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FACULTY OF ECONOMICS – PRILEP

XIV International Conference on Economy, Business & Society in Digitalized Environment

PROCEEDINGS

18-19 September 2026, Prilep, North Macedonia

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CONTENTS

THE PARADOX OF EARLY - STAGE ENTREPRENEURSHIP IN BOSNIA AND HERZEGOVINA AND THE CONSTRAINS OF TRANSITION TO ESTABLISHED ENTREPRENEURSHIP *Bahrija Umihanić, Umihana Umihanić Bukvić*	1
CORPORATE GOVERNANCE IN BUSINESS LAW: THE EXPERIENCE OF NORTH MACEDONIA AND TÜRKIYE *Emilija Gjorgjioska, Mustafa Yasan*	13
LEVEL OF AWARENESS AND PRACTICES REGARDING PACKAGING WASTE SELECTION IN NORTH MACEDONIA *Aleksandar Mateski, Filip Ivanovski, Emilija Gjorgjioska, Violeta Gligorovski*	30
ADVANCED HIGH-RISK INTERNET BANKING IN CROATIA: PREDICTORS AND INSIGHTS *Sandra Pepur, Mario Pepur, Dujam Kovač*	44
IMPROVING THE SUSTAINABILITY OF FOOD WASTE MANAGEMENT IN THE HOSPITALITY SECTOR: EVIDENCE FROM PRISHTINA, REPUBLIC OF KOSOVO *Flutra Mestani, Miroslav Gverovski, Aneta Risteska Jankuloska, Mergim Mestani*	56
INSTITUTIONAL MECHANISMS FOR LOCAL TAX COLLECTION *Emil Mutafov*	71
THE IMPACT OF DIGITAL TRANSFORMATION ON BUSINESS PERFORMANCE: A CASE STUDY OF SMEs IN THE VARDAR REGION *Mensure Hodja, Miroslav Gveroski, Aneta Risteska-Jankuloska*	82
PRAGMATISAM VERSUS IDEALISM IN MARITIME BOUNDARY DELIMITATION: EXPLORING CORRELATIONS, CONTRADICTIONS AND COMPETING APPROACHES IN THE EASERN MEDITERRANEAN *Nikolaos Paounis, Lefteris Topaloglou*	97
JUST ENERGY TRANSITION & LABOR MARKET TRANSFORMATION IN THE REGION OF WESTERN MACEDONIA *Lefteris Topaloglou, Despoina Kanteler, Maria Sambrakou, Pavlidou Sofia & Fenia Pliatsika*	103

REGIONAL VALIDATION OF ENERGY POVERTY INDICATORS IN JUST TRANSITION REGIONS: EVIDENCE FROM WESTERN MACEDONIA, SILESIA & STARA ZAGORA *Maria Sambrakou, Despoina Kanteler, Lefteris Topaloglou, Panayotis Pantazis*	110
ERASMUS+ STUDENTS AS CONSUMERS: ATTITUDES, INTENTIONS AND LOCAL PRODUCT PURCHASING BEHAVIOUR IN CROATIA *Ivana Jadrić*	116
STRATEGIC MANAGEMENT AND FDI IN THE DIGITAL ECONOMY: EMPIRICAL EVIDENCE FROM THE WESTERN BALKANS *Elvis Elezaj, Sokol Berisha, Halit Shabani*	130
FINANCIAL INVESTEMENTS IN RESEARCH, DEVELOPMENT AND INNOVATION: GROWTH ELASTICITY ACROSS INCOME GROUPS *Dance Nikolovska Vrateovska, Snezhana Mojsoska, Ljupco Davcev*	142
CASHLESS PAYMENTS AND CONSUMER SPENDING BEHAVIOUR IN THE BALKANS: EVIDENCE BEFORE AND AFTER COVID-19 *Ivica Tomovski, Gordana Serafimovic, Viktorija Trajkov, Filip Simonovski*	153
LOCAL GOVERNMENTS AND FOREIGN DIRECT INVESTMENT *Rositsa Raykova*	163
THE FISCAL MULTIPLIER OF TOURISM TAXATION IN BULGARIA *Violetka Zheleva*	173
INNOVATIVE MODELS IN RURAL TOURISM: THE SHARING ECONOMY AND DIGITAL NOMADISM *Elena Gospodinova, Violetka Zheleva*	182
DIGITAL TRANSFORMATION IN THE INSURANCE INDUSTRY: CHALLENGES AND OPPORTUNITIES FOR THE DEVELOPMENT OF INSURANCE MARKETS IN DEVELOPING ECONOMIES *Halit Shabani, Ibish Mazreku*	192
THE ROLE OF AI TOOLS IN MODERN WEB DESIGN: A COMPARATIVE OVERVIEW *Dejan Zdraveski, Kosta Sotiroski, Petar Avramovski, Margarita Janeska*	205

