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Geopolitical deadlock and phosphate shortfall behind the price hike? Evidence from Moroccan commodity markets

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Abstract: Phosphate fertilisers rank among limited conventional production aids, requiring eco-unfriendly mining methods. On the other hand, wheat is an indispensable agricultural commodity essential in the food industry. For this reason, it is appropriate to monitor the potential bivariate relationship between these commodities and to follow their future development closely. The article aims to identify a correlation (Kendall's tau) and causal (Granger causality test) between the price of Moroccan phosphate and wheat, applying vector autoregression (VAR). The results show a medium-to-strong correlation between phosphate and wheat, while causal analysis suggests a reciprocal relationship. The final prediction indicates the price stability of Moroccan phosphate and a fall in wheat prices, showing steady trends of the Moroccan phosphate and wheat market affected by the alarming situation in Ukraine. The article's drawbacks are a narrow market specialisation, which ignores other agricultural commodities. Our findings contribute to national officeholders and professional public, private and non-profit agrarian organisations. Investors may benefit from exploring turbulent exogenous variables like a critical geopolitical deadlock in Ukraine. The main contribution highlights the fact that the conventional fertiliser and wheat market situation appears to be stable and free from elements of uncertainty.

Keywords: Granger causality; Kendall's tau; Moroccan phosphate; Vector Autoregression Model; wheat

Phosphorus is essential for lush and luxuriant vegetation, penetrating the organism through its roots. We have recently seen a shortfall of the element in soil ecosystems, hindering healthy plant growth and causing a global lack of food. Farmers settle the issue by adding phosphorus to fertilisers, sometimes reaching 80% of the ratio. Although the element optimally penetrates the ground, it seeps through underground water and wastewater, severely harming the environment. Farmers should avoid over-fertilising to mitigate harmful effects and learn how to use fertilisers efficiently.

Non-renewable phosphate resources are running out, heading for rapid depletion. The statistics suggest 165 to 195 mil. tonnes of production per year, including Morocco, China and the USA as the leading global producers. European states rely heavily on imports (Sun et al. 2018; Bogusz 2022; Gadaleta et al. 2022).

Jia et al. (2018) point to enormous population growth and follow-up heavy demand for natural resources. If minimum items, like phosphorus, enter agricultural production, these meagre resources will cause limited production outputs. This principle is typical for developing countries. But for phosphorus additives,

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we would not be able to cultivate plants, vegetables and fruits for eating or further processing. Jing et al. (2022) consider phosphate fertilisers a trigger mechanism for faster plant growth and nutrient uptake.

Wheat, used mainly for further processing, ranks among essential agricultural commodities on the global market. However, its production suffers from the limited availability of phosphorus, which disappears due to resource depletion from the fertile ground (Majeed et al. 2018; Suleman et al. 2022). Wheat is also a vital nutrient whose lack leads to prolonged starvation of local consumers in many global regions (Yazbeck et al. 2022).

On top of the shortfall of phosphate-based conventional fertilisers, we must consider another crucial factor – the current geopolitical situation. As Ukraine ranks among the leading global wheat producers, the unresolved armed conflict threatens global commodity supplies (Mottaleb et al. 2022). Saadaoui et al. (2022) observe a one-way causal relationship between geopolitical risk and food price. Pereira Domingues Martinho et al. (2022) include a hectare wheat profit rate, global warming, and the COVID-19 pandemic as other exogenous influential factors profoundly inflating wheat prices and other commodities (Abdalla et al. 2023).

The article aims to identify a causal relationship between the market (commodity price) of Moroccan phosphate and wheat. Many economic studies have already covered the topic, including Olagunju et al. (2021), who explored the connection between phosphate fertilisers and wheat prices, and Cordell and Neset (2014) and Chowdhury et al. (2017), who point to dwindling phosphate supplies threatening agricultural production.

To achieve our goal, we formulated these research questions.

RQ_1: Is there a causal relationship between Moroccan phosphate and wheat price?

First, we must find a correlation, but that is not enough. Cointegration allows us to assess the interconnection between the commodities. Reciprocal relationships show that one variable can predict the other.

RQ_2: What will be the price movement in the future?

The prediction is valuable upon confirming the reciprocity of the quantities. Vochozka et al. (2020) suggest a prediction is useful when economic variables significantly correlate. The competitive advantage will allow capturing the market, as limited resources of conventional phosphate fertilisers will likely fuel inflation.

