Revista Portuguesa de Estudos Regionais, nº 73 2026, 53-64

Artigo submetido a 15 de Fevereiro 2025; versão final aceite a 17 de Julho de 2025
Paper submitted on February 15, 2025; final version accepted on July 17, 2025
DOI: https://doi.org/10.59072/rper.vi73.761

Spatial Autocorrelation in Indicators Related to Portuguese Agriculture: Data from the Agricultural Census

Autocorrelação Espacial em Indicadores Relacionados com a Agricultura Portuguesa: Dados do Recenseamento Agrícola

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Abstract

The spatial effects exist and have their impacts when analyses that involve different countries, regions, or municipalities are made. Still, they are sometimes ignored in these assessments and this may bring problems of robustness on the results and conclusions obtained. Additionally, the consideration of these spatial effects may bring relevant insights for the analyses. It can support better the design of common strategies and policies to deal with frameworks that involve different spatial units. In this perspective, this research aims to analyse the current context of the agricultural sector in Portugal and identify spatial autocorrelation effects for agricultural indicators in mainland Portuguese municipalities (parishes), considering the data from the Agricultural Census 2019. These indicators were interrelated through cross-section methodologies, based on the Cobb-Douglas production function. The results obtained highlight relevant signs of spatial autocorrelation effects in different parts of Portugal's mainland and the impact of some production factors on the levels of output.

Keywords: Portuguese municipalities; Cobb-Douglas function; Cross-section methodologies.

JEL codes: C21; Q10.

Resumo

Os efeitos espaciais existem e têm o seu impacto em análises que envolvem países, regiões ou municípios. No entanto, estes efeitos são, em certas circunstâncias, ignorados nestas avaliações, o que pode trazer problemas de robustez nos resultados e conclusões obtidos. Por outro lado, a consideração destes efeitos espaciais pode acrescentar valor para as análises que envolvam diversas localizações. Esta abordagem, pode, nomeadamente, apoiar uma melhor conceção de estratégias e políticas comuns para lidar com enquadramentos que envolvam diferentes unidades espaciais. Nesta perspetiva, esta investigação tem como objetivo analisar o contexto atual da agricultura Portuguesa e identificar efeitos de autocorrelação espacial em indicadores agrícolas nos municípios (freguesias) de Portugal Continental, considerando os dados do Recenseamento Agrícola de 2019. Estes indicadores foram relacionados através de metodologias *cross-section*, com base na função de produção *Cobb-Douglas*. Os resultados obtidos evidenciam indícios relevantes de autocorrelação espacial em diferentes zonas de Portugal Continental e o impacto de alguns fatores de produção nos níveis de output agrícola obtidos.

Palavras-Chave: Municípios portugueses; Função *Cobb-Douglas*; Metodologias *cross-section*.

Códigos JEL: C21; Q10.

1. INTRODUCTION

Agriculture in Portugal has suffered several transformations, some of them are consequences of the worldwide trends for the sector, others are related to socioeconomic dynamics and others are associated with the national and European policies for the sector. The Common Agricultural Policy (CAP) from the European Union has had diverse reforms with implications in the Portuguese context. The CAP reform of 1992, for example, brought deep changes in the measures that had been designed decades before for the European sector (Ackrill et al., 1997). This had relevant impacts on the Portuguese farms with low productivity and weak organisation, namely because the purpose of this CAP reform was to reduce production surpluses (Martinho, 2017).

More recently, international organizations and European institutions have implemented strategies to deal with climate change, which has impacted the dynamics of the farms. Additionally, the context of global warming has implications for farm routines worldwide (Espinosa & Portela, 2025).

Another question is about the trends verified in agriculture worldwide as a consequence of the modernization processes of the associated activities, where it is expected that the farming sector reduces the requirements of labour and the weight in the total gross domestic product. In any event, the agricultural sector in Portugal absorbed some unemployment as a consequence of internal and external disruptions, namely during and after the economic crisis verified in 2011 (Reis & Rolo, 2016).

Considering these frameworks, it is important to bring more contributions to better understand the current reality of the sector in Portugal, namely in terms of relationships between the farming output, farm size and labour force utilised. Additionally, it is important to analyse the spatial autocorrelation effects. Specifically, this research aims to analyse the impacts of the farm size and labour force on the farming output and how these relationships are influenced by the spatial effects.

2. LITERATURE REVIEW

There is an extensive debate about the relevance of farm size and the amount of labour used for the sustainability of the agricultural sector. Studies in these fields have focused on the relationship between farm size and environmental impacts (Cheng et al., 2022), technological progress (Hu et al., 2022), farm viability (Lowder et al., 2025), productivity (Rada & Fuglie, 2019), trade-offs in agricultural outputs (Ren et al., 2024) and sustainability (Ren et al., 2019). The discussion on this subject in Portugal shows that there is room for more contributions, in particular by taking spatial effects into account. The literature shows that there are not many studies on spatial autocorrelation in the agricultural sector in Portugal, highlighting the relevance of this research (Scopus, 2025).