E-COMMERCE TRENDS: NORTH MACEDONIA VIS-À-VIS OTHER EUROPEAN COUNTRIES *Marjan Angeleski, Olivera Kostoska*	220
INNOVATIONS IN DIGITAL BANKING SERVICES *Marina Blazhekovikj Toshevski, Stevcho Dimeski*	231
ACCESSIBILITY IN CULTURAL TOURISM: INCLUSIVE EDUCATIONAL PRACTICES IN GREEK MUSEUMS FOR DEAF AND HARD OF HEARING VISITORS *Athina Tsakiridou*	243
THE IMPACT OF ARTIFICIAL INTELLIGENCE ON INNOVATION PERFORMANCE IN GLOBAL PHARMACEUTICAL COMPANIES *Marjan Gjurikj, Marjan Angeleski*	254
DIGITAL ECOSYSTEM AND COOPERATIVES: DIGITAL MARKETPLACES FOR WOMEN'S COOPERATIVES *Burçin Başaran, Nilüfer Serinikli, Yasemin Oraman*	271
THE INFLUENCE OF DIGITAL SOCIAL PROOF ON ONLINE PURCHASE DECISION *Radoslav Nastasijevikj Vardjiski, Karolina Ilieska, Snezana Obednikovska*	283
STRATEGIES AND INITIATIVES TO REDUCE THE RISKS OF USING GENERATIVE ARTIFICIAL INTELLIGENCE SYSTEMS *Natalia Marinova, Lora Parvanova*	296
BULGARIA'S TRADE IN AGRICULTURAL PRODUCTS: CHALLENGES, OPPORTUNITIES AND DEVELOPMENT PROSPECTS *Iskra Nencheva, Nikolay Penev*	303
REGIONAL READINESS FOR THE AGENT ECONOMY: An ASSESSMENT OF TURKISH PROVINCES *Bige Küçükefe*	314
ANALYSIS OF THE PERFORMANCE OF A BUSINESS ENTITY USING ARTIFICIAL INTELLIGENCE *Mimoza Mijoska*	331
CORRELATION ANALYSIS OF NET WAGES AND THE MINIMUM CONSUMER BASKET IN THE REPUBLIC OF NORTH MACEDONIA AND THE REPUBLIC OF SERBIA *Meri Spirkoska*	346