Literature review. Phosphorus comes from phosphate, occurring in sedimentary deposits or igneous ore, mixed with alkalic rocks. Quality phosphate extraction involves a complex concentration mechanism with several (bio)geochemical processes. Sound knowledge of phosphate extraction procedures compensates for gaps in geochemistry, mitigating the slowdown of extracting future resources (El Bamiki et al. 2021). Underground mining encompasses an elaborate engineer's system and non-linear processes. The largest Chinese mining companies research innovations to stimulate extraction, increasing the country's economic value and streamlining phosphate mining processes in China (Li et al. 2021). Morocco has become the leading phosphorus producer, generating 35 mil. tons a year (Berroug et al. 2021). Historically, Florida is the largest global phosphate maker. The mining industry affects the transport of nutrients from organic and inorganic forms of nitrogen and phosphorus, draining more than 10% of phosphorus from large rivers and tributaries during spells of rain. The proposal will contribute to recultivating phosphorus in watercourses (Duan et al. 2021).

Although phosphorus belongs to limited resources, the element ranks second among essential plant nutrients, stimulating crop growth, development and productivity. Its inappropriate use could cut global crop production (Bhatta et al. 2021). Chowdhury and Zhang (2021) suggest a new system for effectively using phosphorus fertilisers to ensure sustainable resources and protect the environment.

The global agricultural sector is struggling with a lack of phosphorus in soil vegetation. Yang and Yang (2021) explain the use of its residues in multiple soil types according to specific reproduction, suggesting various methods of sowing, cultivating, fertilising and removing phosphorus using phosphate substitution microorganisms. Wali et al. (2022) analyse limited soil eutrophication due to the lack of phosphorus, using biochar (biomass) from wheat straw.

Many experts explore the possibilities of renewing the element from underground water. Maroušek et al. (2020) point to the financial benefits of biochar when extracting phosphorus from wastewater. Since existing results always showed limited potential for mineral renewal (due to high costs), the topic was subject to extensive revision. A new concept involves a cost-saving model producing biochar from fermentation remains, i.e. thermochemical pyrolysis, ensuring eco-friendliness and a low-cost operation. Geissler et al. (2018) emphasise an inevitable transition to regenerative agriculture.

Swap trading of natural fertilisers protects the price risk index, as price movements cannot react to volatile financial markets. The analysis involves ratios and efficiencies of changing urea with ammonium phosphate. The fertiliser indexes reflect the US spot prices over

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a short period (Maples et al. 2019). Phosphate resources are heading to developed countries, according to the geographical position of international businesses. The methodology comes from MRIO (Multi-Regional Input Output) analysis, aiming to end consumers. An optimised supply chain will reduce agricultural costs and the risk of eutrophication (Yang et al. 2019). The indicator of the phosphate fertiliser demand involves price dynamics and responses to changes in time. The global call for the mineral is inelastic in price over short or long periods (Al Rawashdeh 2022).

Economic experts discuss the complicated production, distribution and consumption of natural resources, warning about socio-economic issues in transdisciplinary processes. While the turn of 2007 and 2008 marks a general misconception of the phosphor price peak, the span between 1983 and 2013 saw an annual increase in extracting phosphorites by about 3.2%. Economists try to correct these socially harmful fallacies to increase public knowledge and awareness (Scholz and Steiner 2022).

Determining causal relationships between economic quantities involves the conventional Granger causality test (GC). Despite its wide application, Grosche (2014) and Wimmer et al. (2021) point to the test's inability to assess speculation on the agricultural and energy markets. On the other hand, Apergis et al. (2021) received impressive results using GC to test the connection between economic efficiency and commodity prices. Ye et al. (2019) and Akvildirim et al. (2022) arrived at the same conclusion, observing interactions between macroeconomic quantities in China and economic profitability on futures in troubled times, respectively. Ascorbebeitia et al. (2022) suggest combining GC with the Kendall's tau correlation coefficient when observing Euro Stoxx Index. Fei et al. (2020) use Kendall's tau to explore the relationship between commodity prices and inputs/outputs of cattle breeding.

High-accuracy prediction models involve artificial neural networks (ANN) based on physio-neurological processes for effective learning and data processing (Vochozka et al. 2021). Sahinli (2021) includes vector autoregression as another prediction model when predicting a wheat price in Turkey. Lakkakula (2018) applies VAR to explore interrelationships between five types of fertilisers, indicating urea as a crucial determinant in phosphate fertiliser prices.