The spatial autocorrelation assessments have been considered as approaches of analysis by the different fields of science in research that involve different spatial units (countries, regions, or municipalities, for example). These methodologies were considered, at least mentioned, in studies related to the following issues: Covid-19 incidence in the first wave (Barbosa et al., 2022); the distribution of the manufacturing sector (Barrios et al., 2009); rabbit populations management (Encarnação et al., 2019); distribution of riparian flora (Fernandes et al., 2011); economic impacts of transportation conditions (Fragoso Januário et al., 2021); effects of accessibility transformations (Freiria & Sousa, 2024); unemployment pattern (Grekousis, 2018); labour productivity changes (Melchor-Ferrer, 2020); walkable conditions (Pereira et al., 2023); retaining talent (Rebolho et al., 2023); and historical interrelationships (Román-Busto et al., 2013).

Several theoretical developments have been considered as support for the spatial autocorrelation analysis carried out by the scientific literature. Some of them are based on the economic models related to Verdoorn's law (Martinho et al., 2021) and others on the contributions of the New Economic Geography (Martinho & Barandela, 2021). The spatial autocorrelation assessments are important methodologies to identify correlations between variables of different spatial units and in this way understand better how these indicators interact together and how specific challenges can be dealt. This is particularly useful to identify and design common policies and strategies that can be implemented together in different countries, regions, or municipalities, avoiding the duplications of efforts and saving money (Martinho et al., 2021). The approaches presented in this research take into account other studies carried out for Portugal in these fields, namely that of Dinis (2023) which considers the Cobb-Douglas function as a basis.

3. MATERIAL AND METHODS

Taking into account the objectives proposed for this study, data from the Agricultural Census 2019 (Statistics Portugal, 2025) was considered for the parishes of mainland Portugal. To assess the spatial autocorrelation effects, the procedures proposed by the GeoDa software were followed (Anselin et al., 2006). To deeper assess the spatial effects among Portuguese agricultural indicators, the Cobb-Douglas production function (Cobb & Douglas, 1928) was considered as a base for cross-section regressions with Spatial Autoregressive Model (SAR), with the effects of the dependent variables in neighbouring parishes, and Spatial Error Model (SEM), where the impacts of neighbours are random, (Anselin et al., 2006). To obtain the shapefiles the QGIS software (QGIS.org, 2025) was considered, as well as the information available on the Public Administration open data portal (Direção-Geral do Território, 2025).

Generally, the spatial autocorrelation considers Moran´s I statistics (Moran, 1950) to assess the global and local spatial correlation. For the global spatial autocorrelation is expected that Moran´s I range between 0 and 1 for a positive correlation and among -1 and 0 for a negative one (Anselin et al., 2006). The local spatial autocorrelation considers Moran´s I statistics to identify clusters of positive spatial autocorrelation of negative correlation. In the positive spatial correlation is expected to identify clusters high-high (high values in a spatial unit are correlated with high values in the neighbours) and low-low (low values in a spatial unit are correlated with low values in other spatial units). The high-low and low-high results are related to negative spatial autocorrelation (Anselin, 1995). These methodologies have been considered, for example by Mourão & Bento (2021), for the Portuguese context.

4. DATA ANALYSIS

In general, is in the south of the Portuguese mainland that the farms are larger (figure 1). Parishes from the municipalities of Alcácer do Sal, Mora, Montemor-o-Novo, Ponte de Sor, Serpa, Ferreira do Alentejo, Castro Verde, Redondo, Moura, Mértola, Idanha-a-Nova and Beja are those with the highest utilised agricultural area (ha). On the other hand, parishes from Vendas Novas, Mora, Évora, Monforte, and Moita (municipalities from the south of Portugal) present the largest utilized agricultural area per farm. Parishes from the centre and north of Portugal also have higher values for this variable, namely from Arouca (district of Aveiro) and Vizela (district of Braga) municipalities.

Figure 1. Utilised Agricultural Area across the mainland Portuguese parishes

Mora, Moita, Castro Verde, Mértola, Elvas, Gavião, Alter do Chão, Vendas Novas (from the south of Portugal), Arouca (centre of Portugal), Vizela (north region) and Manteiga (Guarda district) are municipalities where the parishes have the greatest utilized agricultural area per annual work unit.