OPPORTUNITIES AND CHALLENGES OF ARTIFICIAL INTELLIGENCE FOR WOMEN ENTREPRENEURS: EXAMPLES OF WOMEN ENTREPRENEURS IN TÜRKIYE *Nilüfer Serinikli, Burçin Basaran*	359
GLOBALIZATION AS A DRIVER OF COMPETITIVE DYNAMICS: EMPIRICAL EVIDENCE FROM NORTH MACEDONIA *Meri Boshkoska, Emilija Gjorgjioska, Monika Angeloska - Dichovska, Margarita Janeska, Tatjana Spaseska*	369
COST MANAGEMENT AS A BASIS FOR STRATEGIC DECISION-MAKING IN PRICING *Igor Zdravkoski, Pece Nikolovski, Ljupce Markuseski, Miroslav Andonovski*	385
THE IMPACT OF ARTIFICIAL INTELLIGENCE ON REAL-TIME CONSUMER PERSONALIZATION IN E-MARKETING *Goran Kotevski, Karolina Ilieska, Margarita Janeska*	396
A CORPORATE GOVERNANCE MODEL ORIENTED TOWARD ACHIEVING THE SUSTAINABLE DEVELOPMENT GOALS *Angel Sarov, Filip Elenov*	411
BANK-SPECIFIC AND MACROECONOMIC DETERMINANTS ON MARKET CAPITALIZATION: EVIDENCE FROM MACEDONIAN LISTED BANKS *Tatjana Spaseska, Vera Karadjova*	421
FINANCIAL AUTONOMY AND MUNICIPAL PERFORMANCE IN PRISHTINA BASED ON DOCUMENTARY EVIDENCE FROM 2015 TO 2025 *Gjeni Imami, Milaim Mehmeti, Fanka Risteska*	436
QUALITATIVE RESEARCH METHODS IN BANKING RESEARCH: CONTENT ANALYSIS AND CASE STUDY *Milaim Mehmeti, Gjeni Imami, Fanka Risteska*	451
THE ROLE OF EU FUNDS ON SUSTAINBLE DEVELOPMENT IN CROATIA - CASE STUDY ON KRAPINA ZAGORJE COUNTY *Dalibor Hržica, Katarina Svažić, Nikola Sinković*	461
DOMESTIC TOURISM SEASONALITY: IMPACTS OF SCALE AND GEOGRAPHIC CONCENTRATION IN A SMALL ECONOMY *Vera Karadjova, Aleksandar Trajkov*	475

COMMUNICATION AS A SOCIAL CONSTRUCT: DEVELOPING THE COMMUNICATION MATRIX *Violeta Gligorovski, Nikola Dimeski, Tatjana Spaseska, Aneta Risteska Jankuloska, Dragica Odzaklieska*	489
PRODUCTIVITY GAINS AND HERD DECLINE IN MACEDONIA'S DAIRY SECTOR: A NATIONAL AND REGIONAL DECOMPOSITION *Aleksandar Trajkov, Gordana Dimitrovska, Elena Joshevska, Vera Karadjova*	502
FROM DIGITAL DIVIDE TO SMART INTEGRATION: RECONFIGURING TOURISM-AGRICULTURE VALUE CHAINS IN RURAL DESTINATIONS OF NORTH ALBANIA *Sead Baraku, Elidiana Bashi*	510
BUDGET CONSTRAINT IMPACT ON FOOD PREFERENCES IN ECONOMIC UNCERTAINTY *Georgi Aleksiev, Violetka Zheleva*	522
DRAWDOWNS AND RECOVERY PERIODS: AN ALTERNATIVE METHODOLOGICAL PERSPECTIVE ON INVESTMENT RISK *Alexander Ganchev*	534
THE EVOLUTION OF ECONOMIC PLANNING FROM STATIC TO DYNAMIC MODELS IN THE CONTEXT OF DIGITAL TRANSFORMATION *Nadezhda Veselinova*	539
COMMERCIAL ENTREPRENEURIAL NICHES FOR THE DEVELOPMENT OF RURAL TOURISM IN BULGARIA *Tsvetelina Kabakchieva*	548

PRODUCTIVITY GAINS AND HERD DECLINE IN MACEDONIA'S DAIRY SECTOR: A NATIONAL AND REGIONAL DECOMPOSITION

Aleksandar Trajkov[1], Gordana Dimitrovska[2], Elena Joshevska[3], Vera Karadjova[4]

Abstract

This study examines whether productivity gains offset the decline in the number of dairy cows in Macedonia from 2016 to 2025 and how the adjustment varied across the eight planning regions. Official State Statistical Office data are analysed using symmetric endpoint and annual dynamic decompositions, regional concentration and dispersion indicators, and robustness checks. The number of dairy cows fell by 39.1%, while milk yield per cow increased by 18.1%; total cow milk production nevertheless declined by 28.1%. The endpoint decomposition attributes a negative effect of 171.8 million litres to herd contraction and a positive effect of 58.6 million litres to productivity. Productivity therefore compensated only 34.1% of the negative herd effect; annual decomposition and alternative-period checks confirm that herd contraction remained dominant. Regional patterns differed markedly: Polog achieved near-complete productivity compensation, whereas the Southeast expanded its herd but experienced a sharp productivity decline. Concentration and productivity dispersion were higher in 2025 than in 2016, but fluctuated during the period. The findings show that productivity improvements can mitigate, but cannot indefinitely replace, a shrinking production base. Stabilising milk supply therefore requires coordinated measures for herd retention, replacement, and region-specific productivity improvement.

