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Economic resilience of agriculture in England and Wales: a spatial analysis

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ABSTRACT

Agriculture has a hugely important role to play in meeting many of the UN's Sustainable Development Goals (SDGs). Ensuring the economic resilience of farms and improving their capacity to respond to a wide range of challenges is key if agriculture is to contribute positively to achieving SDGs and sustainable growth. This paper aims to calculate the economic vulnerability and resilience of agriculture in England and Wales (UK), by analysing individual farm business data and using it to compute an aggregated agricultural resilience index at regional level across the two countries. The results of our analysis are visualised as maps, showing the geographical distribution of the input indicators and the final composite resilience index. We argue that this type of spatio-economic approach is useful for understanding the geography of agricultural resilience at sub-national levels, which could be valuable for helping to inform decisions and formulate strategies for promoting sustainable agriculture..

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agriculture; resilience; sustainable development goals (SDGs); risk management; agricultural policy; GIS

1. Introduction

The agricultural sector can contribute more than any other for meeting the United Nations' Sustainable Development Goals (SDGs) and achieving sustainable growth (Abraham & Pingali, 2020; United Nations, 2021). Most SDGs can be linked to agriculture as it is the main income-generating activity in developing countries (Gomez y Paloma et al., 2020) and farmers have a major role in managing natural resources all over the globe. Inclusive agriculture can create jobs, thereby reducing food insecurity and inequalities, and providing households in disadvantaged areas with higher incomes and improved nutrition, living, and health standards (SDGs 1, 2, 3, 5, 8, 10). Sustainable agricultural practices can also help to reduce water waste, dependence on fossil fuels, land degradation, biodiversity loss, and help farmers and society respond more effectively to climate change (SDGs 6, 7, 13, 15) Main Map.

However, agriculture is typically a high-risk endeavour, with farmers regularly having to cope with and manage a range of uncertainties such as seasonal and annual weather variation, crop pests and diseases, and volatile markets and prices. Moreover, because of its dependence on natural resources and its high responsiveness to international markets (Tangermann, 2011), the agricultural sector is also highly vulnerable to sudden challenges and structural changes such as those triggered by the COVID-19 pandemic, political reforms, and climate change, for example.

Farmers struggling to make a living are susceptible to abandoning the agricultural sector, and with it their role as providers of food security (and in some cases as stewards of the environment). Therefore, the capacity of farms to respond to challenges is vital for sustainable growth. For these reasons, four of the SDGs frame sustainable growth in relation to building resilience (United Nations, 2015), and policymakers put risk management at the top of the objectives of the Common Agricultural Policy post-2020 (European Commission, 2018) and of the UK's Agricultural Transition Plan 2021–2024 (DEFRA, 2020).

This paper aims to calculate and visualise the geographic distribution of farm resilience in England and Wales, UK. The objective is to produce regional (county) level maps showing different indicators of resilience, and to identify areas where the farming systems have a lower capacity to react and overcome challenges. Such maps could be useful for policymakers when designing and evaluating agricultural policies, by providing evidence to help formulate policies at a regional and local level. Our approach is based on using farm-level indicators related to farms' economic resilience, which is defined as the capacity of a farm to absorb a negative shock through the ability to 'persist' and maintain its commercial nature in the long term (Folke et al., 2003). We focus on England and Wales, but the approach is designed to be reproducible for any country or region where detailed farm accountancy data are available.

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Resilience as a concept is being adopted more and more in academic and policy environments, and there is a growing need for its measurement and assessment, but there are still significant difficulties in operationalising it. Such difficulties arise from the multidimensional and dynamic nature of resilience, and a substantial lack of primary farm business data especially in developing countries where are needed most – therefore more research is needed to develop better agricultural resilience models to further support decision and policy-making processes.

