



ANALYSIS OF THE AGRICULTURAL PRODUCTION MANAGEMENT IN THE WEST OF PARANÁ STATE-BRAZIL: AN APPLICATION OF THE GENERALIZED ADDITIVE MODEL FOR LOCATION, SCALE AND SHAPE (GAMLSS)

**ANALISE DA GESTÃO DA PRODUÇÃO AGROPECUÁRIA DO OESTE
DO PARANÁ-BRASIL: UMA APLICAÇÃO DO MODELO ADITIVO
GENERALIZADO PARA LOCAÇÃO ESCALA E FORMA (GAMLSS)**

ANALYSIS OF THE AGRICULTURAL PRODUCTION MANAGEMENT IN THE WEST OF PARANÁ STATE-BRAZIL: AN APPLICATION OF THE GENERALIZED ADDITIVE MODEL FOR LOCATION, SCALE AND SHAPE (GAMLSS)

ANALISE DA GESTÃO DA PRODUÇÃO AGROPECUÁRIA DO OESTE DO PARANÁ-BRASIL: UMA APLICAÇÃO DO MODELO ADITIVO GENERALIZADO PARA LOCAÇÃO ESCALA E FORMA (GAMLSS)

Elizabeth Giron Cima¹ | Márcio Paulo Oliveira²
Miguel Angel Uribe-Opazo³ | Weimar Freire Rocha-Junior⁴

Received: 03/29/2026
Accepted: 08/11/2025

¹ PhD in Agricultural Engineering (UNIOESTE).
Professor at the FAG University Center.
Cascavel - PR, Brazil.
E-mail: elizabeth.cima@fag.edu.br

³ PhD in Statistics (USP).
Professor at the University of Western Paraná.
Cascavel - PR, Brazil.
E-mail: mopazo@unioeste.br

² PhD in Agricultural Engineering (UNIOESTE).
Professor at the Federal Technological University of Paraná. Toledo - PR, Brazil.
E-mail: marcioliveira@utfpr.edu.br

⁴ PhD in Production Engineering (UFSC).
Professor at the University of Western Paraná. Toledo - PR, Brazil.
E-mail: weimar.junior@unioeste.br

ABSTRACT

The gross value of agricultural production is of fundamental importance for strategic decisions in the agro-industrial sector. The objective of this work was to study the contribution of pig production, poultry production, soybean production, milk production, corn production and soybean production in the gross value of agricultural production using the generalized additive model for location, scale and form (GAMLSS). GAMLSS was described and characterized for the municipalities of the West of Paraná State, Brazil. The dependent variable Gross value of agricultural production from the years 2018 to 2022 and the independent variables included livestock production (poultry, pigs and milk) and agricultural production (crop and soybean) from the harvest years 2018/2019, 2019/2020, 2020/2021, 2021/2022 and 2022/2023. The data were obtained from the *Instituto Paranaense de Desenvolvimento Econômico e Social e Secretaria da Agricultura e do Abastecimento*. The results showed significant adjustments of the gross value of agricultural production for the location, scale and form parameters in relation to agricultural and livestock production in the years under study. The models showed a significant contribution of poultry, soybean, pig, milk and crop production in the location parameter from 2018 to 2022. Economically the results revealed that the West region of Paraná is motivated in relation to the development of Agribusiness since it contributes to the gross value of production promoting the growth and development of the region under study.

Keywords: Agribusiness. Agricultural production. Business strategy. Continuous distribution on the positive real line. Flexible regression.

RESUMO

O valor bruto da produção agropecuária é de fundamental importância para decisões estratégicas no setor agroindustrial. O objetivo deste trabalho foi estudar a contribuição da produção de suínos, produção de aves, produção soja, produção de leite, produção de milho e produção de soja no valor bruto da produção agropecuária utilizando o modelo aditivo generalizado para locação, escala e forma (GAMLSS). O GAMLSS foi descrito e caracterizado para os municípios do Oeste do Paraná-Brasil, utilizando a variável dependente valor bruto da produção agropecuária dos anos 2018 a 2022 e as variáveis independentes de produção pecuária (aves, suínos e leite) e produção agrícola (milho e soja) dos anos-safra 2018/2019, 2019/2020, 2020/2021, 2021/2022 e 2022/2023. Os dados foram obtidos do Instituto Paranaense de Desenvolvimento Econômico e Social e Secretaria da Agricultura e do Abastecimento. Os resultados mostraram ajustes significativos do valor bruto da produção agropecuária para os parâmetros de locação, escala e forma em relação à produção agrícola e pecuária nos anos em estudo. Os modelos mostraram contribuição significativa da produção de aves, soja, suíno, leite e milho no parâmetro de locação nos anos de 2018 a 2022. Economicamente os resultados revelaram que região Oeste do Paraná é motivada em relação ao desenvolvimento do Agronegócio já que o mesmo contribui para o valor bruto da produção promovendo o crescimento e desenvolvimento da região em estudo.

Palavras-chave: Agronegócio. Produção agrícola. Estratégia empresarial. Distribuição contínua na linha real positiva. Regressão flexível.

INTRODUCTION

Agribusiness is a highly decisive and strategic sector in the economic and agricultural activities, because it is representative for the population food supply, thus generating revenues, employability and foreign exchange, which promotes the growth and development of the economic system and society. In the view of the current economic situation of the world, the study shows the scope of its application and its understanding is relevant in the management of decision-making in different areas of internalized economy (Soumitra, 2020; Cima et al., 2023; Cima et al., 2024).

The development of the agricultural and livestock sector considering the gross value of agricultural production depends on decision-making management, emphasized by strategic objectives to ensure a more favorable agricultural production for the growth and development of rural property and processing industry, namely: Cooperatives and Agroindustries (Zsarnóczai; Zéman, 2019; Oliveira et al., 2025). Thus, the scientific literature allows readers and researchers a broad analysis that leads them to understand that there are numerous studies on the challenges of the management of supply chains and supply chain of agricultural production in the different studies, including regions, countries, companies of various property categories and scale production level (Ableeva et al., 2019).



It is observed that the decision-making guided by data management is necessary, as it is the case of the use of methods and estimators of various types of efficiency guided by data management. Currently, a qualitative and quantitative comparative analysis of agro-industrial efficiency and performance needs greater clarity in the information. This is essential for evaluating various types of sustainable agricultural production and environmentally safe production systems, since sustainability is a necessary requirement for these production ecosystems to deliver products and services within the expected quality, as reported by Cima et al. (2021); Cima et al. (2022); Oliveira et al. (2025).

In this analytical perspective, Ferrera de Lima and Desbiens (2000) argue with logical clarity that there is a necessary association between quantitative data and qualitative analysis for a sufficient understanding for decision making considering a strategic breadth of regional development, that guides the purposes of the study objectives. In this sense, the need for clear database initiatives is observed by types of economic activity, including agriculture and livestock (Ableeva et al., 2019), which are relevant for the analysis of public policies aimed at raising resources for this sector. Thus, the *generalized additive models for location scale and shape* (GAMLSS) has been widely used in a wide variety of different areas of knowledge, among them: Economy, biosciences, food production, agrarian among others (Rigby and Stasinopoulos, 2005; De Bastiani et al., 2016).

Relevant studies already carried out showed the importance of this class of models in spatial data analyzes, which corroborate (Stasinopoulos et al., 2017; Zylowski and Korzyra, 2023). The GAMLSS model is a general structure characterized by univariate regression, in which it refers to a single dependent variable, although it may present many explanatory variables. Thus, it is observed that the behavior of the explained variable depends on the predictive variables (independent). This dependence can be linear, nonlinear or non-parametric (Stasinopoulos et al., 2018).

Darmawan et al. (2019) reported that using this model class, found that it is appropriate to investigate agricultural production and that it represented efficiently the study carried out. Villarini et al. (2016) studied and evaluated the GAMLSS model in soybean crop and identified its importance and efficiency in the results obtained. In this sense, the GAMLSS model class allows the adjustment of models with flexible characteristics that accept any distribution for the variable explained, independent, of belonging to some family of distributions, as reported by Rigby and Stasinopoulos (2005).

It is also verified that through GAMLSS, the distribution measures are modeled, named: location, scale and shape of the dependent variable distribution. These measures according to the predictive variables can incorporate non-parametric smoothing functions, random effects, or other additive terms. The objective of this work was to study the contribution of pig production, poultry production, soybean production, milk production, corn production and soybean production in the gross value of agricultural production using the GAMLSS model. This modeling of the agricultural scenario in the western region of Paraná State is necessary and important to increase the knowledge of the influences that the gross value of agricultural production (VBP) receives from different sectors of the economy.

INTEGRATION OF DATA MANAGEMENT IN DECISION-MAKING IN THE AGRICULTURAL SECTOR

It can be considered a strategic trend, the integration of data in ecosystems that cover agribusiness, this practice allows the optimization of more efficient productive operations both in handling and in management, thus this process ensures the optimization of agricultural operations and allows the adoption of more efficient strategies (Gamage et al., 2024). The vision of strategic integration allows us to unify the junction among people, machines and data by integrating innovation in real time, resulting in more sustainable and agile deliveries which promotes the profitability of the agricultural sector (Dharmananda et al., 2024).

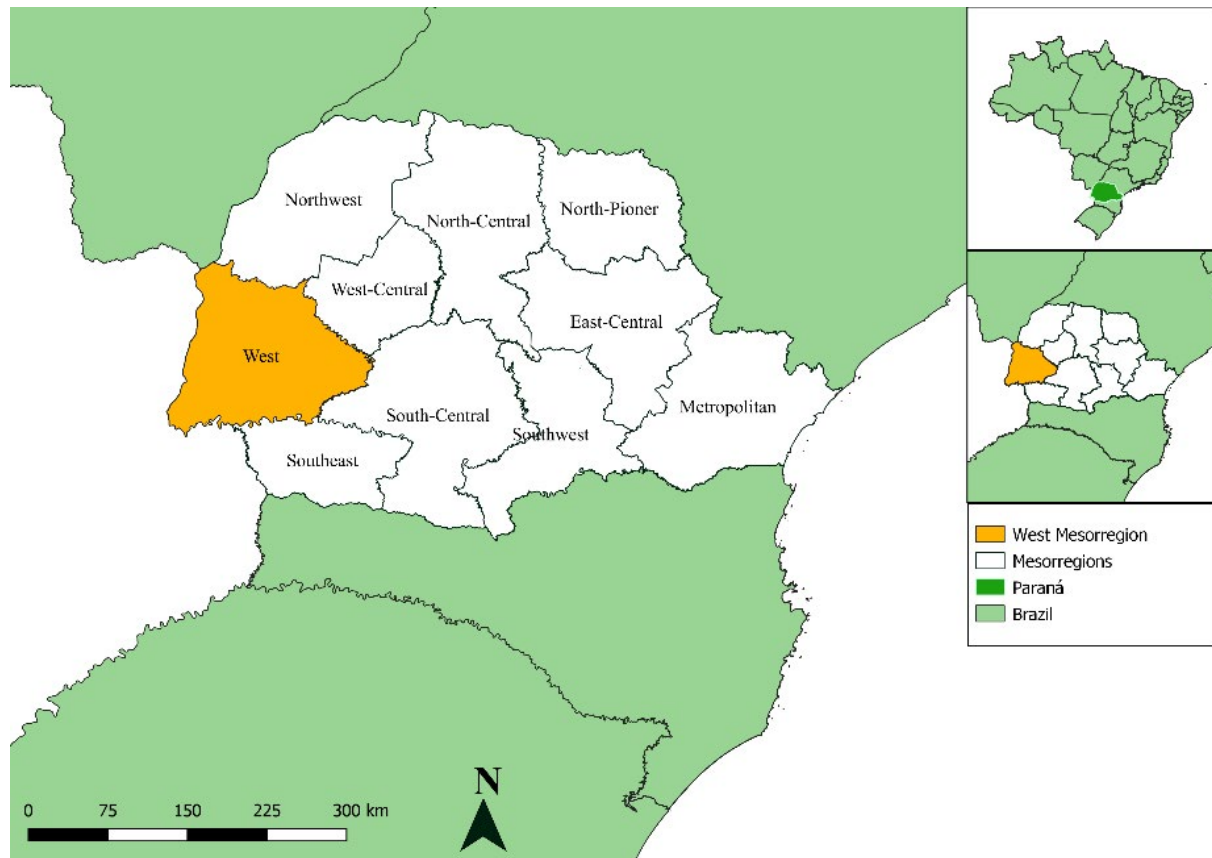
The Integration of data management-driven decision-making which involves all the links of the productive sectors is necessary to meet the high demands of productivity demanded by the markets (Weraikat et al., 2024).