Keywords: agricultural productivity; dairy sector; structural change; decomposition; regional concentration

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1. Introduction

From a production-economics perspective, cow milk output is jointly determined by the number of dairy cows and the average output obtained per animal. This relationship shows that a sector can improve productivity while total output declines if the number of cows falls faster. Equally, an expanding herd may produce only limited growth when milk yield per cow deteriorates. Separating the two effects shows whether production changed mainly because of herd size, milk yield, or both..

The dairy sector in Macedonia has long been characterised by small production units, relatively low average yields, fragmented supply channels, and recurrent pressure on farm viability (Sekovska et al., 2015; Sulejmani & Iseni, 2023). These constraints matter beyond the farm level because a sustained decline in the dairy-cow population may reduce domestic raw-milk supply, weaken processing capacity utilisation, place farm incomes and rural employment under pressure, and reduce the resilience of the food system. Improvements in genetics, nutrition, animal health, housing, and management can raise output per cow, but the central empirical question is whether those gains have been large enough to counterbalance the decline in animal numbers.

International evidence shows that dairy restructuring commonly combines fewer farms or animals with larger herds, higher yields, and a geographical redistribution of production. Shift-share and related decomposition methods have been used to distinguish herd and productivity effects and to identify regions in which intensification offsets structural contraction (Bender Filho et al., 2023; de Oliveira et al., 2024). Evidence from Chile also shows that national averages can hide important regional differences in farm structure and resource use. (Toro-Mujica & Vera-Infanzón, 2024).

This paper contributes to applied agricultural and regional economics by applying a transparent national and regional decomposition to official annual data for 2016-2025. It combines endpoint and annual dynamic decompositions with a compensation rate, regional contribution measures, concentration indicators, productivity dispersion, and a proxy for herd-renewal potential. Three questions guide the analysis: (1) which factor dominated the change in national production; (2) how strongly did regional patterns differ; and (3) did the main conclusion remain stable under alternative periods and levels of aggregation?

2. Data and methodology

2.1 Data and variables

The analysis uses annual aggregate data from the State Statistical Office MAKSTAT database for Macedonia and its eight planning regions. Table ES380M16 provides the number of dairy cows, published milk yield per cow, and

cow milk production. Table ES366M16 provides cattle categories used to construct the herd-renewal proxy. The balanced period covers 2016-2025. All production data are secondary aggregates and contain no farm- or animal-level observations.

Table 1. Variables and analytical role

Variable / symbol	Unit	Analytical role
Cow milk production (P)	'000 L	Outcome and accounting identity
Dairy cows (N)	head	Production-base effect
Derived milk yield (Y*)	L/cow	Productivity effect without rounding residual
Regional production share (s_i)	share	HHI and CR3 concentration
In-calf heifers per 100 dairy cows (R)	no.	Approximate renewal potential

Source: State Statistical Office MAKSTAT; authors' definitions and calculations.

The officially published yield is rounded to whole litres. Direct multiplication of that series by the number of cows can therefore produce a small residual relative to reported total production. To ensure an exact accounting identity, the decomposition uses derived yield Y*, calculated directly from P and N; the published yield remains the descriptive indicator.

$$P_t = N_t \times Y*_t / 1{,}000 \quad (1)$$

$$Y*_t = P_t \times 1{,}000 / N_t \quad (2)$$

2.2 Symmetric and dynamic decomposition

The change between the initial and final years is decomposed symmetrically. This allocates the interaction term equally between the herd-size and productivity components and is invariant to the order in which factors are changed.