2. Materials and methods

2.1. Overview and study area

The methodology adopted in this research is based on the conceptual approach developed by the FAO's (Food and Agriculture Organisation of the United Nations) RIMA (Resilience Index Measurement and Analysis model) which has been successfully applied in more than 10 countries as a diagnostic tool to measure households' resilience to challenges, and as an impact evaluation tool to improve the design of future interventions (Brück et al., 2018; d'Errico et al., 2018; d'Errico & Di Giuseppe, 2018; d'Errico & Pietrelli, 2017). RIMA's approach consists of identifying multiple household characteristics and factors underlying their ability to resist challenges. In the household's case, these factors include income-generating activities, access to assets, public services, safety nets, and institutional/government support. In our case, we have aimed to identify farming systems (i.e. groups of farms in an aggregated geographical area) where farms have a lower capacity to react and overcome shocks/challenges (e.g. economic, social, institutional, and environmental – see Meuwissen et al., 2019) – therefore we based the identification of relevant farm characteristics on agricultural risk management theory (Vigani & Kathage, 2019). According to such theory, the ability of a farm to respond to and overcome challenges is given by five characteristics, namely: (1) financial stability; (2) economic performance; (3) income diversification; (4) crop diversity; and (5) extensification.

These characteristics were calculated using the Farm Business Survey (FBS) data for England and Wales from 2006 to 2015 (10 years) (Duchy College and Rural Business School, (2019a, 2019b, 2019c, 2019d, 2019e); National Assembly for Wales and Department for Environment, Food and Rural Affairs, (2019a, 2019b, 2019c, 2019d, and 2019e)). The FBS is an annual survey funded by the UK Government's Department for Environment, Food and Rural Affairs (Defra) and the Welsh Government and is the largest and most authoritative survey of the finances and performance of individual

farm businesses in England and Wales. Detailed business accounts and general and physical characteristics for about 2400 farms are collected annually.

The FBS data were provided as a series of Microsoft Access databases (one database for each year), which were processed, queried, and analysed using the open-source statistical programming language R (version 4.10 with RStudio v. 1.4.1717). FBS data are anonymised to prevent identification of individual farms, meaning that that data cannot be analysed and reported at a fine spatial resolution, and must be aggregated to county or unitary authority (UA) level in England and Wales. For this research, counties and UAs with low numbers of surveyed farms (<20) in each year of FBS were excluded from the analysis. A minimum sample size of 20 farms per geographical area reflects the actual rural/urban geography of local government areas in England and Wales; that is, counties and UAs with an FBS sample size below 20 were found to be metropolitan areas with a low density of farms, whereas areas with a sample size of 20 or greater were predominantly rural, agricultural areas. Maps were produced using a combination of R and the open-source desktop GIS software QGIS (version 3.16 'Hannover'), using geospatial boundary data for counties and unitary authorities in England and Wales downloaded from the Ordnance Survey Open Data website (Ordnance Survey, 2021). The study area map (Figure 1) shows the 49 counties and UAs which were retained for analysis (i.e. areas where the number of farms in each year of the FBS sample is greater than 20).

2.2. Development of resilience indicators and resilience index

The first resilience characteristic is a farms' financial *stability* (*S*). In the event of a challenge, drawing upon financial reserves is likely to be a key buffering mechanism in maintaining the day-to-day operation of a farm. According to Doeksen and Symes (2015, p. 332), financial vulnerability can 'jeopardise the firm's independence, its flexibility of manoeuvre and, in the long run, threaten its survival'. A common risk management strategy to counter financial vulnerability is to minimise the debt ratio of the business (Darnhofer, 2010), therefore financial stability was calculated as a percentage, based on the ratio of current liabilities to assets (liabilities/assets * 100). Liabilities comprised all current business liabilities, including mortgages, loans (bank and family), leases, hire purchases, creditors, and bank overdrafts. Assets included all agricultural land and woodland, buildings, machinery, crops, livestock, debtors, cash (at the bank and in hand), entitlement to subsidies, and others. It is expected that a farm