The Kendall's tau correlation coefficient will explain our research aims in the first phase, whereas the Granger causality test will complement VAR in the second part. This combination will explore the relationship between two quantities and predict their movement.

MATERIAL AND METHODS

Data. The presented data reflect the indexmundi.com database (IndexMundi 2023), comprising relevant information from stock markets, expressed in US dollars per negotiated ton of the commodity (phosphate and wheat), including closing and unadjusted prices. The data series on Moroccan phosphate and wheat observe monthly periods, starting in January 1993 and ending in September 2022. The series involves 357 inputs, yielding relevant statistical results.

Methods. We constructed all models in the R programming language, setting the significance level at 0.05. An analysis examining the relationship between the Moroccan phosphate and wheat price answers the first research question, using Kendall's tau as an effective statistical instrument of a non-parametric test.

Already included in the VAR, the GC model explores the relationship between Moroccan phosphate and wheat price. The first step involves VAR reflecting time series models, i.e. vectors of endogenous variables. The formula for VAR is as follows:

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + CD_t + u_t \quad (1)$$

where: y_t – vector $K \times 1$ endogenous variable; u_t – error of the same dimensions; $A_1, \ldots, A_p$ – symbolise $K \times K$; C – matrix of possibly deterministic regressors on base ($K \times M$); D – vector with deterministic regressors (e.g. trend, constant etc.).

Addressing Stock and Watson (2019), we can analyse VAR in the R programming language. The analogical formula is the same as in equal 1, supplemented by the second observed variable X_t.

$$Y_t = \beta_{10} + \beta_{11} Y_{t-1} + \ldots + \beta_{1p} Y_{t-p} + \gamma_{11} X_{t-1} + \\ + \gamma_{1p} X_{t-p} + u_{1t} \quad (2)$$

$$X_t = \beta_{20} + \beta_{21} Y_{t-1} + \ldots + \beta_{2p} Y_{t-p} + \gamma_{21} X_{t-1} + \\ + \gamma_{2p} X_{t-p} + u_{2t} \quad (3)$$

where: Y, X – observed vectors of endogenous variables; β – i^{th} variable at time t; γ – i^{th} variable in the previous time step (lagged value).

The prediction reflects ten periods (data frequency corresponds to ten months), from October 2022 to July 2023. Scripts are illustrated in Figures S1–S3 in the Electronic Supplementary Material (ESM).

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RESULTS

Time series correlation analysis. We use the Kendall's tau to apply correlation analysis. Table 1 illustrates Kendall's tau calculations. Given the low *P*-value (2×10^{-16}), we can reject H_0, confirming a close relationship between the observed economic variables.

Value 0.52 indicates a medium-to-strong correlation, presuming that an increase in one quantity triggers an increase in the second variable and *vice versa* (direct proportion).

VAR model. Vector autoregression has a variety of uses. On top of accurate predictions, the model allows for cointegration. Thus, we answer RQ_1 and fulfil RQ_2.

As we preserve the system of the research questions, the first phase involves analysing a causal relationship between two time series, i.e. Moroccan phosphate and wheat, using VAR. The incorporated GC model outlines the connection between the price of Moroccan phosphate and wheat price (Figure 1). *P*-value < 1.244×10^{-8} rejects H_0, accepting the alternative hypothesis on the dependence of the wheat price on phosphate values.

Similarly, we observe the opposite effect when wheat prices affect phosphate rates. The time lags are set to 2 in both cases. *P*-value < 2.2×10^{-16} again rejects H_0, confirming the statistical relevance of H_1 when the wheat price sways Moroccan phosphate (Figure 2).

Now we can use VAR for predicting both observed quantities, whose values are illustrated in Tables 2 (wheat) and 3 (phosphate). Figure 3 depicts the prediction, complying with ten calendar months.

Table 1. Kendall tau calculations

Correlation	*R* (Kendall's tau)	*P* value
Phosphate/wheat	0.52	2.2×10^{-16}

Source: author's own elaboration

```
Model 1: restricted model
Model 2: wheat ~ L(phosphate, 1:2)

Note: Coefficient covariance matrix supplied.

  Res.Df Df      F    Pr(>F)
1    354
2    352  2 19.177 1.244e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 1. Granger causality test between Moroccan phosphate and wheat

Source: author's own elaboration

```
Hypothesis:
L(wheat,2)1 = 0
L(wheat,2)2 = 0

Model 1: restricted model
Model 2: phosphate ~ L(wheat, 1:2)

Note: Coefficient covariance matrix supplied.

