

SIGMA AND BETA CONVERGENCE IN THE ASSESSMENT OF EUROPEAN MILK MARKET INTEGRATION: AN ECONOMETRIC APPROACH FOR SELECTED EU COUNTRIES IN THE YEARS 2013-2026

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Abstract: *The aim of the paper is to assess the degree of integration of the European milk market using econometric methods that examine price convergence. The analysis is based on monthly milk price data for 26 European Union countries and the EU aggregate, covering the period from July 2013 to April 2026. Market integration is evaluated using two approaches. First, σ -convergence is applied by measuring changes in price dispersion across countries over time, including the coefficient of variation calculated monthly, and by analyzing its trend. Second, a β -convergence model is estimated, where the long-term average growth rate of prices is explained by initial price levels, allowing for the identification of a “catching-up” effect (a negative relationship between initial levels and growth rates). The empirical findings indicate the presence of β -convergence, suggesting partial alignment in price formation mechanisms across EU countries. However, the σ -convergence analysis does not confirm a clear and sustained decline in price dispersion over time, indicating possible periods of weakened integration, structural heterogeneity, or divergent adjustment paths among groups of countries. The results imply that while some convergence processes are present, full price integration in the European milk market has not been achieved. This highlights the need for further research on the role of institutional and cost-related factors that may limit market integration.*

Key words: *market integration, milk prices, σ convergence, β convergence, econometric models, European Union*

JEL codes: C23, Q13, F15, E31

1. Introduction

The agricultural market plays a key role in the economic and social structure of the European Union, influencing not only production and export levels but also the incomes of the rural population and the economic stability of Member States. Agriculture remains one of the most integrated areas of EU policy, and the Common Agricultural Policy (CAP) is one of the cornerstones of European integration (San Cristóbal, 2008). The introduction of common regulations, the abolition of internal tariffs, and the establishment of a common external tariff have contributed to deepening economic ties among member states and the development of a single agricultural market. At the same time, the agricultural sector serves a stabilizing function, particularly during periods of economic crisis, by supporting food security and rural development.

The importance of agriculture to the European Union's economy extends beyond its direct contribution to gross domestic product. The agri-food sector accounts for a significant share of employment, particularly in rural areas, and remains closely linked to other sectors of the economy. In many EU countries, agriculture plays a strategic role, supporting the development of the food industry, trade, and services related to food production. Social and environmental aspects also play a significant role, as modern agriculture provides not only market goods but also public goods related to environmental protection, the preservation of biodiversity, and the management of natural resources (Apostolidou et al., 2014).

The market for milk and dairy products plays a particularly important role in the structure of European agriculture. The European Union is one of the world's largest milk producers (approximately 160 mln t in 2023), and the dairy sector is an important source of income for farms in many member states. Milk production also plays a vital role in ensuring food security by providing a stable supply of dairy products to consumers. The dairy sector accounts for approximately 12 percentage-point of the EU's total agricultural output (Alrhoun et al., 2025). In recent decades, the milk market has undergone significant changes related to trade liberalization, reforms of the Common Agricultural Policy, and the gradual reduction of intervention mechanisms. A particularly significant development was the abolition of the milk quota system in 2015, which led to increased competition, a rise in supply, and greater market exposure to price volatility and conditions on the global market (Bojnec & Ferto, 2014).

The integration of the milk market in the European Union is a complex process involving the harmonization of regulations, support mechanisms, and production structures. Existing research indicates that milk prices in most Member States are aligned with the average EU price level, which may indicate a relatively high degree of market integration. At the same time, persistent differences between selected countries suggest the presence of factors limiting full price integration, such as variations in production costs, infrastructure, the level of development of the dairy sector, or differing institutional conditions (Fousekis, 2018; Triatmojo et al., 2025).

Assessing the degree of integration in the milk market requires the use of appropriate analytical tools that allow for the identification of price-level equalization processes among member states. In this context, studies of price convergence are of particular importance. In the economic literature, two complementary approaches are most commonly used: beta (β) convergence and sigma (σ) convergence. The β -convergence allows for an assessment of whether countries initially characterized by higher or lower price levels tend to “catch up” to the average price level through differing rates of change. The σ -convergence, on the other hand, refers to the reduction in price variation between countries over time, indicating the degree of market homogenization. The combined use of both methods allows for a comprehensive assessment of integration processes, as the occurrence of β -convergence does not necessarily imply a permanent decline in price dispersion (Fousekis, 2018; Fousekis & Trachanas, 2016).

