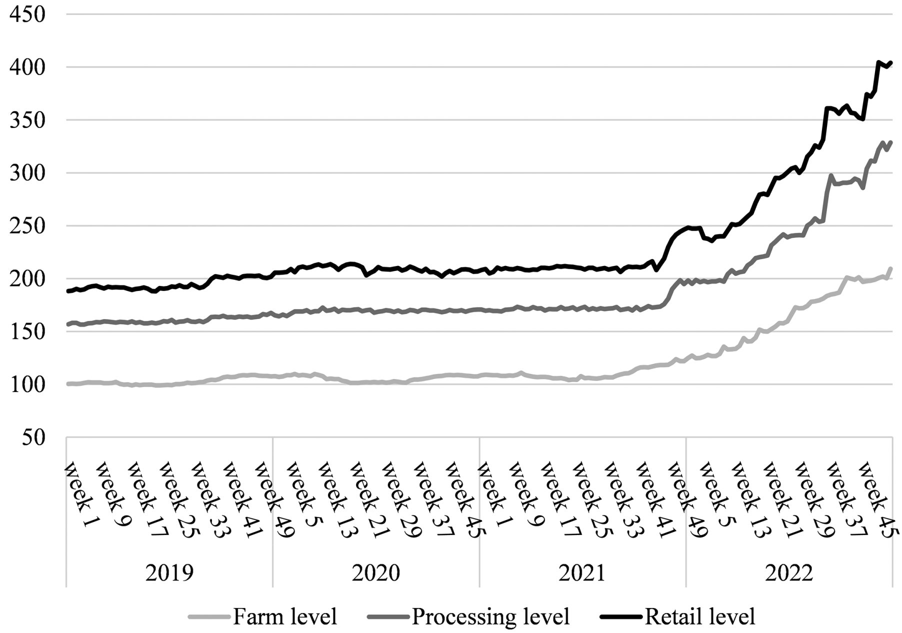

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Figure 1. Deflated weekly fresh milk prices in Hungary (HUF/litre)

Table 1. ADF test results (unit root test)

Variable	Levels Test stat	p-value	First differences Test stat	p-value
Farm	−0.522	0.980	−6.180***	<0.001
Processing	1.387	0.999	−3.485**	0.045
Retail	−0.125	0.999	−6.683***	<0.001

Note(s): The test does not include a constant and a linear trend. Asterisks denote significance at 10% (*), 5% (**), and 1% (***) levels
Source(s): Authors' own work

particularly in Italy, while retailers frequently import foreign dairy products to enhance product variety and offer low-priced items for consumers.

As a result, two error correction regressions were specified: one to estimate the processing level's response to farm-side shocks and another to estimate the processing level's response to retail-side shocks.

The error correction models are specified as follows:

$$\Delta p_{1,t} = \alpha_0 + \alpha^+ ECT^+_{t-1} + \alpha^- ECT^-_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta p_{1,t-i} + \sum_{i=1}^{k} \beta_i \Delta p_{2,t-i} + \varepsilon_t,$$

Table 2. Johansen cointegration test results

H0	Test stat	10% critical value	5% critical value	1% critical value
Farm-retail prices				
$r \leq 1$	2.83	7.52	9.24	12.97
$r = 0$	14.17	17.85	19.96	24.60
Farm-processing prices				
$r \leq 1$	1.71	7.52	9.24	12.97
$r = 0$	31.53***	17.85	19.96	24.60
Processing-retail prices				
$r \leq 1$	7.17	7.52	9.24	12.97
$r = 0$	34.37***	17.85	19.96	24.60

Note(s): Asterisks denote significance at 10% (*), 5% (**), and 1% (***) levels
Source(s): Authors' own work

where $p_{1,t}$ and $p_{2,t}$ represent (logarithmic) prices in week t, ECT_t^+ and ECT_t^- the positive and negative deviations from the long-term equilibrium, respectively, calculated based on the cointegration relationship, while ε_t is the idiosyncratic error term. $p_{1,t}$ and $p_{2,t}$ are specified based on the Granger-causality tests. The parameters of interest are α^+ and α^-, showing the speed of price adjustments once prices deviate from the long-term equilibrium. If $\alpha^+ = \alpha^-$, one can state that the price adjustment is symmetric; otherwise, it is asymmetric.