MATERIAL AND METHODS

The methodology employed was a qualitative and quantitative approach aimed at analyzing a real scenario that involves agricultural and livestock production in the West of Paraná State-Brazil. Figure 1 presents the municipalities, which make up the study area in the state of Paraná. Economic data from the years 2018 to 2022 of the variables were used: Livestock production [quantity/head], gross value of agricultural production [R\$], milk production [thousand/l], corn production and soybean production [t] of the 2018/2019, 2019/2020, 2020/2021, 2021/2022 and 2022/2023.



Figure 1 | Location of the study area



Source: Prepared by the Authors.

The Generalized Additive Model for Location, Scale and Shape (GAMLSS) in its general form is flexible to model the gross value of agricultural production (VBP), since it allows to incorporate the contribution of explanatory variables may include location, scale and shape parameters, it allows to improve the understanding of an agricultural scenario and identify problems that influence the production. In the models for the location parameters, scale and shape, it is possible to evaluate the contribution of the covariates poultry, soybean, pigs, milk and corn in the VBP. GMLSS assumes that variable of interest $Y_i, i = 1, 2, \dots, n$ they are independent observations (Rigby and Stasinopoulos, 2005). Equation (1) presents the general form of the probability distribution of a GAMLSS model with three parameters (μ, σ, ν) :

$$Y \sim D(\mu, \sigma, \nu) \quad (1)$$

where Y is the response variable (VBP), $D(\cdot)$ represents the chosen probability distribution, and μ , σ and ν are, respectively, the location, scale and shape parameters, unknown. Each parameter θ_k ($\theta_1 = \mu$, $\theta_2 = \sigma$ and $\theta_3 = \nu$) is modeled by means of a connection function $g_k(\cdot)$ as follows:

$$g_k(\theta_k) = \mathbf{X}_k \boldsymbol{\beta}_k + \sum_{j=1}^{J_k} h_{jk}(x_{jk}), \quad k = 1, 2, 3 \quad (2)$$

where $\mathbf{X}_k$ is the covariate matrix associated with the parameter k , $\boldsymbol{\beta}_k = (\beta_{1k}, \dots, \beta_{jk})^T$ is the vector of the unknown coefficients of the parametric part, $h_{jk}(\cdot)$ represents soft non-parametric functions applied to covariables x_{jk} and J_k is the number of non-parametric terms included in the model for the parameter k . The models for the present study can be formulated from equation (3)-(5), considering linear effect on covariables, without supportable non- $h_{jk}(\cdot)$ parametric functions, as follows:

$$\hat{\mu}_{year_i} = \beta_{10} + \beta_{11}poultry_{year_i} + \beta_{12}soybean_{year_i} + \beta_{13}pigs_{year_i} + \beta_{14}milk_{year_i} + \beta_{15}corn_{year_i} \quad (3)$$

$$\hat{\sigma}_{i_{year_i}} = \beta_{20} + \beta_{21}poultry_{year_i} + \beta_{22}soybean_{year_i} + \beta_{23}pigs_{year_i} + \beta_{24}milk_{year_i} + \beta_{25}corn_{year_i} \quad (4)$$

$$\hat{\nu}_{i_{year_i}} = \beta_{30} + \beta_{31}poultry_{year_i} + \beta_{32}soybean_{year_i} + \beta_{33}pigs_{year_i} + \beta_{34}milk_{year_i} + \beta_{35}corn_{year_i} \quad (5)$$

where $i = 1, 2, \dots, n$, $\hat{\mu}_i$ the model for the location parameter, $\hat{\sigma}_i$ the model for the scale parameter, and $\hat{\nu}_i$ the model for the shape parameter. The called Generalized Akaike Information Criterion (GAIC) was used for the selection of models from 2018 to 2022, obtained by combinations of components. GAIC is calculated according to equation (6):

$$GAIC(\alpha) = GD + \alpha * df \quad (6)$$

where, $\widehat{GD}$: represents the adjusted global deviation given by $-2\hat{l}$ (is the logarithm of the likelihood function evaluated in the estimated parameters); df : indicates the degree of effective freedom in the proposed model; α : denotes the penalty applied to each degree of freedom. The Schwarz Bayesian Criterion (SBC) is obtained for model selection as defined by to Rigby and Stasinopoulos (2005).

The charts using the `termplot` function for the location parameters μ , scale σ and shape ν for VBP in the years 2018 to 2022 allow to analyze the terms of regression in relation to its predictors, with standard errors and partial residues (Stasinopoulos et al., 2017). To evaluate the quality of the adjustment of the models for the *worm* plot (Buuren and Fredriks, 2001) were used. The problem of the relationship of VBP with dependent variables poultry, soybean, pig, milk and corn was analyzed with the free software R (Development Core Team, 2025), through packages such as *gamlss* and *gamlss.dist*.

RESULTS AND DISCUSSION

The models for the gross value of agricultural production (VBP) were adjusted for the years 2018 to 2022 considering the variables poultry production (*POULTRIES*), soybean (*SOYBEAN*) production, pig production (*PIG*), milk production and corn production (*CORN*), logarithmic processing being used. Estimates with the standard VBP error for the location parameter μ are shown in Table 2, for the scale parameter σ in Table 3 and for the shape parameter ν in Table 4. The models for the parameter μ indicated that the explanatory variables were significant, with positive contributions from 2020 to 2022. The study of the contribution of each variable in the GAMLSS model allows to generate important information related to the agricultural sector for decision-making (Lima-Costa et al., 2020).

It is seen that in the adjustment of the model of the gross value of agricultural production (VBP) of the year 2018, the descriptive level p-value for all the covariables selected in the μ parameter was lower than 5% of significance (Table 1). This indicated that the production of poultry, soybean production, pig production and milk and corn production were significant in relation to the gross value of agricultural production, for the municipalities that make up the western region of Paraná State-Brazil.

Ribeiro et al. (2020) analyzed soybean production in the state of Rio Grande do Sul using the GAMLSS regression model in the year-harvest 2017/2018 and concluded that the production forecast was significant for that year-harvest. They inform that the GAMLSS model can be more accurate than linear regression to model data related to soybean production, constituting a reliable and useful source to assist farmers and managers of the economic sector in their decisions and planning of agricultural crops.

The significance of the covariates under study to explain the μ parameter in relation to the gross value of agricultural production, indicates that in the West region state of Paraná State the livestock production effective exerted influence on the agricultural VBP in the years from 2018 to 2022.

Table 1 | Models estimated with generalized gamma distribution (GG), adjustment for the location parameter μ in the years from 2018 to 2022

Location parameter $\hat{\mu}$		Parameter estimates β_{ij} , standard error (in parentheses) and p-value for $i=1,...,n; j=1,...,5$				
Parameters		2018	2019	2020	2021	2022
$\hat{\mu}$	Intercept	2.523 (0.004) 0.000*	2.587 (0.003) 0.000*	2.559 (2.559) 0.000*	2.531 (0.005) 0.000*	2.523 (0.004) 0.000*
	ln(POULTRIES)	0.007 (0.0003) 0.000*	0.007 (0.0003) 0.000*	0.005 (0.005) 0.000*	0.006 (0.0003) 0.000*	0.007 (0.0002) 0.000*
	ln(SOYBEAN)	0.032 (0.001) 0.000*	0.020 (0.001) 0.000*	0.015 (0.015) 0.000*	0.021 (0.001) 0.000*	0.008 (0.0005) 0.000*
	ln(PIGS)	0.007 (0.0003) 0.000*	0.011 (0.0003) 0.000*	0.006 (0.006) 0.000*	0.004 (0.0002) 0.000*	0.006 (0.0003) 0.000*
	ln(MILK)	-0.002 (0.001) 0.001*	-0.004 (0.0005) 0.000*	0.010 (0.010) 0.000*	0.010 (0.0004) 0.000*	0.008 (0.001) 0.000*
	ln(CORN)	-0.005 (0.001) 0.000*	0.000 (0.001) 0.000ns	0.005 (0.005) 0.000*	0.003 (0.001) 0.001*	0.015 (0.0003) 0.000*

Note: *: significant at 5% odds; ns: not significant.

Source: Prepared by the Authors.



The models for the parameter σ indicated that the explanatory variables were significant, to explain the variability in the scale Table 2. For the year 2021 only the variable pig production and the intercept of the model were significant, but already in 2022 the production of poultry, pigs and milk were significant to explain this parameter, indicating that the scenario under analysis presents high variability. It was also observed the presence of significant influence in most of the studied covariables considering the σ parameter in relation to the gross value of agricultural production. This behavior demonstrates that in the West region of Paraná state the livestock production effective exerted influence on the gross value of agricultural production in the years from 2018 to 2022. Hernandez et al. (2015) when analyzing the GAMLSS model in agro-industrial processes, observed the relevance of the model in the results found, suggest that the results can be used in decision making in the agro-industrial transformation industry. The results are justified by the fact that the significant participation of the West region in agricultural production in the state of Paraná (SEAB, 2023). Strategically, it is observed through the results found, specifically for the production of pigs, that was significant in the years 2018 to 2022 and the soybean production significant in the years 2019 and 2020. The importance of these productive sectors in the participation of the gross value of agricultural production in the West of Paraná State is evident. This information is economically decisive, necessary and important because they allow to show the reality of the political, economic scenario and the agro-industrial trends, thus showing the productive potential of the agricultural sector, showing the relevance of the use of the GAMLSS model applied in agricultural data, according to Darmawan et al. (2019).

Still considering the sigma distribution parameter(σ) it is possible to identify the significance in explaining that such parameter may change over the years as it occurred with corn, significant in 2018 and 2020 and not significant in the years 2019, 2021 and 2022. These results indicate that production management should be carried out in order to create conditions that favor the development and maintenance of productive sectors. Thus, it is important to identify the important variables to explain the variation in the response variable, gross value of agricultural production in the years 2018 to 2022, through the coefficients in the models for the parameters (Stasinopoulos et al., 2017).

Table 2 | Models estimated with generalized gamma distribution (GG), adjustment for the scale parameter σ of VBP in the years from 2018 to 2022

Scale parameter $\hat{\sigma}$		Parameter estimates β_{ij} , standard error (in parentheses) and p-values for $i=1,...,n$; $j=1,...,5$				
Parameters	2018	2019	2020	2021	2022	
Intercept	-9.899	-10.038	-9.984	-9.881	-10.75	
	(1.455)	(0.979)	(1.055)	(1.085)	(1.106)	
	0.000*	0.000*	0.000*	0.000*	0.000*	
ln(POULTRIES)	0.311	-0.039	0.16	0.14	0.402	
	(0.090)	(0.097)	(0.093)	(0.095)	(0.096)	
	0.001*	0.689ns	0.090ns	0.146ns	0.000*	
ln(SOYBEAN)	-0.101	0.501	0.822	0.032	-0.035	
	(0.162)	(0.172)	(0.306)	(0.247)	(0.103)	
	0.539ns	0.006*	0.010*	0.897ns	0.732ns	
ln(PIGS)	0.278	0.230	0.157	0.129	0.199	
	(0.060)	(0.071)	(0.065)	(0.056)	(0.059)	
	0.000*	0.002*	0.020*	0.026*	0.002*	
ln(MILK)	-0.166	-0.322	-0.278	-0.003	-0.264	
	(0.100)	(0.104)	(0.117)	(0.106)	(0.107)	
	0.104ns	0.003*	0.022*	0.975ns	0.017*	
ln(CORN)	-0.005	-0.012	-0.560	0.045	0.000	
	(-0.00001)	(0.152)	(0.246)	(0.211)	(0.000)	
	0.001*	0.938ns	0.028*	0.832ns	0.129ns	

Note: *: significant at 5% odds; ns: not significant.