  Res.Df Df      F    Pr(>F)
1    354
2    352  2 168.83 < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 2. Granger causality test between wheat and Moroccan phosphate

Source: author's own elaboration

Table 2. Wheat movement prediction from October 2022 to July 2023 using VAR

Date	*Fcst*	Lower	Upper	CI
Oct 1, 2022	423.8928	392.2334	455.5522	31.65944
Nov 1, 2022	422.4557	372.3569	472.5544	50.09875
Dec 1, 2022	419.1875	355.2780	483.0969	63.90947
Jan 1, 2023	415.5417	340.7007	490.3827	74.84100
Feb 1, 2023	411.8927	328.0232	495.7621	83.86946
Mar 1, 2023	408.3326	316.7757	499.8895	91.55690
Apr 1, 2023	404.8802	306.6341	503.1263	98.24608
May 1, 2023	401.5352	297.3757	505.6948	104.15952
June 1, 2023	398.2929	288.8429	507.7429	109.45001
July 1, 2023	395.1477	280.9201	509.3752	114.22754

VAR – vector autoregression; *Fcst* – point forecast
Source: author's own elaboration

Table 3. Prediction of the movement of Moroccan phosphate from October 2022 to July 2023 using VAR

Date	*Fcst*	Lower	Upper	CI
Oct 1, 2022	318.1230	287.0188	349.2273	31.10424
Nov 1, 2022	318.2740	271.6085	364.9395	46.66548
Dec 1, 2022	319.1539	262.0989	376.2089	57.05502
Jan 1, 2023	319.9808	255.4182	384.5434	64.56258
Feb 1, 2023	320.4915	250.0865	390.8965	70.40499
Mar 1, 2023	320.6346	245.3766	395.8926	75.25800
Apr 1, 2023	320.4266	240.9114	399.9419	79.51524
May 1, 2023	319.9021	236.4878	403.3163	83.41425
June 1, 2023	319.0975	231.9972	406.1977	87.10028
July 1, 2023	318.0471	227.3858	408.7083	90.66126

VAR – vector autoregression; *Fcst* – point forecast
Source: author's own elaboration

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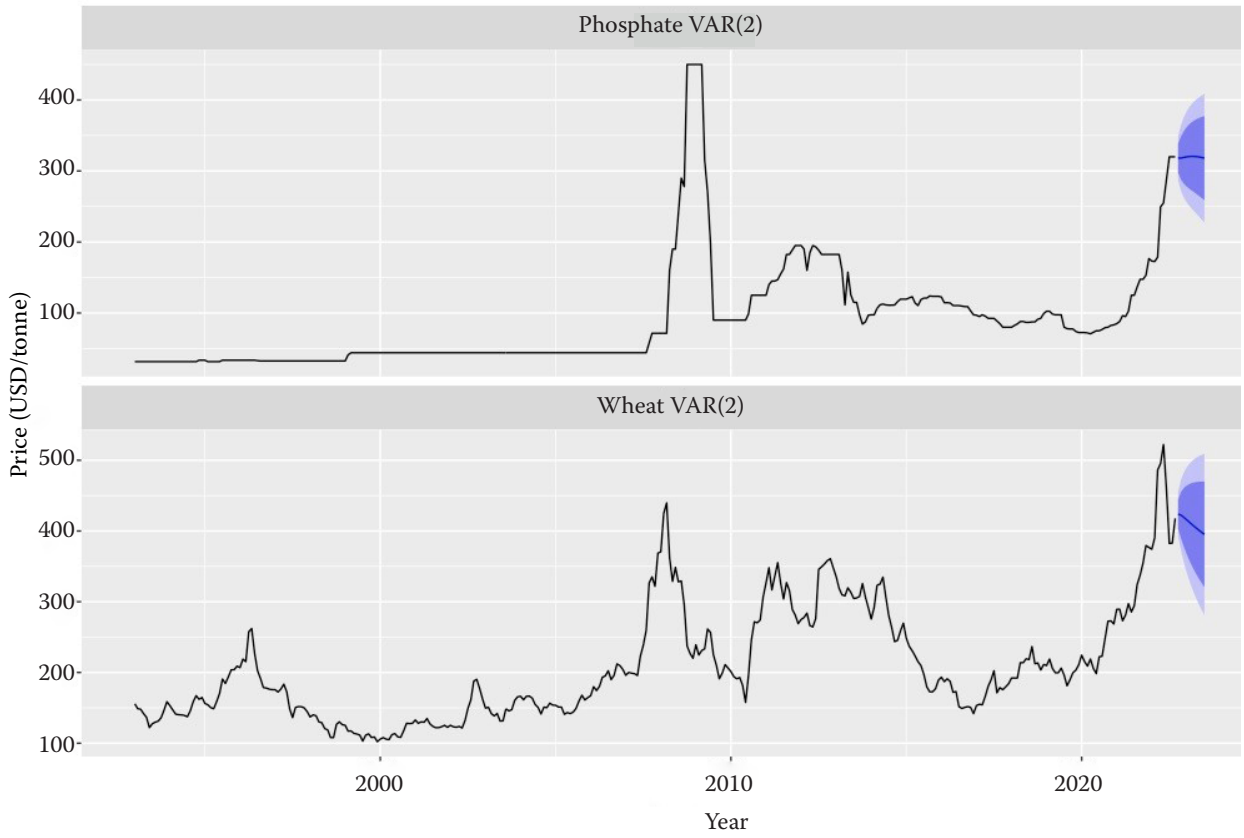