Table 3 presents the results of the error correction model regressions. Column (1) shows the estimation of the processing level's response to farm-side shocks. Figure 2 presents a visual representation of the model, displaying the impulse response functions of positive and negative farm and processing price shocks. When shocks stretch processor margins (ECT+), the speed of adjustment is slow and non-significant. However, for shocks that squeeze processor margins (ECT−), the adjustment is rapid and significant at every level of significance. However, while the F-test for the equality of the two error correction terms does not reject the null hypothesis of equality at 5% significance level, it is rejected at 10%. Hence, there may be some indication of asymmetric price transmission.

Column (2) of Table 3 presents the results of the error correction model, which measures the processing level's response to retail-side shocks. Figure 3 visualises the model by showing the impulse response functions of positive and negative retail and processing price shocks. The data do not support the hypothesis of symmetric price transmission. As the price at the processing level serves as the input price for the retail level, the ECTs pertain to the retail-level

Table 3. Error correction model regression results

Independent variable	(1) Farm ~ processing Δln(processing(t))	(2) Retail ~ processing Δln(processing(t))
(Intercept)	0.000 (0.001)	−0.002 (0.002)
ECT(t−1)+	−0.082 (0.062)	0.169 (0.130)
ECT(t−1)−	−0.255*** (0.071)	−0.476*** (0.124)
Number of lags	6	3
Test of asymmetry (H0: ECT+ = ECT−)		
F-test stat	3.018	9.551
p-value	0.084*	0.002***

Note(s): The number of lagged price variables was selected using the Akaike information criteria. Standard errors in parenthesis. Asterisks denote significance at 10% (*), 5% (**), and 1% (***) levels
Source(s): Authors' own work

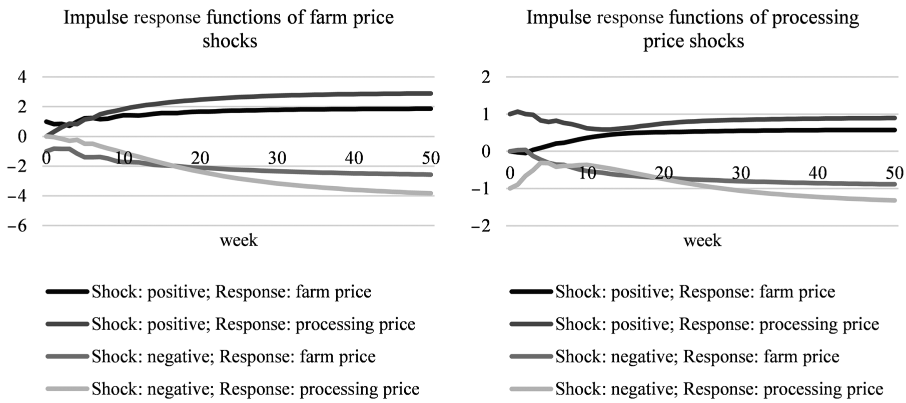

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Figure 2. Impulse response functions of farm and processing price shocks

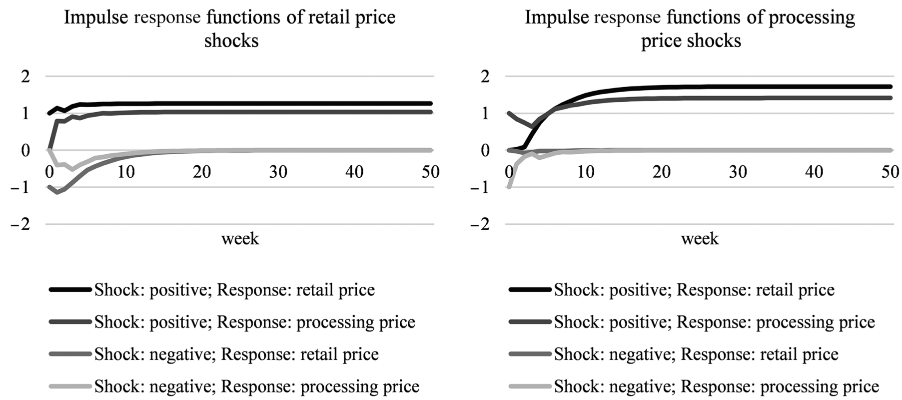

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Figure 3. Impulse response functions of retail and processing price shocks

margin. When processing prices deviate positively from the equilibrium level, and retail margins are lower than usual, processors do not adjust their level. On the other hand, when retail margins are stretched due to negative deviations in processor prices, processors make significant adjustments. The analysis suggests that processors benefit from price deviations.