Source: Prepared by the Authors.

Table 3 observes that for the distribution parameter shape (ν) the value of asymmetry was not significant for corn production for the years 2018 and 2021, and this result may be justified by adverse conditions occurring in the period such as: climatic conditions, production costs or even migration from rural producers to other types of agricultural activity.

Table 3 | Models estimated with generalized gamma distribution (GG), adjustment for the shape parameter $\hat{\nu}$ of VBP in the years from 2018 to 2022

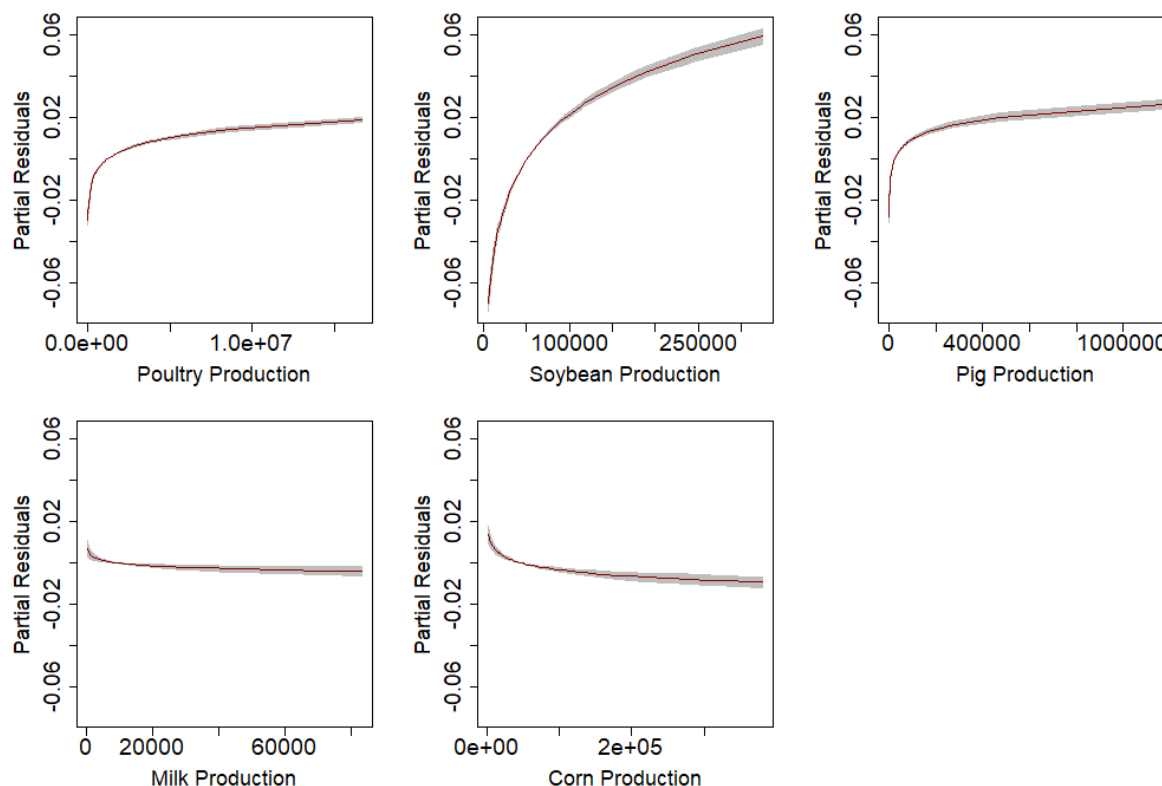
Shape parameter $\hat{\nu}$		Parameter estimates β_{ij} , standard error (in parentheses) and p-value for $i=1,...,n; j=1,...,5$				
Parameters		2018	2019	2020	2021	2022
$\hat{\nu}$	Intercept	2632.60 (1415.56) 0.070ns	-4486.2 (2526.6) 0.083ns	5764.9 (1190.9) 0.000*	2046.05 (1185.37) 0.091ns	6103.7 (1617.7) 0.000*
	ln(POULTRIES)	-684.9 (175.22) 0.000*	-1383.8 (286.7) 0.000*	-342.4 (126.6) 0.010*	-542.44 (175.22) 0.003*	-798.8 (216.4) 0.001*
	ln(SOYBEAN)	1404.86 (252.18) 0.000*	3673 (571.8) 0.000*	-1558.1 (387.4) 0.000*	760.90 (307.88) 0.017*	427.0 (144.5) 0.005*
	ln(PIGS)	-450.19 (97.70) 0.000*	1770.1 (283.3) 0.000*	-497.8 (103.1) 0.000*	-436.61 (80.95) 0.000*	-740.6 (132.8) 0.000*
	ln(MILK)	-248.84 (107.24) 0.025*	-2149.8 (360.8) 0.000*	1296.0 (225.7) 0.000*	526.26 (121.01) 0.000*	595.5 (142.3) 0.000*
	ln(CORN)	-49.31 (148.24) 0.741ns	-1383.5 (308.6) 0.000*	896.8 (278.2) 0.002*	-230.86 (227.13) 0.315ns	405.3 (174.7) 0.025*

Note: *: significant at 5% odds; ns: not significant.

Source: Prepared by the Authors.

In Figure 2 the smoothing termplot chart (Rigby and Stasinopoulos, 2005) shows the behavior for the distribution of the location parameter μ of the gross value of agricultural production of the year 2018. In Figures 2(A)-(B) and (C), it is visible a growing linear behavior for the production of poultry, soybean and pigs, this is the relationship between the gross value of agricultural production with the mentioned productions was increasing respectively. In comparison, milk and corn productions Figures 2(D)-(E), there was a decreasing behavior, indicating a variation in relation to the response variable (gross value of agricultural production), and the model was capable of adjusting functions to represent these variations. This data spatial behavior reveals the profile of production in the analyzed period and suggests that these differences may be related to economic, climatic and seasonal factors.

Figure 2 | Smoothing termplo chart of location parameter μ for the gross value of agricultural production of the year 2018.

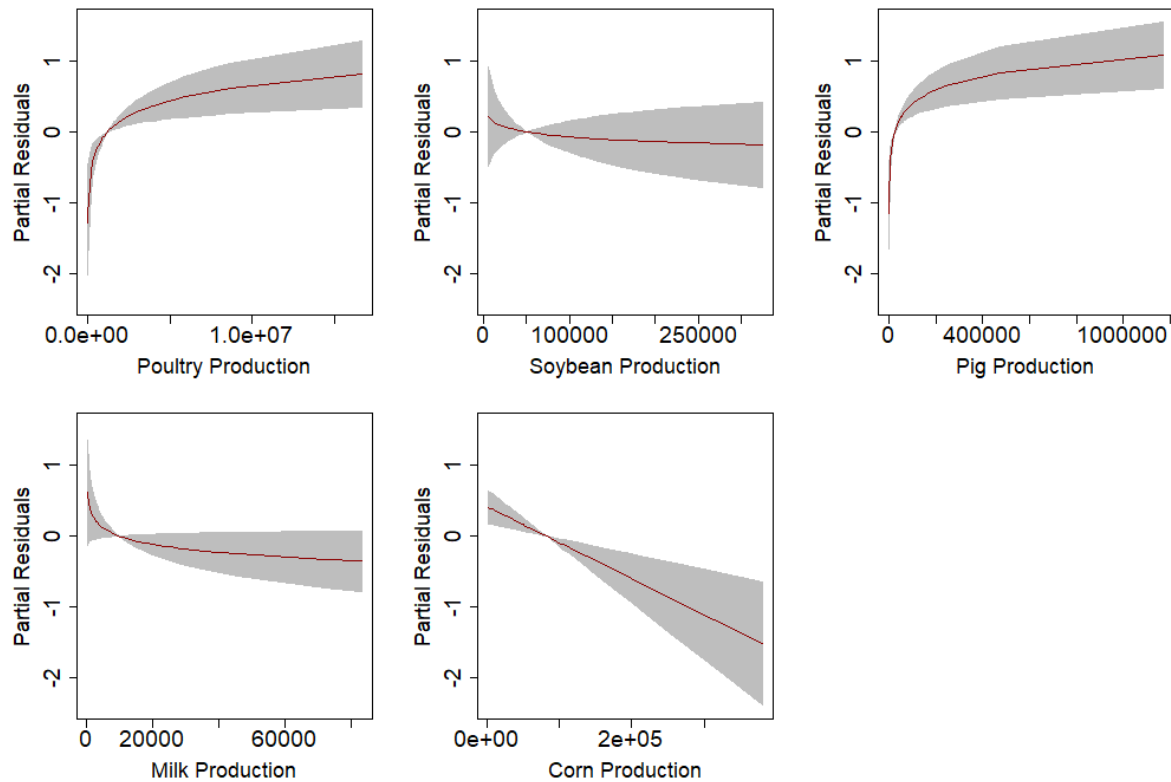


Source: Prepared by the Authors.

Through the smoothing termplo charts of the scale parameter σ for the gross value of agricultural production of the year 2018 (Figure 3) the chart showed an increasing linear behavior of the coefficient of variation of poultry and swine production Figures 3(A) and 3(C). For soybean, milk and corn production Figure 3(B) and Figures 3(D)-(E) the chart shows a decreasing linear behavior for the coefficient of variation of the year 2018.

According to Embrapa (2019), these results are justified by the fact that the year 2018 was marked by the deceleration of soybean, milk and corn production. According to the same source the factors that contributed to this decline was the increase in costs involving the sector amount of the economy, that is, agricultural inputs, another decisive factor was the low grain production in Argentina and the reduction of corn production in Brazil.