Despite the growing number of studies on the integration of agricultural markets, there remains a research gap regarding the dairy market. Previous analyses have often focused on specific countries or other segments of the agricultural market, such as grains or pork. Relatively few studies cover a broad cross-section of EU member states and a long period following the abolition of milk quotas. The use of advanced econometric methods to assess long-term price convergence processes is also limited (Fousekis, 2018). It should be acknowledged that the absolute β -convergence model applied in this study assumes a common long-run equilibrium for all countries. As noted by Próchniak (2019), convergence may not occur when countries are characterized by different steady states, and the omission of country-specific structural factors may limit the model's explanatory power. In the context of the EU milk market, such factors may include differences in production costs, farm structure, CAP support levels, and processing capacity, which may define different long-run price equilibria across member states. The conditional β -convergence framework, which incorporates control variables, represents a natural extension for future research.

The aim of this article is to assess the degree of integration of the European milk market using econometric methods based on the β and σ -convergence concepts. The study was conducted using monthly milk price data for selected European Union countries from 2013 to 2026. The analysis allows us to determine whether processes leading to price harmonization are occurring in the European milk market and to what extent the EU single market promotes the alignment of pricing mechanisms among member states.

2. Methodology and Data

The research methodology employs two complementary concepts: σ -convergence and β -convergence, which are widely applied in analyses of economic integration and cross-country equalization processes. On this basis, empirical approaches to studying the β and σ of convergence were developed, which are now also applied in the analysis of other economic variables, including price levels. The literature emphasizes that prices—like incomes—exhibit a long-term tendency to converge toward an equilibrium level, although this process may vary and depend on structural factors (Glushenkova et al., 2018).

In the context of agricultural markets and price analysis, convergence is regarded as an important measure of market integration, as prices in integrated markets tend to converge over the long term. Price convergence analysis-based approaches are frequently used to assess the degree of integration in the European milk market (Próchniak, 2019). The research methodology employs two complementary concepts: σ -convergence and beta β -convergence, widely applied in analyses of economic integration and the equalization of economic levels across countries (Glushenkova et al., 2018; Simionescu, 2014). The σ -convergence refers to the reduction in price variation among the countries under study over time. This approach allows for an assessment of the degree of market homogenization by analysing changes in the dispersion of milk prices among European Union member states (Simionescu, 2014). The study utilized the coefficient of price variation, calculated for each period using the formula:

$$CV_t = \frac{SD_t}{\bar{P}_t} \quad (1)$$

where: SD_t denotes the standard deviation of milk prices during period t , while $\bar{P}_t$ denotes the average level of milk prices during the same period.

A decline in the coefficient of variation over time is interpreted as convergence of σ , which indicates a narrowing of price differences between countries and increased market

integration (Wang & Sun, 2026). To formally assess the direction of changes in price dispersion, the linear trend of the coefficient of variation was also estimated:

$$CV_t = \alpha + \beta t + \varepsilon_t. \quad (2)$$

A negative and statistically significant value of the β parameter indicates the presence of σ -convergence

The second approach used was β -convergence, also referred to as the “catch-up” effect. This concept allows us to assess whether countries with initially lower milk prices exhibit a faster rate of price growth than countries with higher initial levels (Barro, Sala-i-Martin, 1992). The study employed an absolute beta convergence model in the form:

$$\frac{1}{T} \ln \frac{P_{i,t+T}}{P_{i,t}} = \alpha + \beta \ln P_{i,t} + \varepsilon_i \quad (3)$$

where: $P_{i,t}$ denotes the milk price level in the country during the initial period, and $P_{i,t+T}$ denotes the price level during the final period.

A negative β coefficient indicates price convergence and suggests that countries with lower initial prices experience higher rates of price growth, leading to a gradual alignment of price levels among member states (Markowski, 2022; Twardowska, 2019).