Figure 2. Agricultural Annual Work Units across the mainland Portuguese parishes

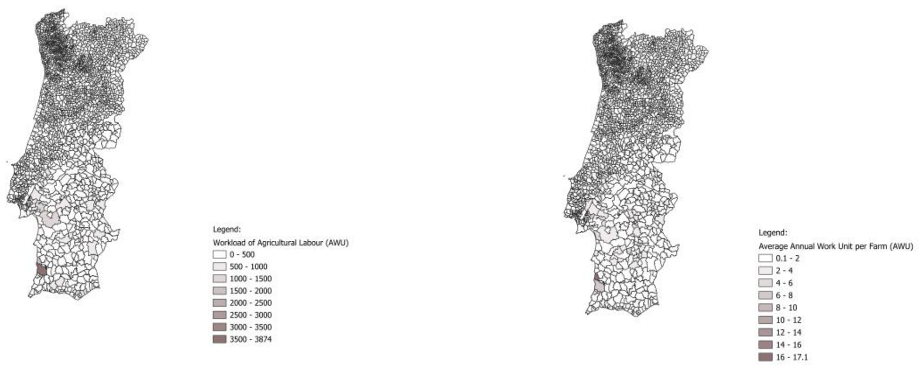
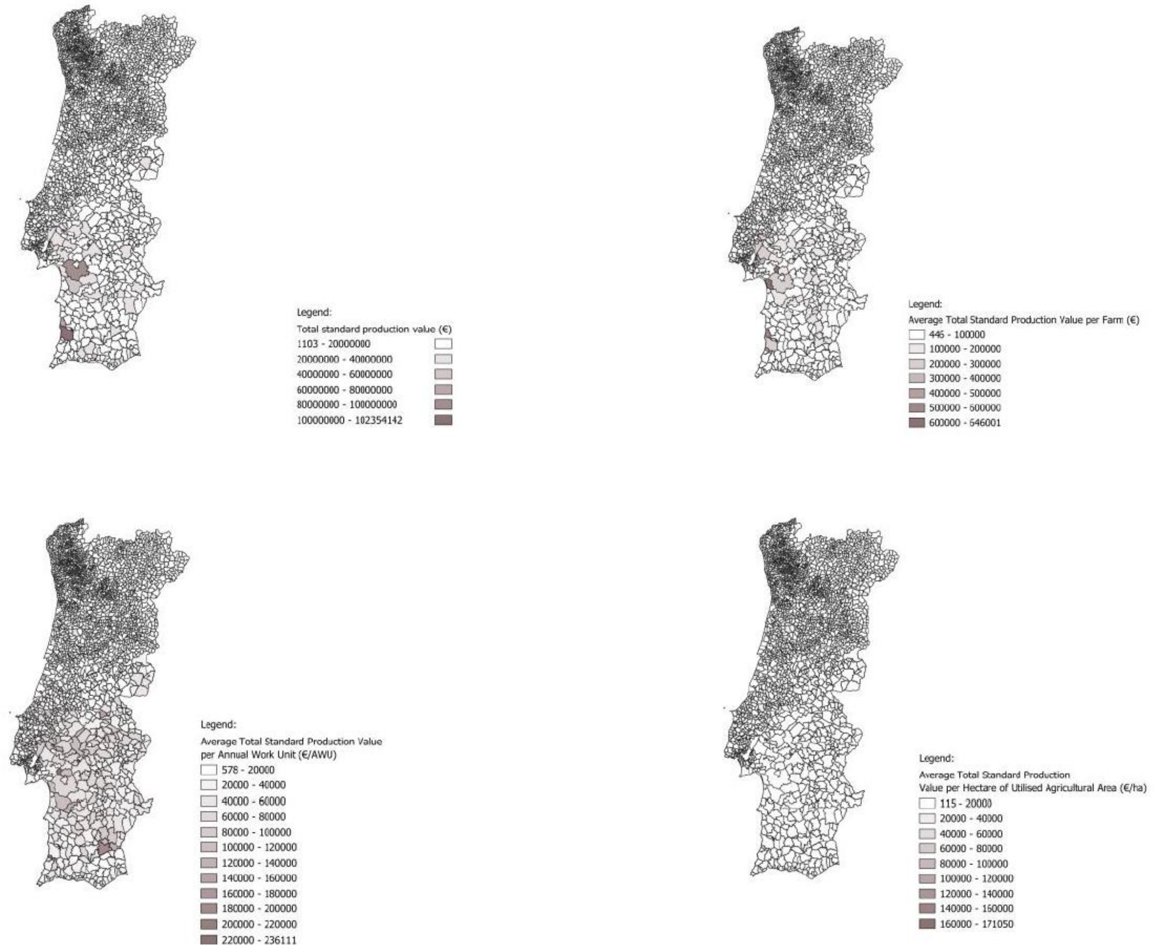


Figure 2 highlights that the parishes from the following municipalities are those with the highest annual work unit per farm: Lisboa; Odemira, Faro, Alcochete, Alcácer do Sal, Ferreira do Alentejo and Montijo (south of Portugal); Alijó, Caminha and Amares (north). In turn, parishes from municipalities of the south of Portugal (Odemira, Alcácer do Sal, Palmela, Faro, Montijo, Ferreira do Alentejo, Silves, Serpa, Alcochete, Montemor-o-Novo and Redondo), the centre (São João da Pesqueira and Bombarral) and the north (Póvoa do Varzim and Guimarães) present the biggest values for the annual work units.