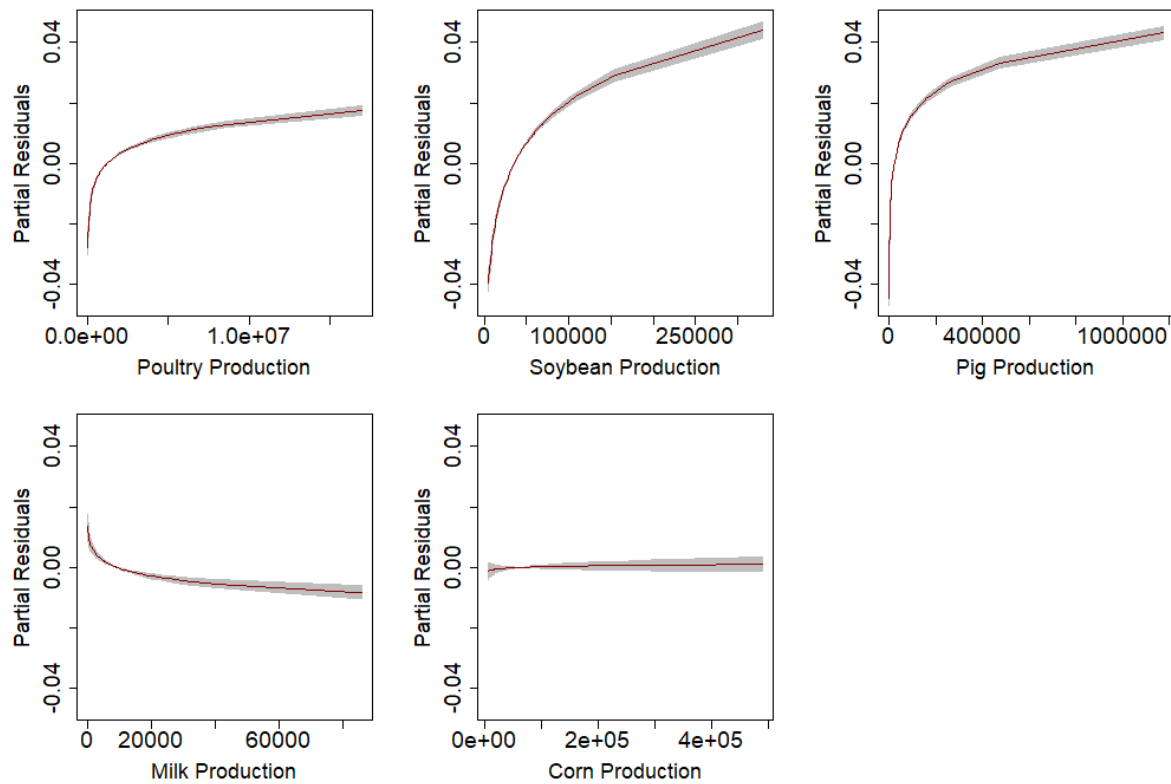
Figure 3 | Smoothing termplot charts of scale parameter σ for the Gross Value of Agricultural production of the year 2018



Source: Prepared by the Authors.

Figure 4(A)-(C) shows an increasing linear behavior among poultry, soybean and pig production and the means (μ) of the Gross Value of Agricultural Production (VBPA) in 2019. It is observed that as the production of these commodities increases, there is a positive and progressive contribution to the VBPA. On the other hand, milk production, represented in Figure 4(E), shows a decrease trend. This result may be associated, as pointed out by SEAB (2019) to an increase in input costs, which negatively impacted the profitability margin of milk production and, consequently, reduced the marketing price of this product in the market.

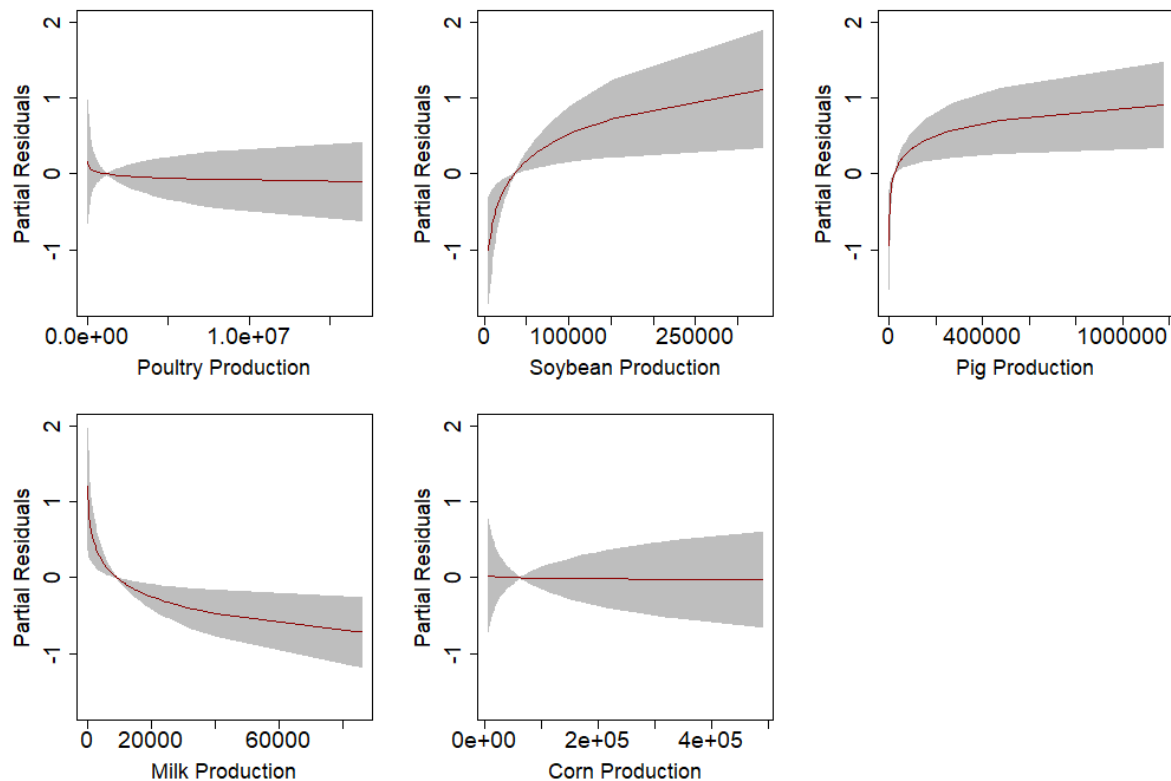
Figure 4 | Termplot charts of location parameter μ for the Gross Value of Agricultural production of the year 2019



Source: Prepared by the Authors.

Figure 5 shows the smoothing charts related to the dispersion distribution (σ), showing the behavior of the coefficient of variation for each production variable analyzed. It is observed that the poultry and corn production (Figures 5A and 5E) presents a constant linear trend, indicating relative stability in the variability of these productions throughout the series. In contrast, soybean and pig production (Figures 5B and 5C) shows increasing linear behavior, suggesting increased variability as the volume produced grows. Milk production (Figure 5D) shows a decreasing linear trend, which indicates a reduction in variability associated with higher production levels.

Figure 5 | Termpilot charts of scale parameter σ for the Gross Value of Agricultural production of the year 2019

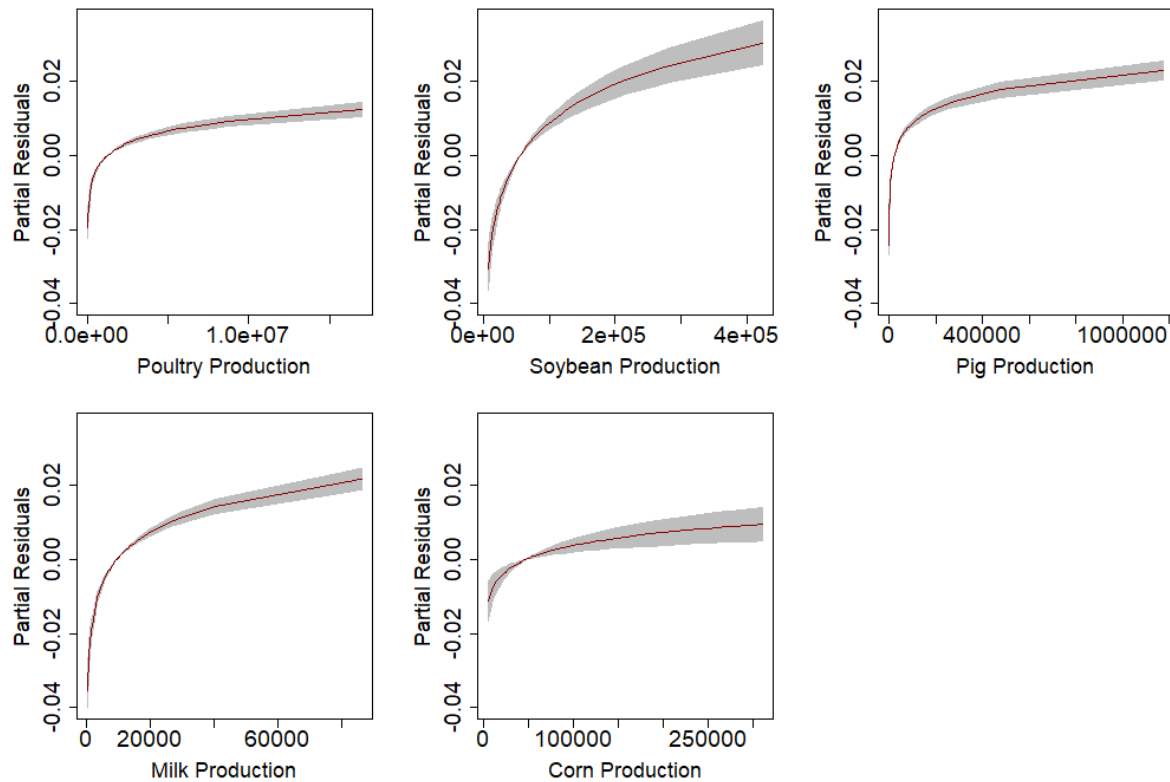


Source: Prepared by the Authors.

Figure 6 shows the termpilot chart for the μ distribution of the gross value of agricultural production of the year 2020. In figure 6 (A) – (E) where the termpLOTS for the distribution of μ are shown, for the variables poultry production and milk production it is possible to observe a growing linear behavior for the μ distribution of the gross value of agricultural production of the year 2020. For soybean production it is possible to identify an expressive growing behavior, which is also observed by the pigs production. Corn production showed a behavior close to linear, according to the results shown in Figures 6(A) – (E) for the year 2020.

These results are justified, according to Embrapa (2021) and Globo Rural (2021) where the production of soybean, milk and poultry was increasing in 2020, and the chicken processing agro-industry showed an increase of 3.3% compared to the year 2019. The same scenario was visible in milk production in which there was an expressive increase in relation to previous years. In addition, soybean production was also favorable in the analyzed period.

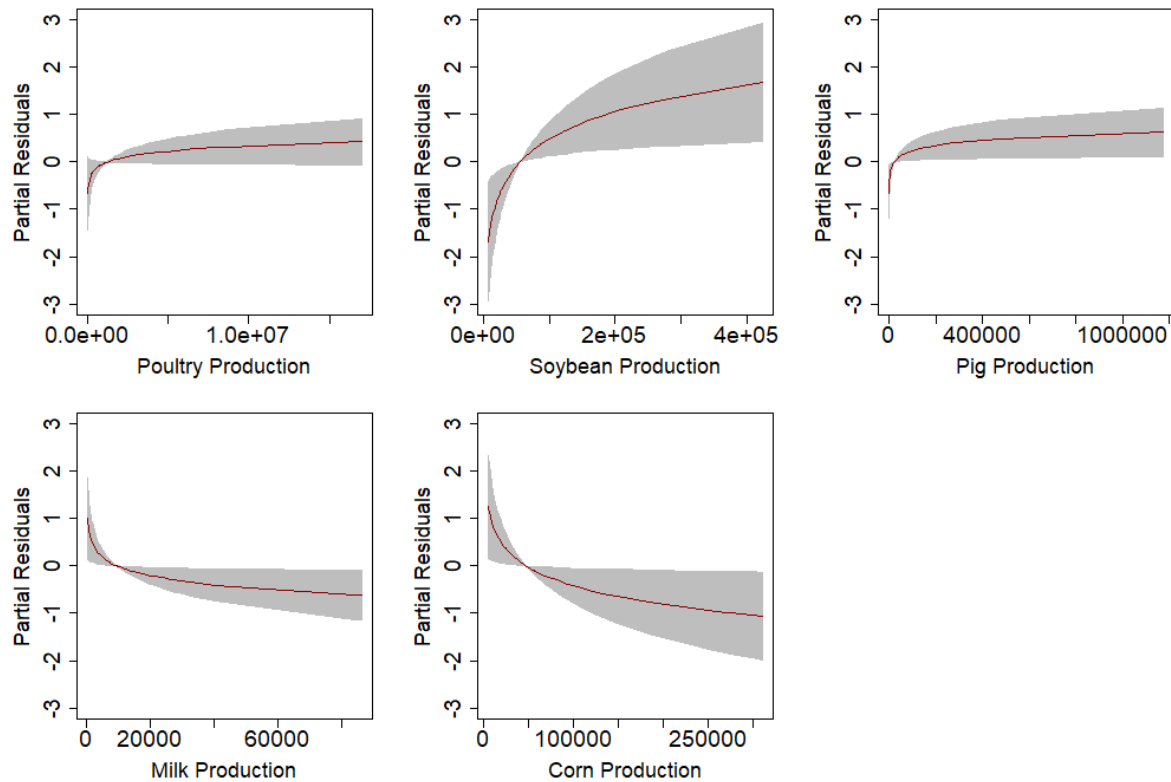
Figure 6 | Termpilot charts of location parameter μ for the Gross Value of Agricultural production of the year 2020



Source: Prepared by the Authors.