Using both methods simultaneously allows for a more comprehensive assessment of milk market integration. The β -convergence identifies the adjustment mechanism between countries, while the σ -convergence makes it possible to assess whether this process leads to an actual reduction in price dispersion. The economic literature emphasizes that the presence of β -convergence is a necessary but insufficient condition for σ -convergence to occur. This means that countries may exhibit a “catch-up” mechanism, yet under the influence of external shocks or structural differences, price dispersion may remain at a relatively high level (Markowski, 2022; Twardowska, 2019).

The analysis was conducted using monthly milk price data for selected European Union countries and the EU aggregate for the period from July 2013 to April 2026. The approach used allows for an assessment of the degree of integration of the milk market following the reforms of the Common Agricultural Policy and the abolition of the milk quota system in the European Union.

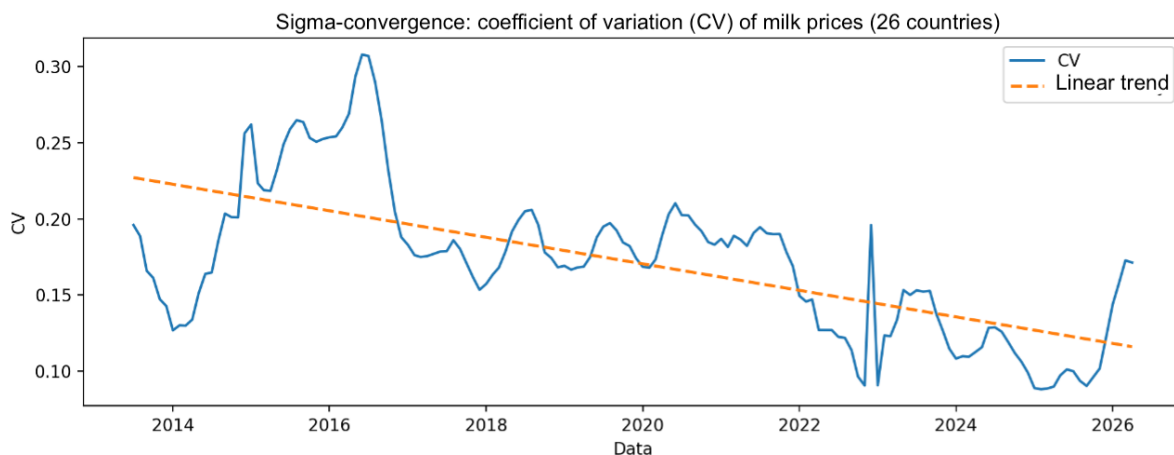
3. Results and Discussion

The analysis covers monthly raw milk prices (EUR/100 kg) in 26 EU countries for the period from July 2013 to April 2026; the data comes from the Milk Market Observatory. The results are presented in terms of two complementary concepts of convergence: σ (changes in price

dispersion over time) and β (the “catch-up” effect, i.e., the relationship between the initial level and the rate of price growth). The calculations of σ -convergence used the coefficient of variation (CV) calculated each month for the cross-section of 26 countries. For β -convergence, an absolute model was estimated based on the average annual growth rate (logarithmic) over the entire study horizon.

An analysis of price dispersion across countries indicates the presence of a σ -convergence process in terms of long-term trends. The monthly coefficient of variation (CV), calculated for a sample of 26 countries, was used as a measure of dispersion. The CV value decreased from 0.196 in July 2013 to 0.171 in April 2026, representing a 12.6 percentage-point decrease relative to the initial level. At the same time, the CV varied over time (Fig. 1). The highest variation was recorded in June 2016 (CV = 0.308), and the lowest in February 2025 (CV = 0.088). The estimation of the linear trend in CV confirms a statistically significant decrease in dispersion (Table 1), indicating a narrowing of price differences between countries during the study period. For a more complete interpretation, it is worth noting that a comparison of the cross-sectional variance of price logarithms between the beginning and end of the period (F-test) does not confirm a significant change in point-to-point variance ($p = 0.521$). This means that the conclusion regarding σ -convergence is based primarily on the direction of changes across the entire sample (trend), rather than solely on a comparison of extreme observations. An analysis of the average CV values across sub-periods indicates a reduction in dispersion in the final part of the sample: July 2013 – December 2019 (CV = 0.200); January 2020 – December 2021 (CV = 0.188); January 2022 – December 2022 (CV = 0.130); January 2023 – April 2026 (CV = 0.120).