Figure 3. Agricultural Total Standard Production Value across the mainland Portuguese parishes



Generally, the parishes from the south of Portugal present higher values for the total standard production value (figure 3), but also parishes from Alvaiázere (centre) and Melgaço (north). When the values of this variable are adjusted by the utilised agricultural area the results are significantly different. In this case, the highest values appear in parishes from the centre and north of Portugal, namely in the following municipalities: Leiria; Albergaria-a-Velha; Figueira da Foz; Sever do Vouga; Oliveira de Frades; and Guimarães.

5. SPATIAL AUTOCORRELATION ANALYSIS

The results for the global spatial autocorrelation (obtained considering a queen matrix for the contiguity weight) show that, in the variables related to the utilised agricultural area, Moran´s I present signs of positive and strong correlation. The significance level depends on the number of permutations, but generally starts at 0.01 for a pseudo p-value with 99 permutations. The queen contiguity matrix has been considered by several studies with robust results (Imran et al., 2023; Pratiwi et al., 2025). The strongest global spatial autocorrelation occurs for the average utilised agricultural area per annual work unit (figure 4). Figure 5 reveals that the global spatial autocorrelation for the variables associated with the annual work units is positive but weak, with values of Moran´s I statistics around 0.3 for the total annual work unit and 0.2 for the average annual work unit per farm.

Figure 4. Global spatial autocorrelation for the Utilised Agricultural Area. a) Total Utilised Agricultural Area; b) Average Utilised Agricultural Area per Farm; c) Average Utilised Agricultural Area per Annual Work Unit