Figure 7(A)-(E) presents the termpilot charts related to the dispersion distribution (σ), allowing to analyze the behavior of the coefficient of variation in relation to the different production variables. It is observed that the poultry production (Figure 7A) shows a growth trend of the coefficient of variation as the volume produced increases. Soybean production (Figure 7B) also shows increasing behavior, although more sharply in the initial ranges and with increased uncertainty in the higher values. For pig production (Figure 7C), the variation remains relatively stable, close to a smooth linear pattern. Milk (Figure 7D) and corn (Figure 7E) productions showed a decreasing trend of the coefficient of variation, suggesting a lower relative dispersion in higher production levels, possibly associated with more standardized production processes or scale gains.

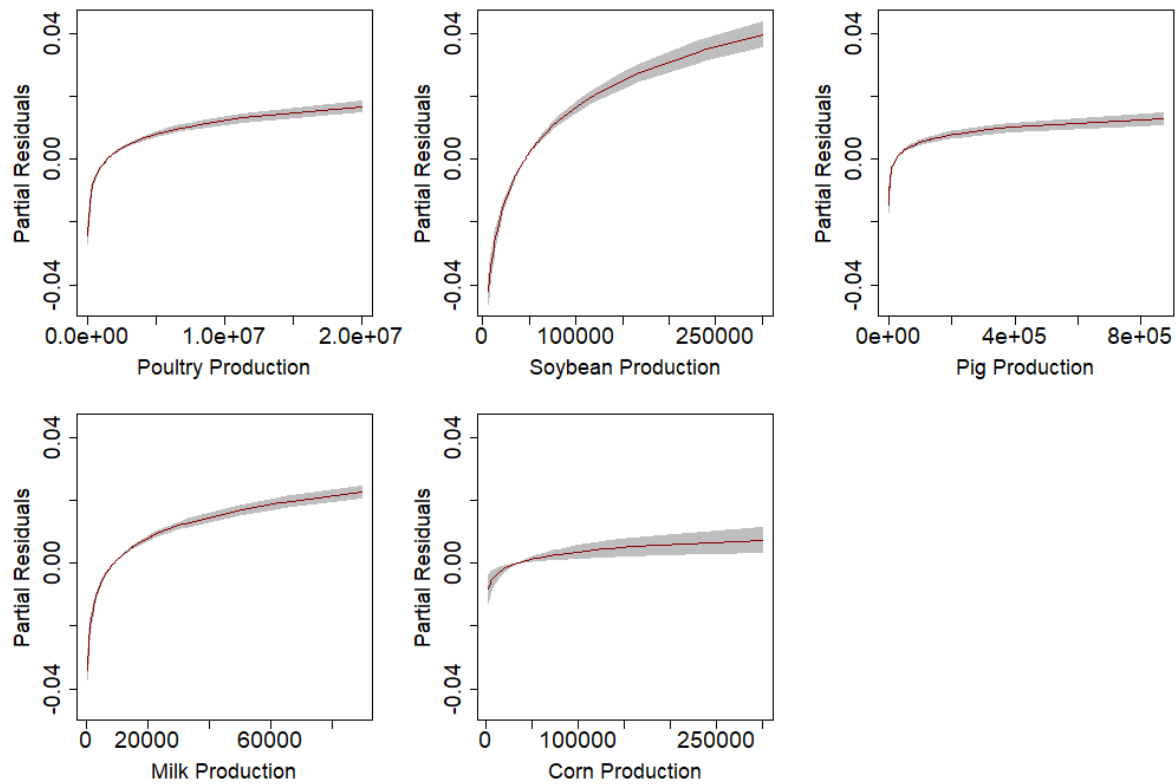
Figure 7 | Termpilot charts of scale parameter σ for the Gross Value of Agricultural production of the year 2020



Source: Prepared by the Authors.

Figure 8(A)-(E) shows the termpilot charts regarding the distribution of means(μ) for the year 2021, showing a growing trend in all the variables analyzed. It is observed that pig production (Figure 8C) and corn production (Figure 8E) present behavior closer to a linear relationship, while the other variables show marked growth in the initial ranges followed by smoothing at higher levels of production. In general, these results suggest a scenario of productive recovery for the analyzed commodities in the period, reflecting possible economic resumption and stability in the contribution of these activities to the Gross Value of Agricultural Production.

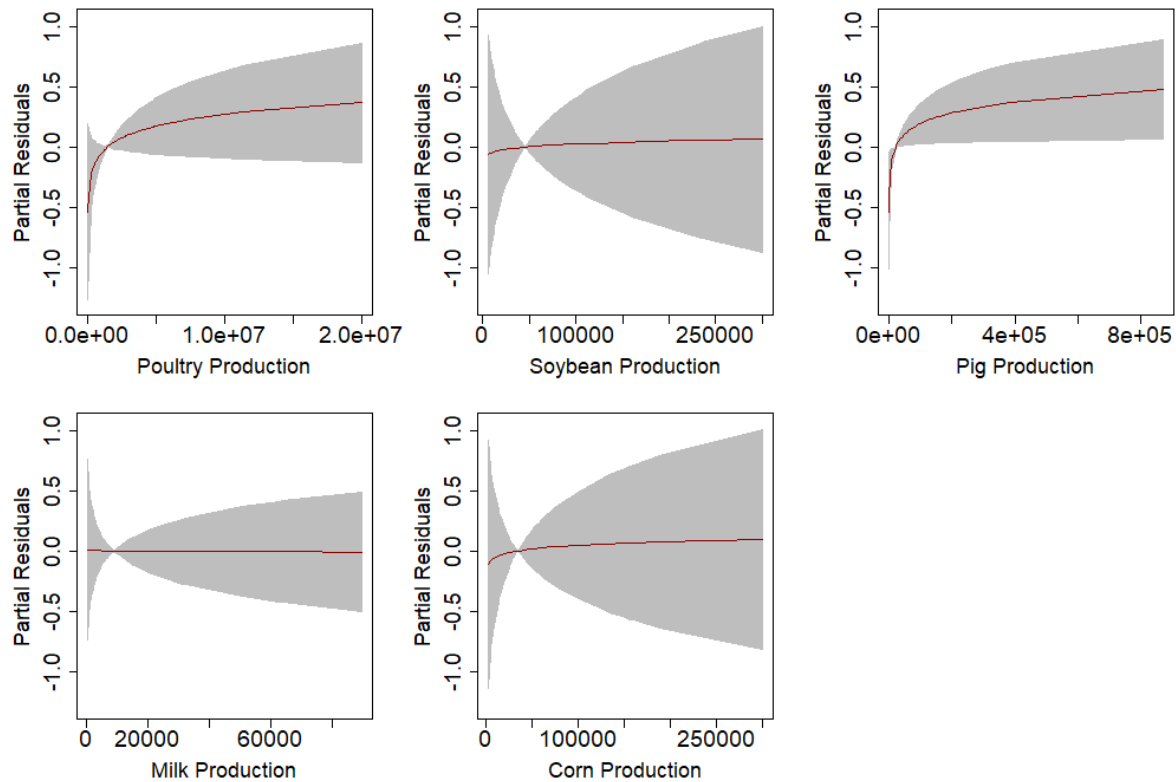
Figure 8 | Termplo chart of location parameter μ for the Gross Value of Agricultural production of the year 2021



Source: Prepared by the Authors.

Figure 9(A)-(E) presents the termplo charts related to the dispersion distribution (σ) for the year 2021, allowing to analyze the behavior of the coefficient of variation in relation to the studies production variables. It is observed that, for poultry, soybean, pigs, milk and corn, the trend remains close to a linear pattern, without abrupt variations along the production range. The 95% confidence bands have relatively high amplitude, indicating greater uncertainty in the estimation of the dispersion coefficient variation and suggesting that the observed effects should be interpreted with caution, especially in the extremities of the distributions.

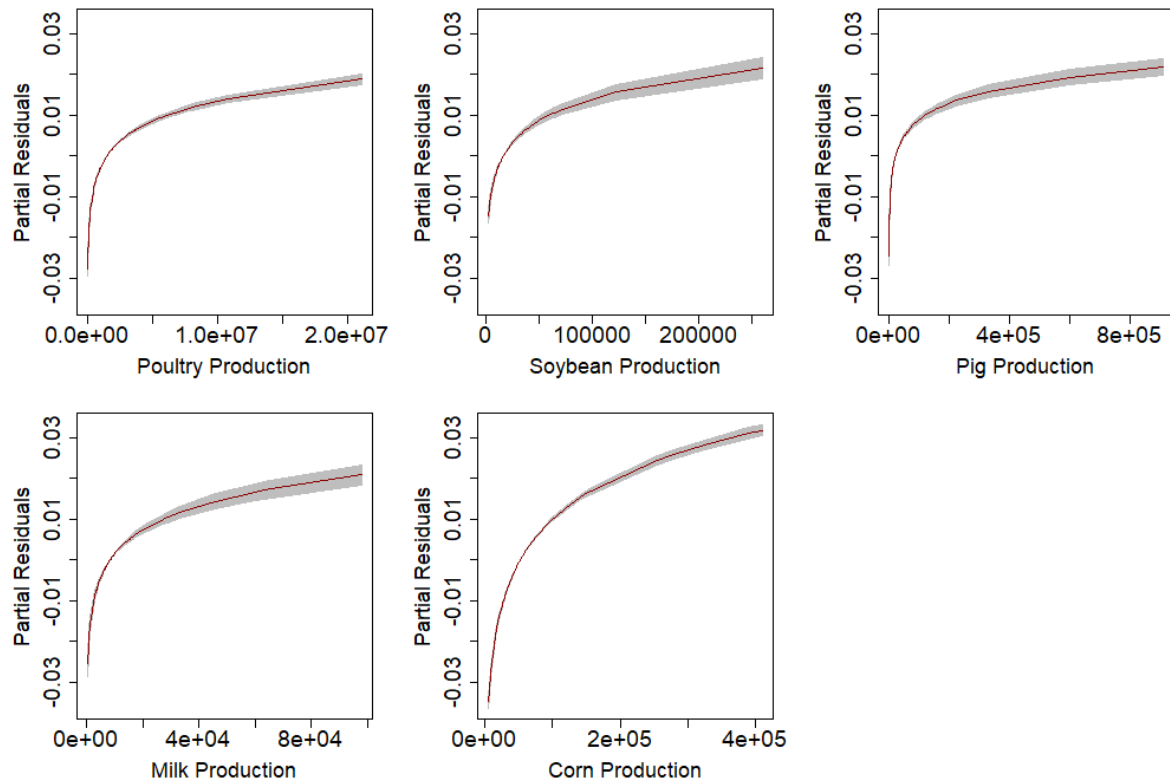
Figure 9 | Termplo chart of scale parameter σ for the Gross Value of Agricultural production of the year 2021



Source: Prepared by the Authors.