$$E^N = (N_1 - N_0) \times (Y*_1 + Y*_0) / 2{,}000 \quad (3)$$

$$E^y = (Y*_1 - Y*_0) \times (N_1 + N_0) / 2{,}000 \quad (4)$$

$$\Delta P = E^N + E^y \quad (5)$$

The same equations are applied to every pair of consecutive years and the annual effects are summed. Endpoint decomposition captures the net difference between 2016 and 2025, whereas dynamic decomposition reflects the full annual path. When the herd effect is negative and the productivity effect positive, compensation is CR = E^y / $|E^N|$ x 100. A value below 100% indicates partial compensation. Regional contribution is measured as each region's production change divided by the national production change.

2.3 Concentration, dispersion, renewal, and robustness

Regional concentration is measured by HHI = Σs_i^2 and CR3, the combined production share of the three largest regions. Productivity dispersion is measured by the coefficient of variation across regional milk yields. The number of in-calf heifers per 100 dairy cows over two years is used only as an approximate indicator of immediate replacement potential; it is not a forecast of future herd

size. Robustness is assessed with alternative start and end years, three-year averages, and a comparison of national decomposition with the sum of regional decompositions. Because the analysis is an exact arithmetic decomposition, The results are interpreted by their size and direction rather than statistical significance.

3. Results

3.1 National trends and decomposition

Between 2016 and 2025, the number of dairy cows declined from 132,332 to 80,605, a fall of 51,727 head or 39.1%. Published milk yield increased from 3,046 to 3,596 litres per cow, or 18.1%. Total cow milk production nevertheless fell from 403.0 to 289.9 million litres, a decline of 113.2 million litres or 28.1%. Figure 1 shows that milk yield varied over time, but its increase was not enough to prevent total production from declining as the herd shrank..

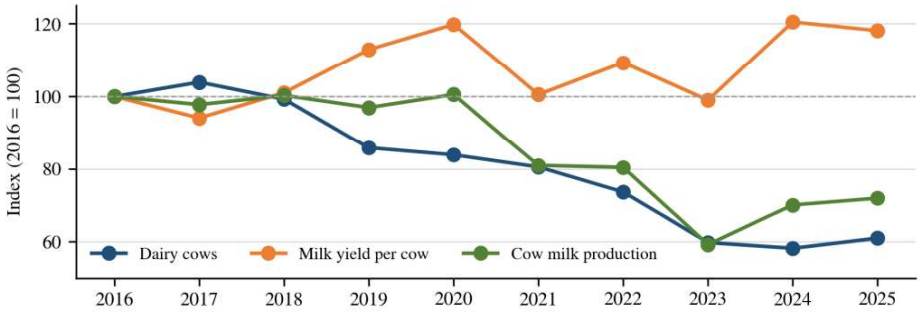


Figure 1. National cow milk indicators, 2016-2025
Source: Authors' calculations based on State Statistical Office MAKSTAT data.

Table 2. National change and decomposition, 2016-2025

Indicator / approach	Change, 2016-2025	Herd effect	Yield effect
Dairy cows	-51,727 (-39.1%)	-	-
Milk yield	+550 L/cow (+18.1%)	-	-
Cow milk production	-113.2 million L (-28.1%)	-	-
Endpoint decomposition	-113.2 million L	-171.8	+58.6
Dynamic decomposition	-113.2 million L	-166.1	+53.0

Source: Authors' calculations based on State Statistical Office MAKSTAT data.

The endpoint decomposition assigns a negative effect of 171.8 million litres to the reduction in dairy-cow numbers and a positive productivity effect of 58.6 million litres. Productivity therefore compensated 34.1% of the herd effect. The annual dynamic approach produces a comparable result: a herd effect of -166.1 million litres, a productivity effect of 53.0 million litres, and compensation of 31.9%. Both methods lead to the same conclusion, showing that the result does not depend only on the comparison between 2016 and 2025..