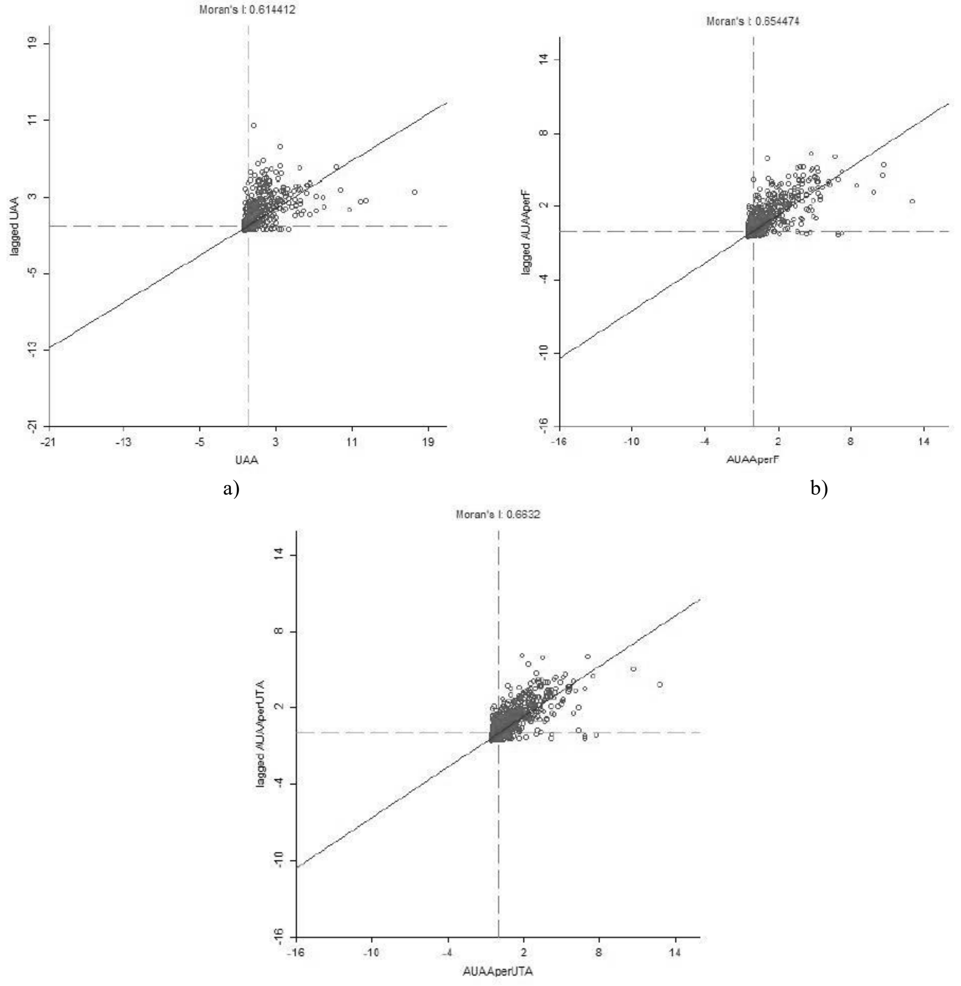
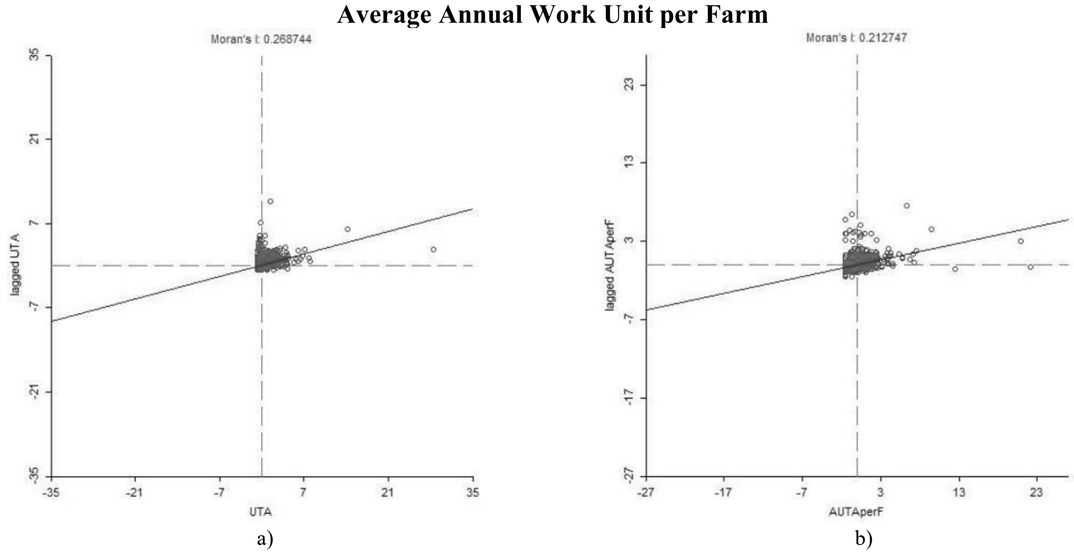
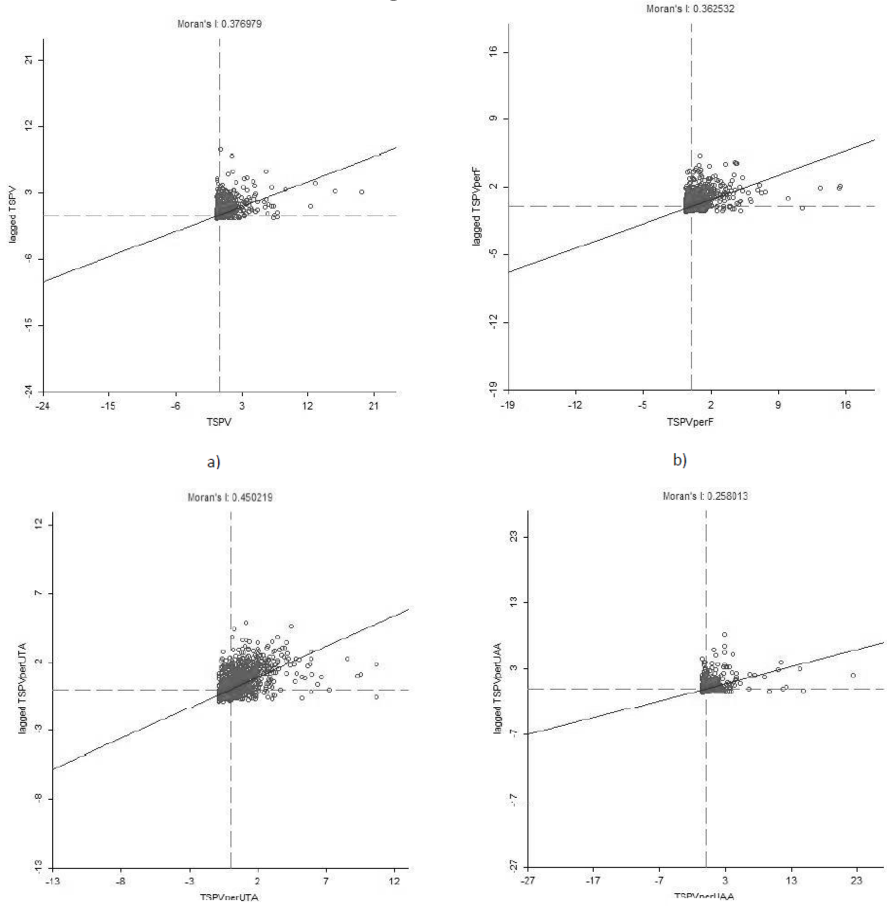