Figure 10(A)-(E) shows the termplo charts regarding the distribution of means(μ) for the year 2022, showing a growing trend in all the variables analyzed. In each case, there is a sharp increase in partial waste as production increases, characterizing a non-linear positive relationship. This pattern indicates that increases in poultry, soybean, pigs, milk and corn production are associated with increases in the model response variable. In general, the curves show rapid growth in the initial production ranges, followed by a smoothing process at higher levels, suggesting a decreasing marginal effect as the production reaches higher levels.

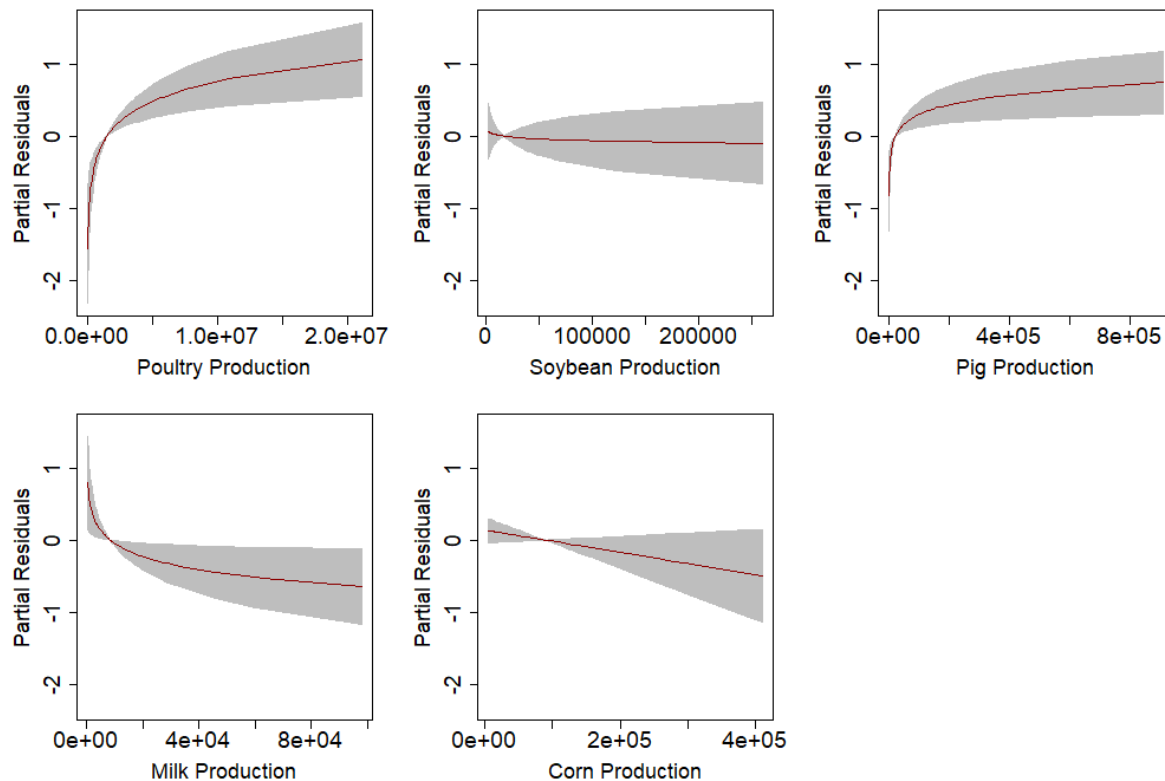
Figure 10 | Termplot charts of location parameter μ for the Gross Value of Agricultural production of the year 2022



Source: Prepared by the Authors.

Figure 11(A)-(E) presents the termplot charts for the scale parameter (σ), allowing to evaluate the influence of the production variables on the dispersion of the model. It is observed that the soybean (Figure 11B) and pigs production (Figure 11C) has a reduced effect on the response variable, remaining close to a pattern of stability along the production levels. On the other hand, milk (Figure 11D) and corn (Figure 11E) production show negative behavior, suggesting a decrease in the scale parameter as the volume produced increases, which may indicate lower relative variability in these scenarios. On the other hand, poultry production (Figure 11A) presents a moderate positive relationship, with a tendency to increase the scale parameter at higher productive levels.

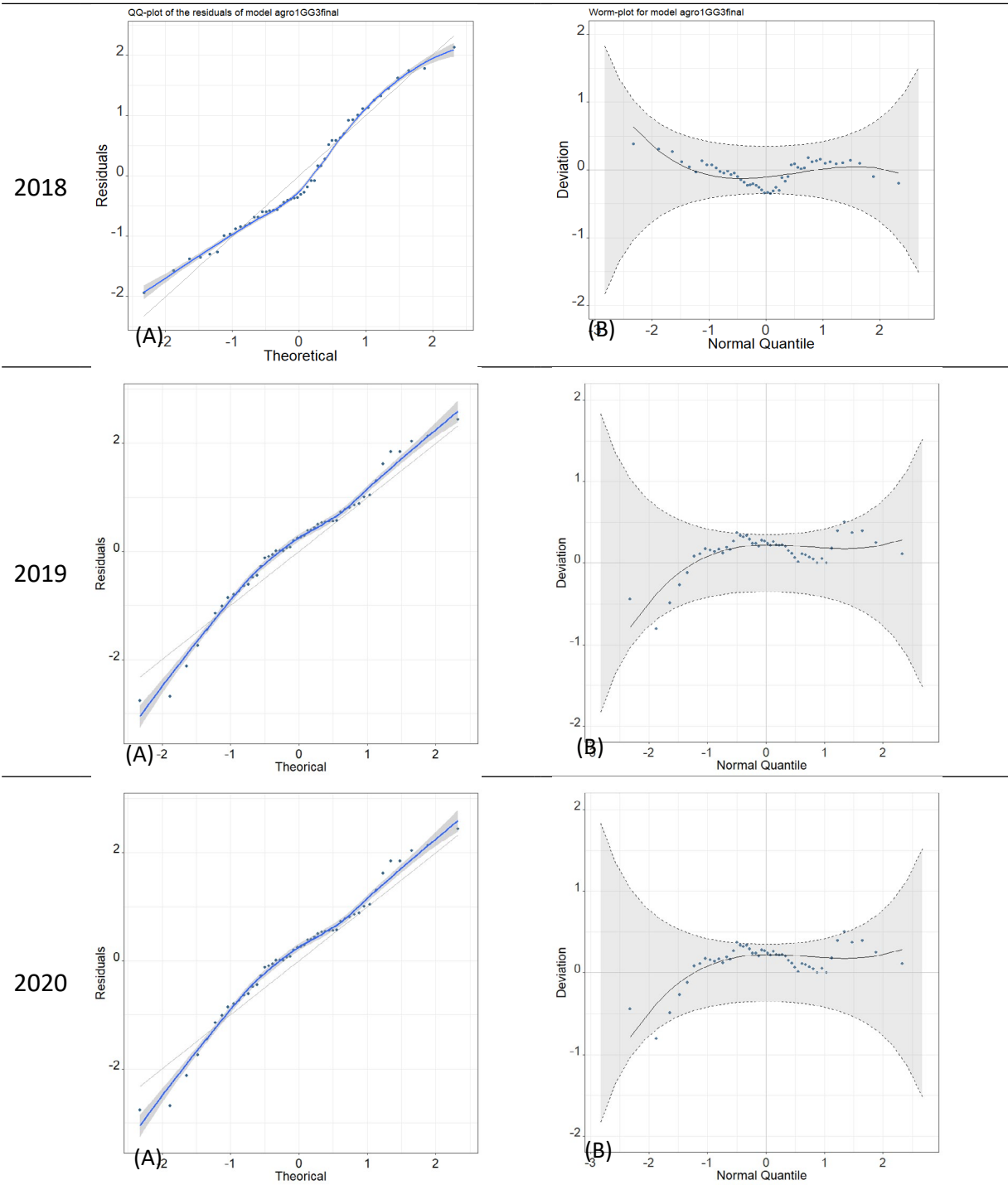
Figure 11 | Smoothing termplot charts of scale parameter σ for the Gross Value of Agricultural production of the year 2022

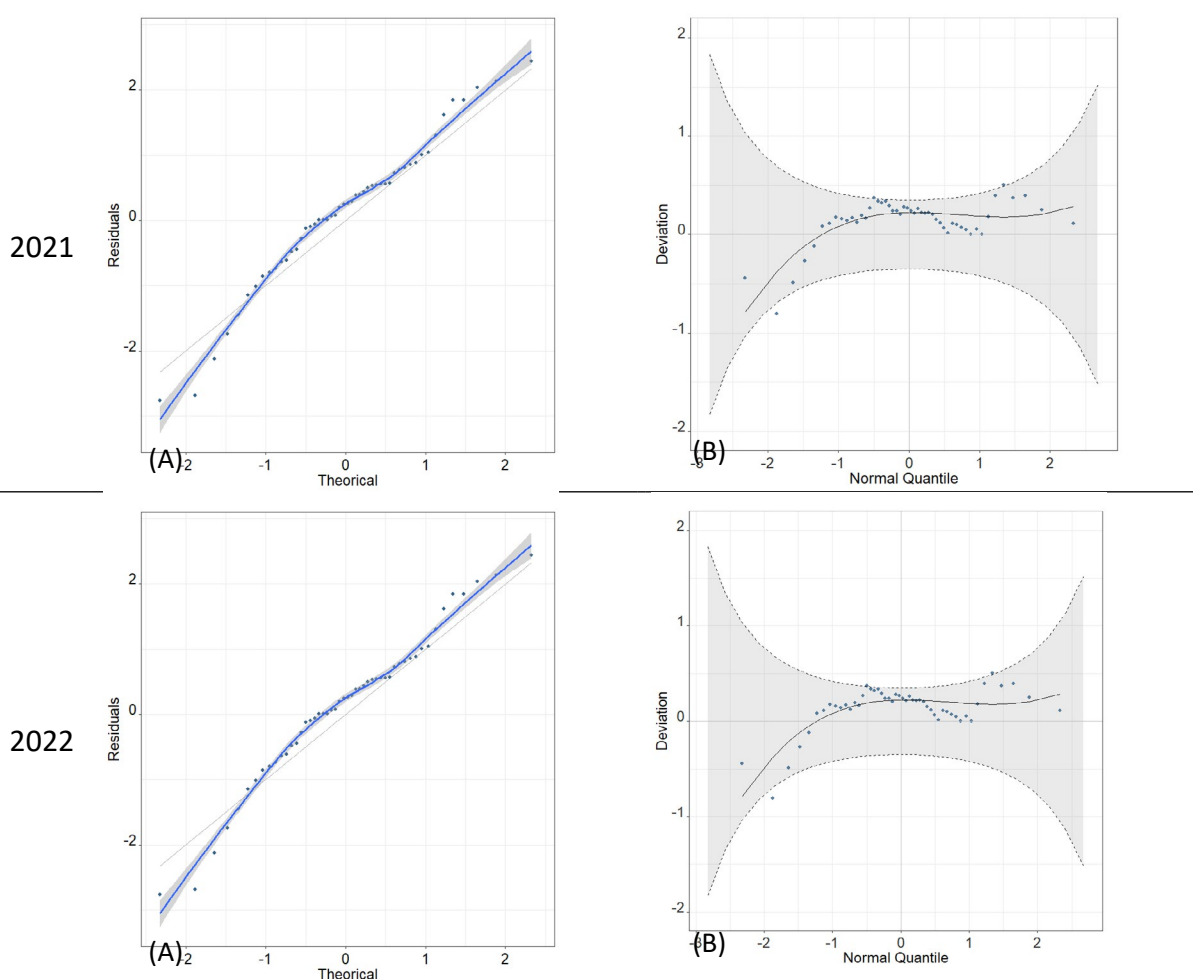


Source: Prepared by the Authors.