3.2 Regional heterogeneity

Seven regions recorded fewer dairy cows in 2025 than in 2016, while milk yield increased in seven. The Southeast followed the opposite path: dairy-cow numbers rose by 91.0%, but yield fell by 44.4%, limiting production growth to 6.2%. Polog represents the strongest productivity-compensation case. Its cow population fell by 27.4%, but a 33.8% yield gain offset 91.1% of the negative herd effect, leaving production only 2.9% lower. By contrast, the Southwest experienced a 71.3% production decline because a very large herd contraction was accompanied by almost no endpoint productivity gain.

Table 3. Regional change and symmetric decomposition, 2016-2025

Region	ΔN	ΔY*	ΔP	Compensation
Vardar	(38.5)	+26.5	(22.2)	49.1
East	(44.2)	+23.1	(31.3)	36.5
Southwest	(71.5)	+0.8	(71.3)	0.7
Southeast	+91.0	(44.4)	+6.2	n.a.
Pelagonia	(50.3)	+22.9	(38.9)	30.6
Polog	(27.4)	+33.8	(2.9)	91.1
Northeast	(52.5)	+36.2	(35.2)	43.1
Skopje	(39.7)	+32.5	(20.1)	56.4

Note: All change and compensation values are percentages. Parentheses indicate declines; n.a. means the compensation condition is not met. Detailed effects are shown in Fig. 2.

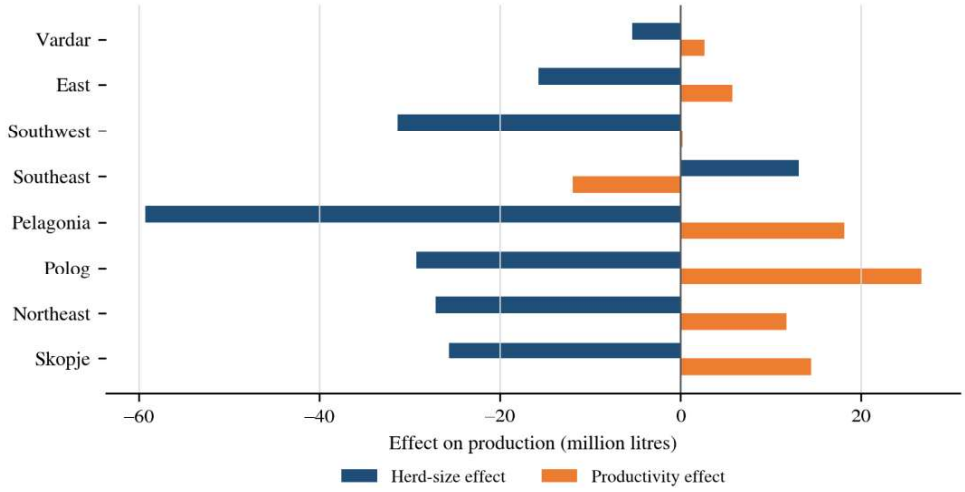


Figure 2. Regional herd-size and productivity effects
Source: Authors' calculations based on State Statistical Office MAKSTAT data.

Pelagonia accounted for 36.4% of the national decline, followed by the Southwest (27.5%), Northeast (13.7%), Skopje (9.9%), and East (8.8%). The Southeast had a contribution of -1.0% because its production increase partly moderated the national fall. The regional results show why policy cannot focus on

animal numbers alone: in the Southeast, herd expansion without productivity maintenance generated little output growth, while in Polog productivity almost neutralised contraction.

3.3 Concentration, dispersion, renewal, and robustness

HHI increased from 0.172 in 2016 to 0.190 in 2025, and CR3 from 62.7% to 68.2%. These endpoint comparisons indicate greater concentration, but the annual path was not monotonic: HHI peaked at 0.218 in 2020 and CR3 at 73.0% in 2022. Regional productivity dispersion was also higher at the end of the period. The coefficient of variation rose from 14.1% to 27.6%, but reached its maximum of 34.4% in 2023. Concentration and productivity differences were higher in 2025 than in 2016, but varied from year to year.

The national renewal proxy declined from 11.1 to 7.1 in-calf heifers per 100 dairy cows over two years, a fall of 36.5%. This reinforces the evidence of a weakening production base, although the indicator does not cover all reproductive, culling, and management flows.