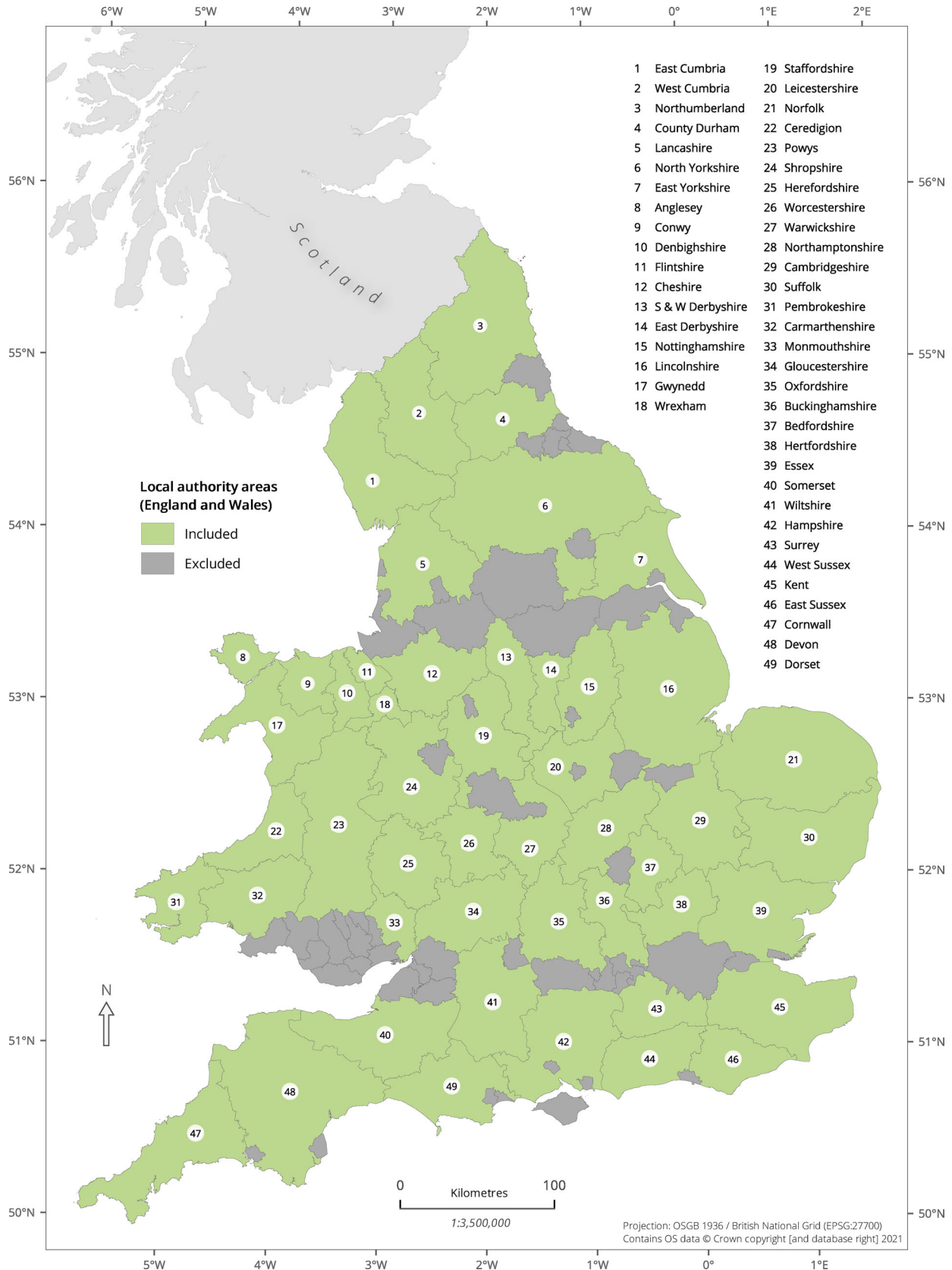


Figure 1. Study area map showing the county and unitary authority areas in England and Wales included in the analysis.

which is economically vulnerable (i.e. with a high debt ratio and overexposed in terms of liabilities, and therefore with a lower proportion of its own capital to deal with unexpected challenges) will display a lower capacity to cope against them.

The farm’s economic *performance* (*P*) is a measure of the productivity and efficiency of a farm business and it is an important determining factor in the capacity of a business to maintain its function in response to a challenge. [Abson et al. \(2013\)](#), for

example, used agricultural gross margin as a proxy for economic resilience of lowland farms in the UK. A farm's performance indicates its ability to convert inputs into outputs as a function of managerial decisions. More efficient use of production factors suggests higher returns for unit of inputs, which can be capitalised to reduce debts, thereby increasing financial stability and persistence in the face of turbulence. Hence, we calculate performance as the ratio between outputs and total business costs (inputs), expressed as a percentage. Outputs extracted from the FBS for use in this calculation included outputs from crops, livestock, and diversified activities, but not agricultural subsidies. Costs included a wide range of farm business costs, with an adjustment for unpaid labour. Farms with higher economic performance can benefit from higher returns and liquidity to face a period of unfavourable production conditions.