In Figure 12(A) the QQ-norm charts (R Core Team, 2025) that test the normality of the residues are represented, and it was observed that the points approach the confidence bands, therefore, this indicates that the residues of the VBP model for the years from 2018 to 2022. These charts indicate normal distribution, which implies that the model suggests a good fit because the points are aligned on the straight line that corroborates Jaya and Chadidjah (2021). In Figure 12(B) with the *worm* plot charts of GAMLSS models (Rigby and Stasinopoulos, 2005) for VBP in the years 2018 to 2022, it is verified that all the points plotted were close to the 95% confidence band, indicating a suitable fit by the model. Oliveira et al.(2019) studied and analyzed the generalized additive models by location, scale and shape in agricultural data, and concluded that the model was efficient in the study.

Figure 12 | *QQ-norm* (A) and worm plot (B) charts for the gross value of agricultural production in the years from 2018 to 2020





Source: Prepared by the Authors.

Table 4 shows the adjusted coefficients of the GAMLSS models for the parameters of location ($\hat{\mu}_i$), scale ($\hat{\sigma}_i$) and shape ($\hat{\nu}_i$) in the years from 2018 to 2022. The logarithmic function was used as a link function to model the parameters.

POULTRIES

Table 4 | Models for VBP considering the parameters of location ($\hat{\mu}_i$), scale ($\hat{\sigma}_i$) and shape ($\hat{\nu}_i$) in the years from 2018 to 2022

Ano	Modelos
2018	$\hat{\mu}_i = \exp\{2,533 + 0,068 \cdot \ln(\text{poultres18}_i) + 0,033 \cdot \ln(\text{soybean18}_i) + 0,069 \cdot \ln(\text{pigs18}_i) - 0,019 \cdot \ln(\text{milk18}_i) - 0,006 \cdot \ln(\text{corn18}_i)\}$
	$\hat{\sigma}_i = \exp\{-9,880 + 0,311 \cdot \ln(\text{poultres18}_i) + 0,268 \cdot \ln(\text{pigs18}_i) - 0,007 \cdot \ln(\text{corn18}_i)\}$
	$\hat{\nu}_i = \exp\{2653,40 + 651,33 \cdot \ln(\text{poultres18}_i) + 1455,83 \cdot \ln(\text{soybean18}_i) - 453,24 \cdot \ln(\text{pigs18}_i) - 240,41 \cdot \ln(\text{corn18}_i)\}$
2019	$\hat{\mu}_i = \exp\{2,577 + 0,008 \cdot \ln(\text{poultres19}_i) + 0,026 \cdot \ln(\text{soybean19}_i) + 0,015 \cdot \ln(\text{pigs19}_i) - 0,006 \cdot \ln(\text{milk19}_i)\}$
	$\hat{\sigma}_i = \exp\{-10,041 + 0,501 \cdot \ln(\text{soybean19}_i) + 0,241 \cdot \ln(\text{pigs19}_i) - 0,331 \cdot \ln(\text{milk19}_i)\}$
	$\hat{\nu}_i = \exp\{1393,7 \cdot \ln(\text{poultres19}_i) + 3694,0 \cdot \ln(\text{soybean19}_i) - 1781,2 \cdot \ln(\text{pigs19}_i) - 2150,9 \cdot \ln(\text{milk19}_i) - 1377,4 \cdot \ln(\text{corn19}_i)\}$
2020	$\hat{\mu}_i = \exp\{2,562 + 0,005 \cdot \ln(\text{poultres20}_i) + 0,047 \cdot \ln(\text{soybean20}_i) + 0,007 \cdot \ln(\text{pigs20}_i) - 0,032 \cdot \ln(\text{milk20}_i) - 0,006 \cdot \ln(\text{corn20}_i)\}$
	$\hat{\sigma}_i = \exp\{-9,965 + 0,822 \cdot \ln(\text{soy20}_i) + 0,162 \cdot \ln(\text{pigs20}_i) - 0,278 \cdot \ln(\text{milk20}_i) - 0,571 \cdot \ln(\text{corn20}_i)\}$
	$\hat{\nu}_i = \exp\{5776,4 - 342,4 \cdot \ln(\text{poultres20}_i) - 1562,7 \cdot \ln(\text{soybean20}_i) - 495,7 \cdot \ln(\text{pigs20}_i) + 1281,7 \cdot \ln(\text{milk20}_i) + 889,5 \cdot \ln(\text{corn20}_i)\}$
2021	$\hat{\mu}_i = \exp\{2542 + 0,007 \cdot \ln(\text{poultres21}_i) + 0,032 \cdot \ln(\text{soybean21}_i) + 0,007 \cdot \ln(\text{pigs21}_i) + 0,041 \cdot \ln(\text{milk21}_i) + 0,004 \cdot \ln(\text{corn21}_i)\}$
	$\hat{\sigma}_i = \exp\{-9,972 + 0,131 \cdot \ln(\text{pigs21}_i)\}$
	$\hat{\nu}_i = \exp\{-544,33 \cdot \ln(\text{poultry21}_i) + 767,3 \cdot \ln(\text{soybean21}_i) - 441,72 \cdot \ln(\text{pigs21}_i) + 541,31 \cdot \ln(\text{milk21}_i)\}$
2022	$\hat{\mu}_i = \exp\{2,533 + 0,007 \cdot \ln(\text{poultres22}_i) + 0,007 \cdot \ln(\text{soybean22}_i) + 0,005 \cdot \ln(\text{pigs22}_i) + 0,009 \cdot \ln(\text{milk22}_i) - 0,022 \cdot \ln(\text{corn22}_i)\}$
	$\hat{\sigma}_i = \exp\{-10,740 + 0,402 \cdot \ln(\text{poultres22}_i) + 0,189 \cdot \ln(\text{sui22}_i) - 0,254 \cdot \ln(\text{milk22}_i)\}$
	$\hat{\nu}_i = \exp\{6142,5 - 795,1 \cdot \ln(\text{poultres22}_i) + 431,4 \cdot \ln(\text{soybean22}_i) - 743,7 \cdot \ln(\text{pigs22}_i) + 591,8 \cdot \ln(\text{milk22}_i) + 408,1 \cdot \ln(\text{corn22}_i)\}$

Source: Prepared by the Authors.



By means of the quality analysis of the models fit, Table 4 shows the best model adjusted by the Generalized Akaike Information Criterion (GAIC) and Schwarz criteria (SBC).

The best adjusted model was the gross value of the agricultural production of 2018, which in fact is justified, by the fact that the year 2018 Paraná State-Brazil, it reached representative levels of agricultural production favoring the growth of the gross value of agricultural production of that year, which corroborate Seab (2018) and Seab (2019).

Table 4 | Statistical results of the GAMLSS model for the gross value of agricultural production from the years from 2018 to 2020 for the fifty municipalities of Paraná State

Response Variable (y)	GAIC	SBC
VBP 2018	-31.602	2.814
VBP 2019	-22.250	12.167
VBP 2020	-40.221	-5.804
VBP 2021	-58.785	-24.369
VBP 2022	-38.468	-4.051

Source: Prepared by the Authors.

The results of the graphical and diagnostic analyses of the residuals and the generalized Akaike information criteria (GAIC) and Schwarz criteria (SBC) indicated that the GAMLSS model classes appear to be appropriate for estimating the parameters of the gross value function of agricultural production and that the best-fitted model was for the year 2021. These results clearly demonstrate the importance of applying the generalized linear model for scale and shape location to agricultural and livestock data (Fantazzini et al., 2020; Ribeiro et al., 2020). The GAMLSS model in the analysis performed proved to be highly flexible and consistent across the variables studied, and indeed the results presented reflect the explanatory influence of the agricultural workforce on the gross value of agricultural production, which corroborates Darmawan et al. (2019).

CONCLUSION

The GAMLSS model best suited to describe VBP was from the year 2021, allowing its own distributions to describe the different characteristics of each distribution analyzed. The model was also advantageous, because the location and scale parameters depended on the co-variables analyzed. Thus, the nature of the response variable was described and interpreted in a way much more portrayed with reality.

Through the sigma distribution of the scale, from 2018 to 2022, it was observed that pig production, milk production and soybean production significantly influenced the variability of the VBP response variable. The result showed that the best model, according to the GAIC criterion, for the VBP was for the year 2021, followed by 2020 and 2022, indicating that the variables analyzed for the rental and scale parameters were significant.

The GAMLSS model was promising for the analysis of data on livestock production and grain production (corn and soybean), indicating their contribution in the composition of the mean parameter for VBP in the years under study. The GAMLSS models showed a relevant performance in the analyzed variables, identifying functions for the variability of the coefficients used in the estimation of the parameters, confirming the relationship of the VBP with the independent variables under study and the importance of these in the configuration of the economic scenario.

ACKNOWLEDGMENT

The authors thank the financial support of the National Council for Scientific and Technological Development (CNPq) and the Graduate Program in Regional Development and Agribusiness of UNIOESTE-Paraná State-Brazil (PGDRA), Federal University of Paraná (UTFPR) to the Laboratory of Spatial Statistics (LEE) of the State University of the West of Paraná State-Brazil and to the University Center FAG-Paraná State-Brazil.