Figure 5. Global spatial autocorrelation for the Annual Work Unit. a) Total Annual Work Unit; b) Average Annual Work Unit per Farm



The global spatial autocorrelation is also positive for the variables related to total standard production value (figure 6), with the highest value of the Moran´s I obtained for the average total standard production value per annual work unit.

Figure 6. Global spatial autocorrelation for the Total Standard Production Value. a) Total Standard Production Value; b) Average Total Standard Production Value per Farm; c) Average Total Standard Production Value per Annual Work Unit; d) Average Total Standard Production Value per Utilised Agricultural Area



Figures 7, 8 and 9 show that, in general, there is positive local spatial autocorrelation in the south of Portugal for high-high values and in the north for low-low results (with a significance level of 0.05).

Figure 7. Local spatial autocorrelation for the Utilised Agricultural Area. a) Total Utilised Agricultural Area; b) Average Utilised Agricultural Area per Farm; c) Average Utilised Agricultural Area per Annual Work Unit

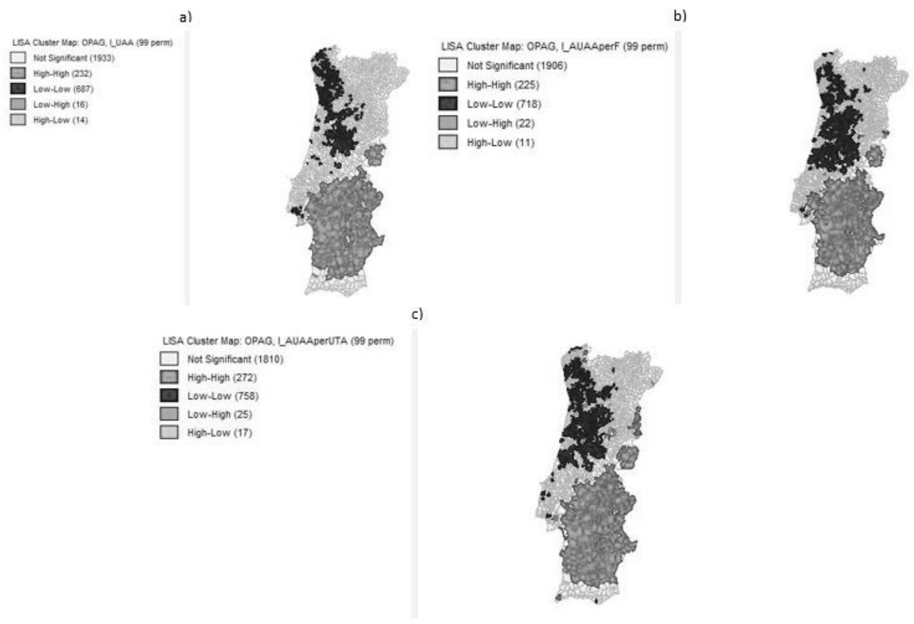


Figure 8. Local spatial autocorrelation for the Annual Work Unit. a) Total Annual Work Unit; b) Average Annual Work Unit per Farm