Diversity is seen as an important strategy across disciplines for reducing various risks through a portfolio approach to risk management (Martin & Sunely, 2015). We consider two types of diversity. First, the farm's *income diversification (D)*. For a farm business, increased diversity can be implied to mean greater flexibility; an important characteristic that can enable farms absorb negative shocks, and to adapt to new circumstances over time (Darnhofer, 2010; Darnhofer et al., 2016). By diversifying the farm income, low revenues in some farming activities can be offset by higher revenues in other activities, stabilising overall income and therefore increasing resilience (Abson et al., 2013; Meuwissen et al., 2019; Van Asseldonk & Huirne, 2008). Therefore, financial diversification can lead to greater capacity to adapt and transform. We calculate diversification as the ratio between total farm income and the income from diversified (i.e. non-agricultural) activities, expressed as a percentage. Diversified activities include those associated with retailing, rents, tourism and catering, crafts, and power generation.

The second important type of diversity is *crop diversity (C)*. Production risks include biotic and abiotic challenges such as extreme and more variable weather brought about by climate change, and disease, insect, and weed pressures can be potentially mitigated with an appropriate crop diversification strategy (Matsushita et al., 2016; Roesch-Mcnally et al., 2018). Because different crops will respond differently to challenges, a diversified portfolio of crops can improve agro-ecosystem resilience by reducing the probability of crop failures and maintaining productivity, while being less exposed to production risks and yield variability (Abson et al., 2013; Di Falco & Chavas, 2006). Crop diversity was calculated using a Simpson Diversity Index (SDI), constructed using SQL queries to extract data on individual crops for each farm from the FBS dataset. The SDI measures both the richness

and evenness of the crops on a farm, where richness is the number of crop types present on each farm, and evenness is the abundance of the different crop types, based on area. The resulting index is a value for each farm ranging from 0 to 1, where the greater the value, the greater the crop diversity.

Extensification (E) is the final resilience indicator. Input-intensive production systems rely heavily on energy for machinery and agro-chemicals for fertilisation and pest management. Such inputs are highly dependent on international market prices and their volatility - therefore more intensive farms are more exposed to market and price shocks, while extensive production systems have a relatively reduced dependency on critical inputs (Rose & Krausmann, 2013). Extensification was calculated as the total inputs divided by the total area of utilised agricultural land. Input expenses were extracted individually as raw variables from the FBS, and include costs associated with agricultural machinery (fuel, oil, and running costs), fertilisers, and crop protection.

Once the individual characteristics had been calculated, it was necessary to process and normalise/standardise the data, so that the variables could be combined to calculate a composite index. This involved calculating the natural logarithm for the variables with large values and data ranges (i.e. stability, performance, and extensification) and then normalising each variable using the min-max method, so that each resilience variable was given a value in the range of 0 and 1. The final processing step involved converting the stability and extensification resilience variables to negative values by multiplying them by -1 , as increases in positive values for these variables were thought to have a negative impact on the ability of a farm to resist challenges. The composite index was calculated as a standardised aggregation of the characteristics as in (1) and (2):

$$ER_i = S_i + P_i + D_i + C_i + E_i \quad (1)$$

$$ERI_i = \frac{ER_i - ER_{min}}{ER_{MAX} - ER_{min}} \quad (2)$$

where $i = 1 \dots n$ number of farms.

As a robustness check, the correlation between the variables of the index was calculated and it is very low, between -0.2 and 0.3 . This confirms that each dimension of the index measures a different element of resilience and that variables are not collinear. Moreover, the composite index *ERI* was also calculated using Cronbach Alpha (*Alpha*) and Principal Component Analysis (*PCA*)¹. The correlation between the three measures of *ERI* is always positive and statistically significant at 1% level, suggesting that *ERI* is robustly computed across different methodologies.