REFERENCES

- ABLEEVA, A.M.; SALIMOVA, G.A.; RAFIKOVA, N.T.; FAZRAHMANOV, I. I.; ZALILOVA, Z.A.; LUBOVA, T.N.; NIGMATULLINA, G.R.; GIRFANOVA, I.N.; FARRAHOVA, F.F.; HAZIEVA, A.M. Economic Evaluation of the Efficiency of Supply Chain Management in Agricultural Production Based on Multidimensional Research Methods, **International Journal of Supply Chain Management**, v. 8, n. 1, p. 328-338, 2019. ISSN: 2050-7399.
- AKAIKE, H. **Information measures and model selection**. Proceedings of the 44th Session of the International Statistical Institute, vol. 1, p. 277-291, 1983.
- BUUREN, V.; FREDRIKS, M. Worm plot: simple diagnostic device for modelling growth reference curves, **Statistics in Medicine**, v. 20, n. 8, p. 1259-1277, 2001. DOI: 10.1002/sim.746.
- CIMA, E. G.; ROCHA-JUNIOR, W. F.; URIBE-OPAZO, M. A.; BOMBACINI, M. R. O novo traçado da Ferroeste: uma perspectiva para o desenvolvimento do Oeste do Paraná-Brasil, **Revista Brasileira de Gestão e Desenvolvimento Regional**, v.18, n. 3, p.371-383, 2022. ISSN 1809-239X.
- CIMA, E. G.; ROCHA-JUNIOR, W. F.; URIBE-OPAZO, M. A.; DALPOSSO, G. H. An Analysis of the Gross Domestic Product of Municipalities: A Spatial Glance into the State of Paraná-Brazil, **AGRIS on-line Papers in Economics and Informatics**, v. 15, n. 2, p. 19-29, 2023. ISSN 1804-1930. DOI 10.7160/aol.2023.150202.
- CIMA, E. G.; OLIVEIRA, M.P.; ROCHA-JUNIOR, W. F.; URIBE-OPAZO, M. A. longitudinal mixed models for the gross value Of agricultural production: a spatial and Regional assessment in the state of Paraná-Brazil, **Revista Brasileira de Gestão e Desenvolvimento Regional**, v.20, n. 1, p.372-393, 2024. ISSN 1809-239X.
- DANTAS, L.G.; SANTOS, C.A.C.; RICARDO A.; OLINDA, R.A.; BRITO, J.I.B.; SANTOS, C.A. G.; MARTIN, E S. P. R.; OLIVEIRA, G.; BRUNSELL, N.A. Rainfall Prediction in the State of Paraíba, Northeastern Brazil Using Generalized Additive Models. **Water**, v.12, n.2478, p.1-26, 2020. DOI: 10.3390/w12092478.
- DHARMANANDA M.; MAHMOD, B.; DEFALLA, A.; PUROHIT, N.; SINGH, S.K.; JOSEPH, B.; MOHANADASAN, T.; MITTAL, M.; VYAS, P. Strategic integration: Exploring the intersection of technology, finance, and management in today's business environment, **Journal of Infrastructure, Policy and Development**, v.8,n.8, 4871, p. 1-17, 2024. DOI: <https://doi.org/10.24294/jipd.v8i8.4871>.
- DARMAWAN, A.S.; ANGGRAENI, D.; TIRTA, I.M. Application of generalized additive model location, scale and shape (GAMLSS) for rice production in Banyuwangi regency. **Journal of Physics**, Conf. Ser. 1211 012025, p.1-9, 2019. DOI: 10.1088/1742-6596/1211/1/012025.
- DE BASTIANI, F.; RIGBY, F.R. A.; DIMITRIOS, M.; STASINOPOULOUS; CYSNEIROS H.M. and Uribe-Opazo, M.A. Gaussian Markov random field spatial models in GAMLSS, **Journal of Applied Statistics**, v.45, n.1, p.168-186, 2016. ISSN: 02664763. DOI:<http://dx.doi.org/10.1080/02664763.2016.1269728>.
- DUNN, P. K.; SMYTH, G. K. Randomized quantile residuals, **Journal of Computational and Graphical Statistics**, v.5, n.3, p. 236–244, 1996. Disponível em: https://www.jstor.org/stable/1390802?seq=1#page_scan_tab_contents. Acesso em: 12 Out de 2020. DOI:10.2307/1390802.
- EMBRAPA Empresa Brasileira de Pesquisa Agropecuária (2018). **Custos de produção de suínos e de frangos de corte sobem em maio e chegam a pontuação recorde**. Disponível em: <https://www.embrapa.br/busca-de-noticias/-/noticia/13594416/embrapa-custos-de-producao-de-suinos-e-de-frangos-de-corte-sobem-em-maio-e-chegam-a-pontuacao-recorde>. Acesso em 02 mai de 2019.
- EMBRAPA Empresa Brasileira de Pesquisa Agropecuária (2019). Estagnada em 2018, pecuária de leite deve crescer este ano. Disponível em: <https://www.embrapa.br/busca-de-noticias/-/noticia/40556629/estagnada-em-2018-pecuaria-de-leite-deve-crescer-este-ano>. Acesso em: 19 Ago de 2025.



EMBRAPA Empresa Brasileira de Pesquisa Agropecuária (2021). Brasil é o quarto maior produtor de grãos e o maior exportador de carne bovina do mundo, diz estudo. Disponível em: <https://www.embrapa.br/busca-de-noticias/-/noticia/62619259/brasil-e-o-quarto-maior-produtor-de-graos-e-o-maior-exportador-de-carne-bovina-do-mundo-diz-estudo>. Acesso em: 19 Ago de 2025.

GLOBO RURAL (2021). Abate de frangos subiu 3,3% e produção de ovos foi recorde em 2020. Disponível em: <https://globo.rural.globo.com/Estadao/noticia/2021/03/abate-de-frangos-subiu-33-e-producao-de-ovos-foi-recorde-em-2020.html>. Acesso em: 19 de Agosto de 2025.

FANTAZZINI, G. R.; ROSA, S.D.V.F.; LISKA, G.R.; CARVALHO, L.M.R.; COELHO, S.V.B.; CIRILO, M.A.; RIBIEIRO, F.A.S. Correlation between historical data of the germination test and of the tetrazolium test in coffee seeds by GAMLSS, **Seed Science and Technology**, 48, 2, 179-188, 2020. <https://doi.org/10.15258/sst.2020.48.2.05>.

FERRERA DE LIMA, J.; DESBIENS, Y. L'approche quantitative et qualitative dans les études du développement regional, **Informe GEPEC**, v. 13, n. 1, p. 123–130, 2000. DOI: 10.48075/igepec.v13i1.2568. Disponível em: <https://e-revista.unioeste.br/index.php/gepec/article/view/2568>. Acesso em: 15 de fevereiro de 2023.

GAMAGE, A.; GANGAHAGEDARA, R.; SUBASINGHE, GAMAGE, J.; Chamini GURUGE, C.; SENARATNE, S.; RANDIKA, T.; RATHNAYAKE, C.; HAMEED, Z.; MADHUJITH, T.; MERAH, O. Advancing sustainability: The impact of emerging technologies in agriculture, **Current Plant Biology**, v.40 (2024) 100420, p. 1-16, 2024. DOI: <https://doi.org/10.1016/j.cpb.2024.100420>.

HERNANDEZ.; F. TORRES, M.; ARTEAGA, L.; CASTRO, C. Modelos GAMLSS aplicados en el tratamiento de residuos agroindustriales, **Comunicaciones en Estadística**, v. 8, n. 2, p. 245–254, 2015. DOI: <https://doi.org/10.15332/s2027-3355.2015.0002.07>.

IPARDES Instituto Paranaense de Desenvolvimento Econômico e social (2025). **Índice Iparades de Desempenho Municipal – IPDM**. Disponível em: http://www.ipardes.gov.br/index.php?pg_conteudo=1&cod_conteudo=19. Acesso em: 22 de abril de 2019.

JAIA, I. G. N. M.; CHADIDJAH, A. Spatial Autoregressive in Ecological Studies: A Comparison of the SAR and CAR Models, **Engineering Letters**, v. 29 n. 1, pp. 1-6, 2021. ISSN: 1816-0948.

LIMA-COSTA, A.C.; OLIVEIRA, A.D.M.; CARACIOLO, J.P.S.; LUCENA, R.L.L.; LEITE, M.L.M,V. A GAMLSS approach to predicting growth of *Nopalea cochenillifera* Giant Sweet clone submitted to water and saline stress, **Biometry, Modelling and Statistic**, v. 44, e54939, pp. 1-9, 2020. DOI: 10.4025/actasciagron.v44i1.54939.

OLIVEIRA, T. A.; XAVIER, S.F. A.; AMORIM FARIA, G.A. F.; LOPES, B.G.; BARBOSA, E.M.; PEIXOTO, E.P.B. An Application of Generalized Additive Models of Location, Scale, and Shape (GAMLSS) to estimate the Eucalyptus Height. **Revista Ciência e Natura**, Santa Maria, v. 42 n. 15, p. 01-10, 2019. DOI: 10.5902/2179460X41710.

OLIVEIRA, M. P.; CIMA, E.G.; OPAZO, M. A. U.; ROCHA-JUNIOR, W.F. Kernel density estimator in the mapping of agricultural production of the west of Paraná-Brazil, **Revista brasileira de gestão e desenvolvimento regional**, v. 20, p. 1-20, 2025. DOI: <https://doi.org/10.54399/rbgdr.v21i1.7995>.

RIBEIRO, T.F.; SEIDEL, E.J.; GUERRA, R.R.; FERNANDO A.; PEÑA-RAMÍREZ, F.A.; SILVA, A.M. Soybean production value in the Rio Grande do Sul under the GAMLSS framework, **Communications in Statistics: Case Studies, Data Analysis and Applications, Mathematics, Statistics & Data Science**, v,7, n.2,p. 146-165, 2021, DOI: 10.1080/23737484.2020.1852131.

RIGBY, R. A.; STASINOPOULOS, D. M. Generalized Additive Models for Location, Scale and Shape, **Journal of the Royal Statistical Society: Series C (Applied Statistics)**, v. 54, n. 3, p. 507-554, 2005. DOI: <https://doi.org/10.1111/j.14679876.2005.00510.x>.

R CORE TEAM. qqnorm: Quantile-Quantile Plots for Normality. *R: stats package – documentação oficial*. Disponível em: <https://stat.ethz.ch/R-manual/R-devel/library/stats/html/qqnorm.html>. Acesso em: 10 de novembro de 2025.

R Development Core Team, R. **A language and environment for statistical computing**. Vienna, Austria: R Foundation for



Statistical Computing, ISBN 3-90005107-0. Disponível em: <http://www.R-project.org>. Acesso em: 10 de Maio de 2025.

RIBEIRO, T.F.; SEIDEL, E.J.; GUERRA, R.R.; FERNANDO A.; PEÑA-RAMÍREZ, F.A.; SILVA, A.M. Soybean production value in the Rio Grande do Sul under the GAMLSS framework, *Communications in Statistics: Case Studies, Data Analysis and Applications. Mathematics, Statistics & Data Science*, v.7, n.2, p. 146-165, 2021, DOI: 10.1080/23737484.2020.1852131.

SEAB/DERAL - Secretaria da Agricultura e do Abastecimento do Paraná / Departamento de Economia Rural. **Valor Bruto da Produção Rural Paranaense 2017**. Disponível em: https://www.agricultura.pr.gov.br/sites/default/arquivos_restritos/files/documento/2019-09/vbp2017analisecompletavd.pdf. Acesso em: 14 de março de 2023.

SEAB/DERAL - Secretaria da Agricultura e do Abastecimento do Paraná / Departamento de Economia Rural. **Banco de Dados da Produção Agropecuária no Paraná**. Situação mensal de plantio, colheita e comercialização de produtos agrícolas no Paraná. Disponível em: in <http://www.agricultura.pr.gov.br>. Acesso: 10 fevereiro, de 2019.

STASINOPOULOS, D.M.; RIGBY, R.A.; HELLER, G.Z.; VOUDOURIS, V.; DE BASTIANI, F, **Flexible Regression and Smoothing: Using GAMLSS in R**. Boca Raton, FL: Chapman & Hall, 2017.

SOUMITRA, D.; LANVIN, B.; VINCENT, S.W. **Global innovation index 2020. Who Will Finance Innovation?** Cornell University, INSEAD, and the World Intellectual Property Organization, 13th edition, 2020.

STACY, E.W. A generalization of the gamma distribution, *Annals of Mathematical Statistics*, v.33, n. 3, 1187-1192, 1962. DOI: DOI: 10.1214/AOMS/1177704481.

VILLARINI, G.; JONES, C.S.; SCHILLING, K.E. Soybean Area and Base ow Driving Nitrate in Iowa's Raccoon River, *Journal of Environmental Quality*, v. 45, p.1949–1959, 2206. DOI: 10.2134/jeq2016. 05.0180.

VOUDOURIS, V.; AYRES, R.; SERRENHO, A.C.; KIOSE, D. The economic growth enigma revisited: The EU-15 since the 1970s, *Energy Policy*, v.86, p.812–32, 2015. DOI: 10.1016/j.enpol.2015.04.027.

WERAIKAT, D.; ŠORIČ, K.; ŽAGAR, M.; SOKAČ, M. Data Analytics in Agriculture: Enhancing Decision-Making for Crop Yield Optimization and Sustainable Practices, *Sustainability*, v.16, n.17:7331, p.1-12, 2024. DOI: <https://doi.org/10.3390/su16177331>.

ZSARNÓCZAI, J.S.; ZÉMAN, Z. Output value and productivity of agricultural industry in Central-East Europe, *Agricultural Economics – Czech*, v. 65, n. 4, p. 185–193, 2019. DOI: <https://doi.org/10.17221/128/2018-AGRICECON>.

ŻYŁOWSKI, T.; KOZYRA, J. Crop Cultivation Efficiency and GHG Emission: SBM-DEA Model with Undesirable Output Approach, *Sustainability*, n.15,p.1-8, 2023. 10557. DOI: <https://doi.org/10.3390/su151310557>.



Esta obra está licenciada com uma Licença Creative Commons Atribuição 4.0 Internacional.