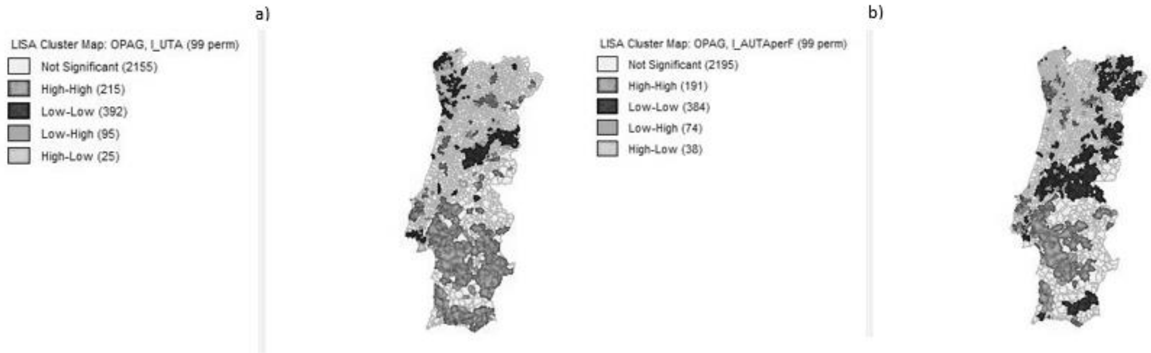
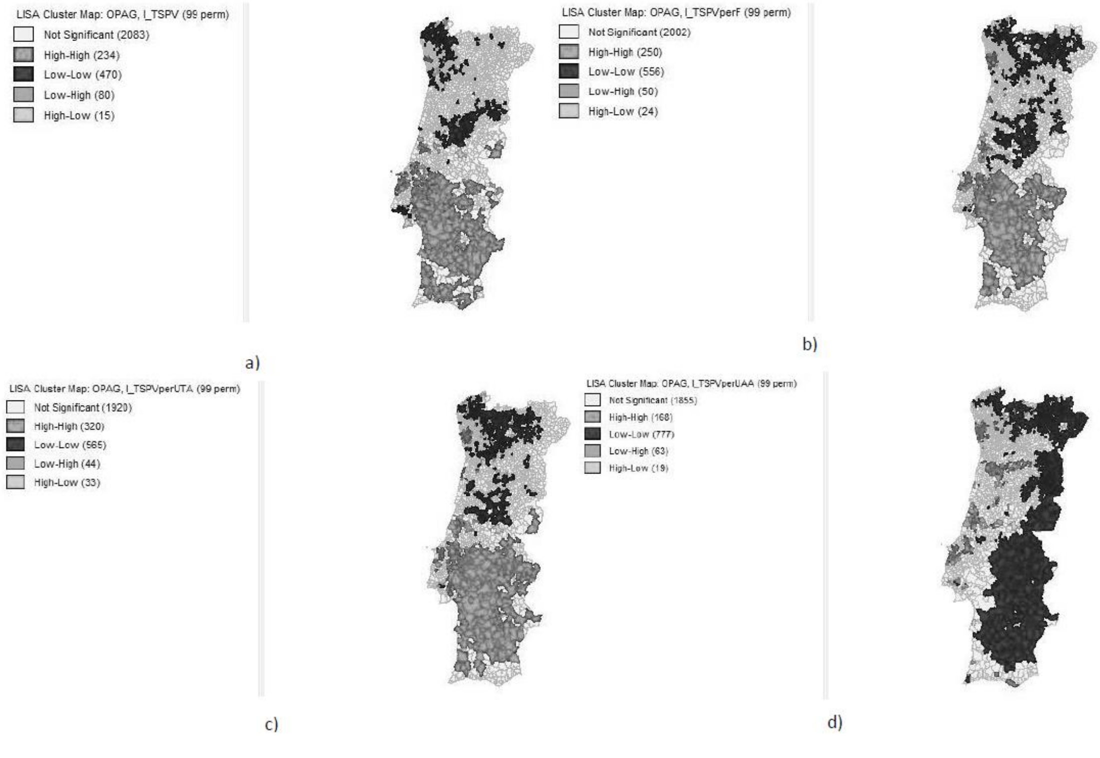


Figure 9. Local spatial autocorrelation for the Total Standard Production Value. a) Total Standard Production Value; b) Average Total Standard Production Value per Farm; c) Average Total Standard Production Value per Annual Work Unit; d) Average Total Standard Production Value per Utilised Agricultural Area



The great exception is for the average total standard production value per utilised agricultural area that has a positive local correlation for low-low values in a large part of Portugal. The positive autocorrelation for high-high values appears only in some parishes of the Portuguese littoral north and centre.

6. RESULTS

In this section, the models used were first estimated using ordinary least-squares (OLS) approaches, with results for Lagrange Multiplier (LM) tests to assess the presence of spatial lag or spatial error effects, then re-estimated with the presence of spatial autocorrelation effects using Maximum likelihood (ML) regressions. This is a methodology for specifying models with spatial effects. The choice of SEM or SAR is related to the level of statistical significance of the LM tests

(Florax et al., 2003). Table 1 shows the results of the OLS regressions and Table 3 the findings of the ML regressions. Table 2 reveals that the level of statistical significance is higher for the LM error tests (particularly the robust one). These results about the diagnostics for spatial dependence highlights that the SEM is the most adjusted.