3. Results

Geographic relationships across counties and UAs for each indicator of economic resilience were analysed using Moran's I measure of spatial autocorrelation. This is computed by calculating the standard deviation for the target variable in each geographical unit and comparing the *z*-values in each area to those in spatially contiguous areas. Moran's I helps determine whether the data are positively, negatively or randomly correlated (clustered) in geographical space. The Moran's I statistic reports a value between -1 and $+1$, where $+1$ is a perfect clustering of data (i.e. highly spatially autocorrelated) and -1 is perfect dispersal of data (i.e. highly spatially autocorrelated). A value of 0 means there is a completely random spatial dispersal of values. The Moran's I statistics for the resilience variables are presented in Figure 2. Data points (one for each county/UA region) in the lower-left or upper right quadrants of the Moran's plots indicate positive spatial autocorrelation of values that are lower or higher than the sample mean (indicated by the dotted lines), respectively. If data points are grouped in these quadrants, there is a geographic 'clustering' of data points with similar values. The slope of the line shows the degree of spatial autocorrelation; the steeper the line, the stronger the level of spatial autocorrelation. Data points in the lower-right and upper-left quadrants are negatively spatially autocorrelated; that is, these values carry little similarity to their neighbouring ones. Moran's I values ($p < 0.005$) for the crop diversity (0.21) and performance (0.17) are positive, but fairly weak. The data for stability (0.37) and extensification (0.37) are more strongly positively correlated, while the value for diversification (0.74) shows a very strong positive spatial autocorrelation, suggesting a substantial geographical clustering of this indicator.

The maps in Figure 3 illustrate the different levels of spatial autocorrelation and show where data values are clustered. The clearest example of this is, as we might expect given it is high Moran's I value, diversification, which shows a definite clustering of data values in South East England, an area of high population density and economic activity where opportunities for farm diversification would likely be greatest.

Moran's I computed for the composite index ERI (0.08) suggests a weakly positive geographical distribution of resilience (Figure 1). Variation between and within counties/UAs was tested using ANOVA ($F = 25.15$, $p < 2e-16$), which suggested that the variation of resilience means among different counties is significantly larger than the variation of resilience within each county. Hence, we can conclude that for our confidence interval we accept the alternative hypothesis that there does appear to be a significant relationship between resilience and geographical

units, as measured at county/UA level in England and Wales. The Main Map shows the county-level maps for the resilience indicators and composite resilience index, along with the study area map of England and Wales, for reference.

4. Discussion and conclusions

The output maps produced from the analysis provide significant information in relation to resilience and the SDGs. Areas such as Dorset, Lincolnshire, and the West Midlands have a high level of farms' financial stability, reducing the probability of deprivation and falling into inequality traps in rural areas, indicating positive alignments to 'SDG 1 – No poverty' and 'SDG 10 – Reduced inequalities'. However, financial stability does not necessarily correspond to the improved business performance that can lead to higher farm's income and sustainable growth, supporting 'SDG 8 – Decent work and economic growth' and 'SDG 11 – Sustainable communities' (although it should be recognised that if not implemented in a sustainable way, improved business performance could potentially have a negative impact on SDGs – e.g. '6 – Clean water' and '12 – Responsible consumption and production'). We found higher farm performance in the East of England, East Sussex, and Northumberland. Agricultural diversification is significant in the southern Midlands and South East of the country, while crop diversification is highest among farms in the middle-central counties and south-west of England. Crop diversity and extensification are linked to environmental and conservation practices, which support SDGs such as '6 – Clean water', '12 – Responsible production', '13 – Climate action' and '15 – Life on land'. Combining this information into a single resilience index, our results show that the most economic vulnerable counties include Lancashire, Nottinghamshire, Worcestershire, Carmarthenshire, Ceredigion, Anglesey, and Denbighshire, while the most economic resilient are Northumberland, Warwickshire, Oxfordshire, Northamptonshire, Buckinghamshire, Wiltshire, Hampshire, Kent, and East Sussex. This synthetic information is useful to assess and design SDGs' strategies for overall sustainable growth.

We argue that visualising the geographic distribution of farms' resilience to challenges is an important tool for identifying sub-regions where farming systems have particular needs for support to become more resilient and therefore to create an enabling environment for the continuation of the agriculture business, with positive effects on food security, agroecosystems stewardship, and overall sustainable growth. Though our analysis is conducted with data for UK farms, many other counties have similar surveys collecting business and accountancy data, such