The period under investigation can be divided into three subperiods:

- Normal period: From the beginning of the time series (1st week of January 2019) to the first COVID-19-related lockdown measures in Hungary (3rd week of March 2020);
- COVID-19 period: From the first COVID-19-related lockdown measures in Hungary (4th week of March 2020) to the outbreak of the Russian war against Ukraine (3rd week of February 2022);

- Russian war against Ukraine period: From the outbreak of the Russian war against Ukraine (4th week of February 2022) to the end of the time series (4th week of December 2022).

Estimating the error correction model regressions for these subperiods (see the Appendix) yielded similar, though not identical, results. However, it is important to note that the results from the subsamples should be analysed with caution due to the short time periods. Retail and processing prices were adjusted symmetrically for the normal period and the Russian war against Ukraine period. Asymmetric price transmission between retail and processing prices was found only for the COVID-19 period.

5. Discussion and policy implications

The empirical evidence indicates an asymmetric price transmission in the Hungarian milk supply chain between 2019 and 2022. The results suggest that processors can pass on raw milk price increases and maintain their margins even during economic crises, disruptions and high inflationary pressures. This finding is consistent with those of Bhandari and Ravishankar (2020), Wang *et al.* (2020) and Acosta *et al.* (2021), which demonstrate that processors were in a more advantageous position than dairy farmers during the COVID-19 pandemic.

Our findings confirm that processing firms adjust immediately to price shocks that stretch retail margins but do not adjust to shocks that squeeze them. It suggests that processing firms can keep pace with retail price increases but are not similarly constrained by retail price decreases. Therefore, if demand increases, retailers can increase their prices, and processing firms can push for a commensurate increase in wholesale prices, benefitting from the revenue and profit increase resulting from growing demand. However, it is worth noting that processing firms are not obligated to adjust their prices immediately in case of a decrease in retail margins (possibly due to a decline in demand).

This study's results contradict those of Bakucs *et al.* (2012), who found symmetric price transmission in the Hungarian milk supply chain. Nevertheless, other studies (e.g. Rezitis, 2019; Yu and Gould, 2019) have identified asymmetric price transmission in other countries. Yu and Gould (2019) have attributed this to market power on the retail side. Conversely, our findings indicate that milk processors exhibited some market power within the supply chain during the crises under investigation, particularly during the COVID-19 pandemic.

The results of the price transmission analysis play a crucial role in assessing the effects of recent crises on the dairy industry and its product prices. Some of these crises have significantly impacted farm-level actors, including feed shortages, pasture degradation resulting from significant droughts during the summer of 2022, and higher feed prices due to increased fertiliser prices caused by the rise in natural gas prices. Some shocks, such as the energy crisis, have affected the entire supply chain (Li *et al.*, 2018). It should be noted that processing-level firms could pass margin-squeezing price changes to the consumer level but were not obligated to pass on margin-stretching changes. Additionally, it is important to consider that non-competitive market structures can contribute to inflationary trends. However, it is primarily at the retail level that the pricing behaviour of other levels in the supply chain becomes visible to consumers and politicians.

Both the emergence of the COVID-19 pandemic and the subsequent government responses to it affected consumers in ways that provide a potential explanation for the market power of the processing sector. At the very beginning of the pandemic, panic buying led to increased demand, while during the first and second waves of the pandemic, lockdowns and other restrictive measures disrupted international supply chains (Akber and Paltasingh, 2022; Verma *et al.*, 2024). It also negatively impacted imported products, and retailers had to rely more on local suppliers (Coluccia *et al.*, 2021). At the same time, government subsidies, demand stimulation, monetary easing (Bareith and Fertő, 2024) and lower-than-expected job losses helped to maintain or even increase demand. Stimulated consumer demand was one of the reasons for the exceptionally high inflation in Hungary, as government subsidies were still high in 2022, which was connected to the parliamentary election. As a result, processors could pass on cost increases to consumers as demand was also high during the period of energy price increases. These factors increased the bargaining power of processors and reduced competition among them as supply was more constrained than demand (Lusk *et al.*, 2021). As a result, processors had market power in the supply chain. This explanation is further supported by the fact that the pre-COVID-19 subsample exhibited a symmetric price transmission for the processor-retailer relationship.