Table 1. Cross-section regression results considering the logarithm of the Total Standard Production Value as dependent variable

Variable	Coefficient	Standard Error	t-Statistic	Probability
Constant	6.769	0.082	82.505	0.000
Logarithm of Annual Work Unit	0.962	0.028	34.134	0.000
Logarithm of Utilised Agricultural Area	0.457	0.018	24.905	0.000

Table 2. Diagnostics for spatial dependence considering the logarithm of the Total Standard Production Value as the dependent variable, and the logarithm of the Annual Work Unit and Utilised Agricultural Area as independent variables

Test	Value	Probability
Lagrange Multiplier (lag)	250.316	0.000
Robust LM (lag)	1.826	0.177
Lagrange Multiplier (error)	844.798	0.000
Robust LM (error)	596.308	0.000

Table 1 reveals that when the annual work unit and the utilised agricultural area grow by 1%, the total standard production value grows by 0.96% and 0.46%, respectively. These results show that the marginal impact of agricultural labour is higher than that of the number of hectares. Table 3 confirms the greater marginal impact of the agricultural annual work unit on the agricultural output and a coefficient for the spatially lagged error term of 0.59. Positive values for lambda mean that the residuals show spatial clustering and values close to 1 mean that there is a relevant set of spatial phenomena that are not explained by the independent variables.

Table 3. Cross-section regression results considering the logarithm of the Total Standard Production Value as the dependent variable and SEM

Variable	Coefficient	Standard Error	z-value	Probability
Constant	6.597	0.098	67.583	0.000
Logarithm of Annual Work Unit	0.825	0.032	25.682	0.000
Logarithm of Utilised Agricultural Area	0.591	0.024	24.203	0.000
Lambda	0.568	0.021	27.208	0.000

7. DISCUSSION

This research intended to analyse the spatial autocorrelation effects in the Portuguese parishes for farming indicators considering data from the Agricultural Census 2019. This statistical information was also assessed through cross-section methodologies with SAR and SEM. For the spatial autocorrelation, the procedures proposed by the software GeoDa were followed. For the global and local spatial autocorrelation was analysed taking into account Moran´s I statistics.

The spatial correlation approaches have been considered by the scientific literature to assess the most diverse issues, since the flora and fauna management (Encarnação et al., 2019; Fernandes et al., 2011)until the social and economic dynamics (Barrios et al., 2009). These assessments also include the historical relationships (Román-Busto et al., 2013), infrastructure network (Fragoso Januário et al., 2021) and health subjects (Barbosa et al., 2022). Several models from the economic theories, for example, have also been considered as the basis to highlight the SAR and SEM. This includes the Keynesian, Neoclassical theories and the developments of the New Economic Geography (Martinho et al., 2021; Martinho & Barandela, 2021).

The data analysis highlighted the higher size of the farms in the south of Portugal, namely in the Alentejo region. When the number of hectares is divided by the number of farms and the number of agricultural annual work units, the parishes in the north and centre of Portugal also have the highest values, namely in the following municipalities: Arouca; Vizela; and Manteigas. Parishes from the north and centre of Portugal also present the highest values for average annual work unit per farm, the annual work units and the average total standard production value per utilised agricultural area.

The global spatial autocorrelation presents positive values for the Moran´s I statistics and the highest results were obtained for the variables related to the utilised agricultural area (total and divided by the number of farms and the annual work units). In general, the parishes from the south of Portugal have positive local spatial correlation for high-high values, except for the average total standard production value per utilised agricultural area.

The results from the cross-section regressions highlight the higher elasticities of the relationships between the total standard production value and the annual work units and the relevance of the SEM (showing that there are spatial processes related to the total standard production value that are not explained by the independent variables).

8. CONCLUSIONS

The contexts described in the data analysis are a consequence of farm size, which has implications for the number of hectares per farm and the labour required. In general, smaller farms require more labour due to the difficulties inherent in mechanisation and/or the production systems adopted. The spatial autocorrelation assessment shows greater uniformity in the size of farms in the parishes in the south of the country. The same is not true for productivity per hectare. The results from the regressions reveal that the size of farms and the labour force used are important in explaining the economic dynamics of the agricultural sector in Portugal, even in times of modernisation of the sector and the eventual release of workforce to other labour markets. Additionally, the findings obtained with this research show the importance of considering common strategies for the Portuguese parishes, because, in some cases, they are strongly spatially autocorrelated and the pertinence of holistic approaches for agricultural development, taking into account the farming sector in perspective of regional development.

The data available for Portuguese parishes relating to the variables considered in this research is limited, particularly for time series, and this limits the possibilities for analysis. In any case, the contributions made by this study can be used as a basis for future studies that consider panel data.

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ACKNOWLEDGMENTS

This work is funded by National Funds through the FCT - Foundation for Science and Technology, I.P., within the scope of the project Refª UIDB/00681. Furthermore, we would like to thank the CERNAS Research Centre and the Polytechnic Institute of Viseu for their support. This work was developed under the Science4Policy 2023 (S4P-23): annual science for policy project call, an initiative by PlanAPP - Competence Centre for Planning, Policy and Foresight in Public Administration in partnership with the Foundation for Science and Technology, financed by Portugal's Recovery and Resilience Plan.