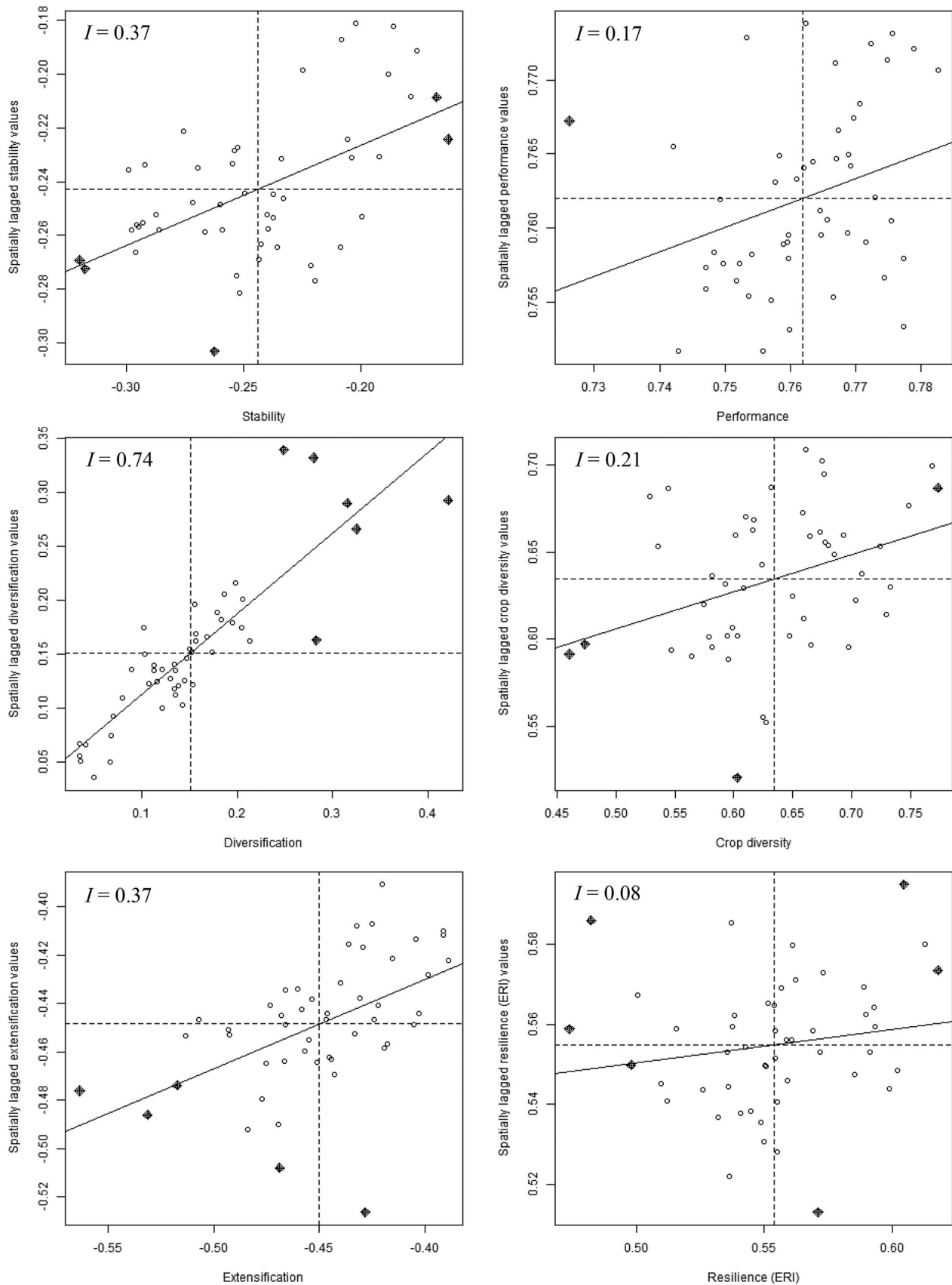


Figure 2. Moran's I plots showing the spatial autocorrelation for individual and composite indicators. Each data point is a geographical unit (i.e. county/UA).

as the EU's Farm Accountancy Data Network (FADN), that would allow replication/comparative analysis of the work conducted in this study.

Software

The processing and analysis of the FBS data (including production of the Moran's I plots) were conducted