Table 4. Robustness and structural checks

Check	Result	Interpretation
Alternative endpoint: 2016-2024	35.1% compensation	Herd effect remains dominant
Alternative start: 2017-2025	43.3% compensation	Largest offset, still incomplete
Alternative start: 2018-2025	32.5% compensation	Consistent with baseline
Three-year averages	26.0% compensation	Most stable additional check
National vs regional endpoints	34.1% vs 37.4%	Different allocation, same net change
National vs regional dynamic	31.9% vs 31.5%	Very close cumulative result

Source: Authors' robustness calculations. Net changes reconcile within 1-2 thousand litres due to official rounding.

All alternative periods lead to the same conclusion: the decline in the number of dairy cows is the dominant negative factor. The magnitude and, for the 2016-2023 endpoint, even the direction of the productivity effect depend on the selected final year; three-year averages therefore provide a more stable sensitivity check. National and regionally summed decompositions allocate the two effects differently because aggregate yield also reflects changes in regional production weights. This is an aggregation effect, not a computational error, since the net production change is preserved.

4. Discussion and economic policy implications

The results show that the dairy sector is producing more milk per cow but losing cows faster than productivity can offset. This is structurally different from simultaneous decline in herd size and yield: technical improvement is present, yet it is not sufficient to stabilise aggregate production. From an economic

perspective, the result points to a weakening domestic supply base, with potential consequences for farm viability and processing capacity utilisation. The result is consistent with international studies in which productivity gains coexist with declining animal numbers and with a redistribution of production toward a smaller number of locations (Bender Filho et al., 2023; de Oliveira et al., 2024).

Regional heterogeneity is the most policy-relevant result. Polog demonstrates that strong productivity growth can substantially reduce the output consequences of herd contraction. The Southeast demonstrates the reverse: increasing the number of cows has limited value when output per animal deteriorates sharply. Support measures should therefore be differentiated and economically targeted. Regions dominated by herd loss require retention, replacement, and entry incentives, together with access to investment finance, while regions with expanding herds but weak yield require productivity-enhancing investments in nutrition, health, genetics, housing, and day-to-day management.

Greater regional concentration can bring both benefits and risks. Spatial specialisation may support processing linkages, specialised services, and economies of scale. At the same time, greater dependence on a limited number of regions can increase exposure to local climatic, animal-health, feed-price, or market shocks. The higher coefficient of variation further indicates that national average productivity gains have not produced regional convergence. A national programme based on uniform productivity targets would therefore overlook very different starting positions and constraints.

The analysis also highlights data priorities. Better information is needed on farm numbers and size classes, breeds, lactation structure, culling, reproduction, feeding systems, milk quality, purchase prices, subsidies, and production costs. Linking such information to farm-level technology adoption would allow future studies to move from accounting decomposition toward causal analysis. With the current aggregate data, the analysis shows how much of the change is linked to herd size and milk yield, but it cannot explain how farms respond to prices, subsidies, or other incentives.

5. Conclusion

From 2016 to 2025, Macedonia lost 39.1% of its dairy cows, while milk yield per cow increased by 18.1%. Total cow milk production consequently declined by 28.1%. The symmetric decomposition shows that the negative herd-size effect reached 171.8 million litres and was offset by a positive productivity effect of 58.6 million litres. Compensation of 34.1%, confirmed by the dynamic and robustness results, was economically important but insufficient.

The regions showed different patterns of change in herd size and productivity. Polog achieved near-complete productivity compensation, while the Southeast expanded its herd but experienced a severe fall in yield. Pelagonia and the Southwest contributed most to the national decline. Concentration and

regional productivity differences were higher in 2025 than in 2016, although both indicators fluctuated substantially during the period. The economic implication is clear: productivity improvements can partly offset the production losses caused by herd decline, but they cannot indefinitely replace a shrinking and weakly renewed production base. Sustainable recovery requires coordinated incentives for herd retention and replacement, productivity-enhancing investment, and region-specific measures that reflect different structural constraints.

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