Fig. 1 Milk price volatility factor (CV) over time and adjusted trend line



Source: own analysis based on the data Milk Market Observatory (https://agriculture.ec.europa.eu/data-and-analysis/markets/overviews/market-observatories/milk_en: 22.05.2026)

Tab. 3 Results of the σ -Convergence Assessment (Linear Trend CV)

	Parameter	SE	t	p
α (const)	0.227	0.006	37.623	0.000
β (trend)	-0.002	0.000	-10.644	0.000
$R^2 = 0.427$, $N = 154$				

Source: own analysis based on the data Milk Market Observatory (https://agriculture.ec.europa.eu/data-and-analysis/markets/overviews/market-observatories/milk_en: 22.05.2026)

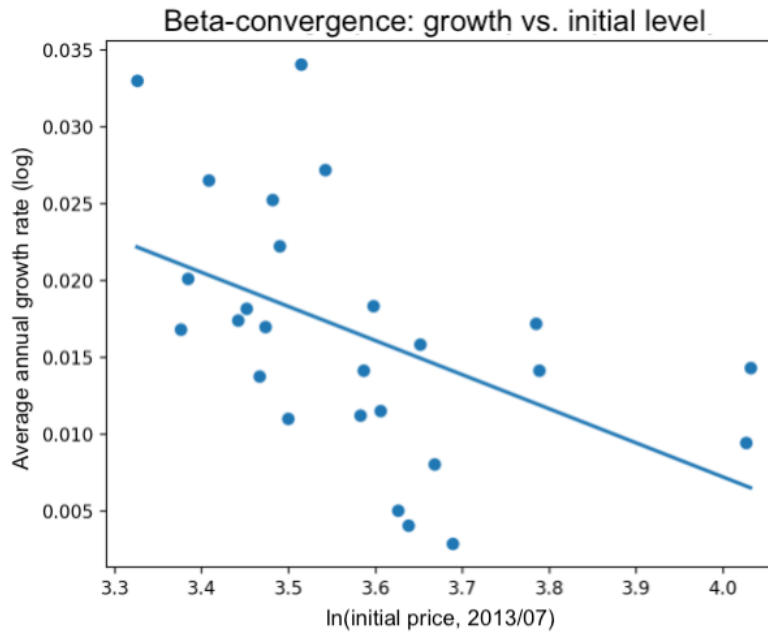
β -type convergence implies that the lower the initial price level, the higher the average rate of price growth should be. The estimated model of absolute β -convergence confirms the existence of a statistically significant negative relationship between $\ln(P_0)$ and the average annual rate of price growth over the entire period (Table 2). The coefficient β was -0.022 ($t=-2.734$, $p = 0.011$), with $R^2 = 0.237$. Thus, countries with relatively lower initial price levels exhibited, on average, faster price growth, which helps reduce price differences. Based on the β parameter, the convergence rate was estimated at $\beta \approx 0.026$ (i.e., approx. 2.6% per year) and the half-life at ≈ 26.6 years. This relationship is illustrated in Figure 2, which shows a regression line with a negative slope.

Tab. 2 Results of the β Convergence Assessment

	Parameter	SE	t	p
α (const)	0.096	0.029	3.297	0.000
β [$\ln(P_0)$]	-0.022	0.008	-2.734	0.000
$R^2 = 0.237$, $N = 26$				

Source: own analysis based on the data Milk Market Observatory (https://agriculture.ec.europa.eu/data-and-analysis/markets/overviews/market-observatories/milk_en: 22.05.2026)

Fig. 2 Relationship between the average annual growth rate and the initial level (β -convergence)



Source: own analysis based on the data Milk Market Observatory (https://agriculture.ec.europa.eu/data-and-analysis/markets/overviews/market-observatories/milk_en; 22.05.2026)