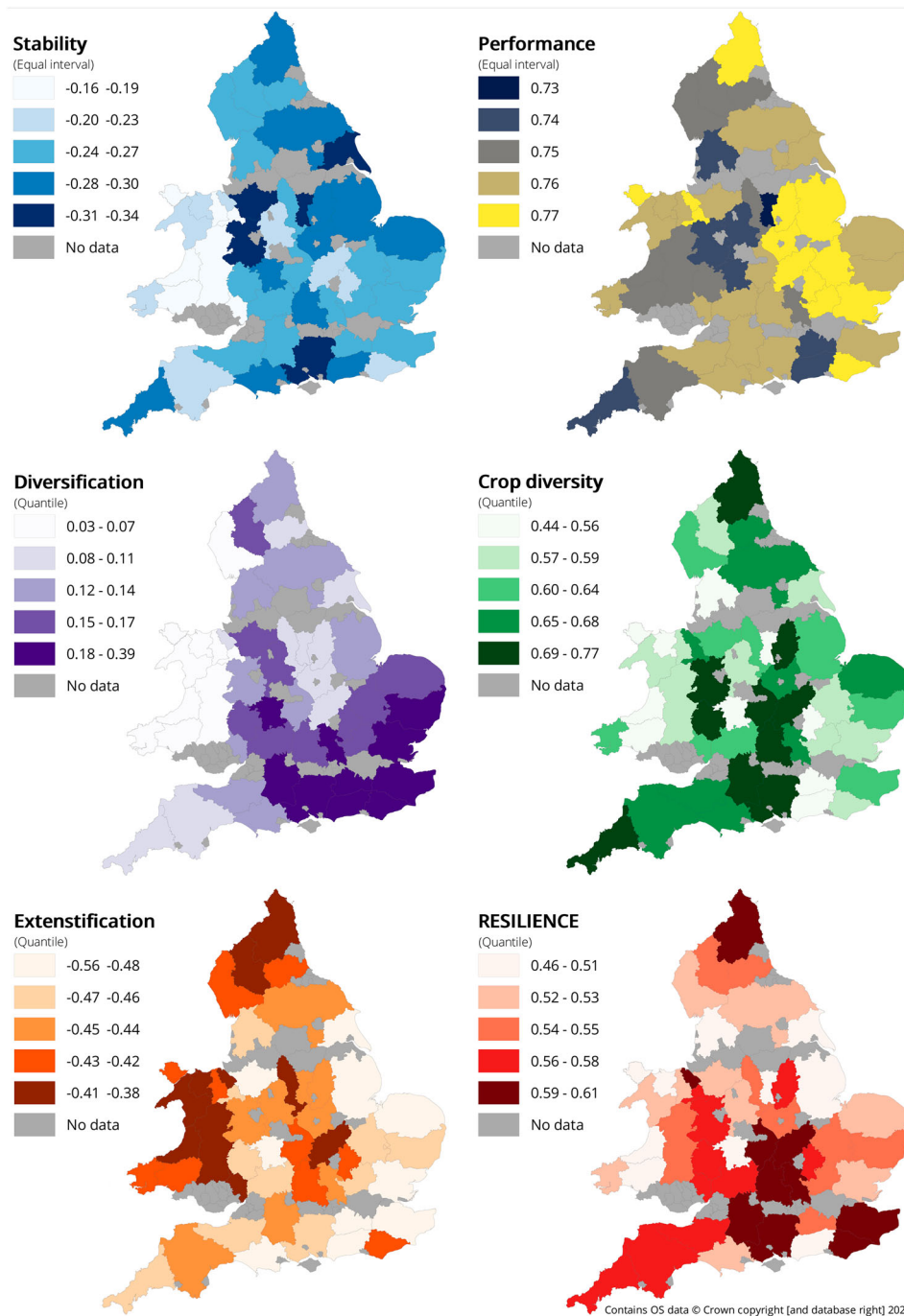


Figure 3. Maps showing the spatial distribution of the five individual resilience indicators plus the composite resilience index. Values are in descending order, with higher numbers at the lower end of each legend – higher values mean the indicator contributes more positively to increasing resilience.

using the open-source statistical programming language R (version 4.10 with RStudio v. 1.4.1717). ESRI Shapefiles were outputted from R and visualised as maps using the open-source desktop GIS software QGIS (version 3.16 ‘Hannover’).

Geolocation information

England and Wales, United Kingdom.

Note

1. Details of the estimation of *Alpha* and *PCA* are available upon request to the authors.

Data availability statement

This research is based on the data collected from an annual survey called the Farm Business Survey (FBS) for England and Wales. The data are available under strict licence from the UK Data Service (UKDS – <https://ukdataservice.ac.uk/>) and is not open data – we therefore cannot make this data available as part of the submission. Full licencing information for each year of the FBS used in this research is shown in the References section. Spatial boundary data for county and unitary authority areas in England and Wales was provided by the Ordnance Survey – this is open data and is available to download at: <https://www.ordnancesurvey.co.uk/business-government/products/boundaryline>.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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