As asymmetric price transmission can lead to significant welfare losses (Yu and Gould, 2019), public policies must be implemented to address these asymmetries. Based on our findings, governments should focus mainly on the processing sector to address high food inflation and welfare losses in times of crisis. The dairy processing sector is an oligopolistic market, with the three largest companies owning almost 50% and the five largest companies owning two-thirds of the Hungarian market. Reducing market concentration and increasing competition at the processing level can lead to lower prices and greater food security, as Acosta *et al.* (2019) observed in the case of the milk market in Panama. In addition, making supply chains more resilient can have substantial policy benefits in times of crisis, leading to lower food prices.

It is also important to consider supply-side factors when demand stimuli are applied. Stimulating demand without considering supply shocks and trends can lead to market power, resulting in higher prices and inflation. It can be potentially mitigated by winding down international trade restrictions and improving the price competitiveness of other substituting products, like plant-based milk alternatives. Since plant-based milk alternatives are real substitutes for cow's milk based on consumer preferences (Slade and Markevych, 2024; Capps and Wang, 2024), these products can constitute effective constraints against the price increases of dairy products and local processing companies (Chung and Seok, 2024).

The most important limitation of the paper is that the period under investigation encompassed a multitude of crises, rendering it challenging to determine the individual impacts of each crisis. A further limitation is that the study focused solely on fresh milk, with no consideration for other dairy products.

The results of the study provide a foundation for future research. First, it is worthwhile to investigate the market power of processors in countries with fewer government subsidies (i.e. lower demand) in 2022. Second, future research can examine the pricing dynamics of the Hungarian milk supply chain in the post-crisis period with a particular focus on the market power of processors. Third, a more detailed pricing analysis can be conducted to understand how the pricing strategies of processors and retailers altered during this period.

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Appendix

Table A1. Enders-Siklos test results for nonlinear cointegration

Coefficients	Estimate	Std. error	t	p-value
Panel A: farm ~ processing				
Φ_low	−0.118	0.052	−2.247	0.026*
Φ_high	−0.163	0.052	−3.089	0.002**
ΔΦ	0.045	0.071	0.638	0.523
H0	p-value			
Φ_low = Φ_high	0.535			
Panel B: retail ~ processing				
Φ_low	−0.297	0.077	−3.831	<0.001***
Φ_high	−0.394	0.085	−4.596	<0.001***
ΔΦ	−0.112	0.069	−1.601	0.110
H0	p-value			
Φ_low = Φ_high	0.373			
Panel C: farm ~ retail				
Φ_low	−0.123	0.049	−2.486	0.013*
Φ_high	−0.141	0.048	−2.916	0.003**
ΔΦ	0.107	0.070	1.533	0.126
H0	p-value			
Φ_low = Φ_high	0.791			

Note(s): Asterisks denote significance at 10% (*), 5% (**), and 1% (***) levels
Source(s): Authors' own work

Table A2. Error correction regression results for the subsamples (processing-farm); dependent variable: Δln (processing(t))

Independent variable	Normal period	COVID-19 period	Russian war against Ukraine period
(Intercept)	0.001 (0.002)	0.001 (0.001)	0.008 (0.007)
ECT(t−1)+	−0.418* (0.213)	−0.129 (0.080)	−0.264 (0.194)
ECT(t−1)−	−0.176 (0.247)	−0.119 (0.071)	−0.250 (0.189)
Number of lags	1	2	1
Test of asymmetry (H0: ECT+ = ECT−)			
F-test stat	0.397	0.016	0.002
p-value	0.531	0.899	0.968

Note(s): The number of lagged price variables was selected using the Akaike information criteria. Standard errors in parenthesis. Asterisks denote significance at 10% (*), 5% (**), and 1% (***) levels
Source(s): Authors' own work

Table A3. Error correction regression results for the subsamples (processing-retail); dependent variable: Δln (processing(t))

Independent variable	Normal period	COVID-19 period	Russian war against Ukraine period
(Intercept)	0.000 (0.001)	−0.003** (0.001)	0.012** (0.005)
ECT(t−1)+	−0.544** (0.235)	0.094 (0.139)	−0.145 (0.138)
ECT(t−1)−	−0.645** (0.319)	−0.737*** (0.181)	−0.024 (0.169)
Number of lags	1	1	1
Test of asymmetry (H0: ECT+ = ECT−)			
F-test stat	0.055	10.079	0.193
p-value	0.816	0.002	0.663

Note(s): The number of lagged price variables was selected using the Akaike information criteria. Standard errors in parenthesis. Asterisks denote significance at 10% (*), 5% (**), and 1% (***) levels
Source(s): Authors' own work

Corresponding author
Zombor Berezvai can be contacted at: zombor.berezvai@uni-corvinus.hu