The obtained results are consistent with earlier empirical studies on EU agricultural and dairy market integration. Roman and Roman (2020) showed that raw milk prices in EU countries tend to align over time, although full synchronization has not yet been achieved. Similarly, Bakucs, Benedek and Fertő (2019) found that price transmission in the European dairy sector is incomplete and heterogeneous across countries. Our results support this interpretation: the statistically significant β -convergence confirms the existence of a catching-up mechanism, while the relatively slow speed of convergence and the non-monotonic path of σ -convergence suggest that integration remains partial and sensitive to structural differences and external shocks. This conclusion is also in line with Bareith and Fertő (2025), who identified heterogeneous convergence dynamics and structural breaks in EU food markets.

4. Conclusions

This study has several limitations. First, the estimated β -convergence model is an absolute specification and therefore assumes a common long-run equilibrium across countries. This approach does not account for country-specific structural factors such as differences in production costs, farm structure, dairy processing capacity, market organization, or the scale of CAP support. As a result, part of the observed variation in milk price dynamics may reflect structural heterogeneity rather than pure market integration. Second, the analysis focuses on

raw milk prices and does not explicitly model transmission channels, transaction costs, or institutional changes. Therefore, future research should extend the analysis toward conditional β -convergence models and convergence club approaches.

The study clearly showed the existence of statistically and economically significant absolute β -convergence in milk prices among the 26 EU countries analyzed during the study period (July 2013–April 2026). This confirms the presence of a “catching-up effect,” whereby countries with relatively low initial price levels (mainly from Central and Eastern Europe) exhibited higher growth rates than countries with an established, high price position. This process reflects ongoing market integration and indicates a gradual blurring of historical structural differences in the European milk market.

An analysis based on σ -convergence revealed a statistically significant negative trend in the coefficient of variation (CV), indicating a real decline in price dispersion over the long term. Although the pace of this convergence is not rapid, the systematic narrowing of price deviations from the EU average suggests that the mechanisms of the Common Agricultural Policy and the free movement of goods effectively limit extreme price heterogeneity, bringing member states closer to a common price level. Despite the downward trend, the pattern of price volatility (CV) over time was clearly non-monotonic, with periods of sharp increases in dispersion (particularly in 2016 and during periods of high volatility in energy and feed prices). This suggests that the European milk market is highly sensitive to external market and political shocks, which can temporarily destabilize the convergence process. This phenomenon indicates that market integration is not an irreversible process and requires constant monitoring in the context of income security for agricultural producers.

The above findings are consistent with prior empirical studies on EU agricultural market integration. Roman and Roman (2020), analysing raw milk prices across 24 EU member states in 2005–2018, confirmed the presence of a catch-up process whereby a country with an initially lower price level gradually converged toward higher-price markets, while noting that full price synchronisation had not yet been achieved, which is reflected in the slow convergence rate and long half-life estimated in the present study. Similarly, Bakucs, Benedek and Fertő (2019) demonstrated that perfect price transmission across EU milk markets remains the exception rather than the rule, with integration more pronounced among Old Member States than New Member States, suggesting that institutional and structural differences continue to constrain full price arbitrage. The absence of full price integration is also consistent with the findings of Bareith and Fertő (2025), who, examining food price inflation across EU-27 in 2005–2024,

found no overall convergence but identified multiple convergence clubs, and showed that the European food market remains highly exposed to external price shocks, which corresponds to the periods of sharply increased price dispersion observed in the present analysis.

The estimated rate of convergence and the half-life (over 26 years) suggest that full price convergence is a process spanning decades. This is likely due to persistent differences in production costs, processing structures, and local consumer purchasing power. The fact that the absolute β -convergence model explains only part of the variation points to the significant role of specific national conditions that hinder full arbitrage-driven price adjustment.

In light of the results obtained, future research should focus on verifying conditional convergence, taking into account, among other factors, the level of public support, labor costs, and the degree of concentration in the dairy industry in individual countries. It also seems important to examine the existence of so-called convergence clubs (clusters), which would help answer the question of whether the price convergence process is occurring across the entire European Union or only within specific groups of countries with similar market infrastructure.

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