Figure 3. VAR prediction of Moroccan phosphate and wheat

VAR – vector autoregression
Source: author's own elaboration

The wheat values show a slightly downward trend, falling by 6.7% (based on the first to the last observed month). The lower prediction limit sees a more drastic decline, indicating a difference of 28% between the first and last monitored month. The upper boundary shows a growth trend with a difference of 11% between the first and last month of the period.

Based on the data, the prediction trend of Moroccan phosphate is constant, ranging from 318 USD·t^{-1} to 320 USD·t^{-1}. The lower limit reflects a steady decline in prices, indicating a difference of almost 21% between the first to the last month. On the other hand, the upper boundary shows a price increase, implying a rise of about 17% (408.7 USD·t^{-1}) in July 2023 compared to October 2022.

Figure 3 shows a time series of Moroccan phosphate and wheat, including a ten-month prediction. The determination coefficient, adjusted *R*-squared, stretches from 0.959103 and 0.9552096, indicating a quality statistical regressive apparatus.

DISCUSSION

The article aimed to explore the relationship between the price of Moroccan phosphate and wheat, tackling two research questions.

RQ$_1$: Is there a causal relationship between Moroccan phosphate and wheat prices? First, we performed a non-parametric correlation test based on Kendall's tau of Ascorbebeitia et al. (2022), revealing a medium-to-strong direct correlation between phosphate and wheat prices (r = 0.52). VAR and GC tests confirmed reciprocity, i.e. the inflationary effect of Moroccan phosphate and wheat prices flows both ways.

RQ$_2$: What will be the price movement in the future? According to a prediction suggested by Vochozka et al. (2020), we confirmed a very close correlation and causal relationship between the price of Moroccan phosphate and wheat price on the commodity market. The prevailing trend in wheat prices does not agree

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with Mottaleb et al. (2022), who warn about threatened wheat supplies due to the Russian-Ukrainian conflict. Rather than that, our prediction proves a constant decline in its price. Moroccan phosphate values do not cause worries either. Since the commodity shows little volatility, its rates will oscillate around the final price from September 2022 (318 USD·t^{-1}).

The research suffers from a limited view of the market and insufficient identification of potential endogenous and exogenous variables. A further inquest should measure the impact of Moroccan-extracted phosphates and alternative fertilisers (urea etc.) on agricultural production, as these crop production aids affect global phosphate prices (Lakkakula 2018). The military conflict in Ukraine gave rise to many factors involved in the wheat price slump, including unblocking transport routes. Although statistically stable (proved by *P*-values and adjusted *R*-squared), using only one model cannot yield reliable results.

Further research should explore other impactful commodities and their link to Moroccan phosphate (corn etc.), examining a causal relationship between unconventional fertilisers (Lakkakulay 2018) and production outputs. Statistically, the apparatus might involve other prediction models to compare the outcomes for higher reliability.

Our findings can appeal to policymakers, including national politicians or state, private or non-profit agrarian organisations. The results can also be significant to investors, reflecting bearish market sentiments in adverse market conditions (lack of resources and ethics of extraction). Although seemingly sequential (short-term), the findings reflect turbulent times, adding value to our conclusions.

CONCLUSION

The study aimed to explore the relationship between the commodity price of Moroccan phosphate and wheat prices, using VAR as a predictor. Kendall's tau and GC non-parametric correlation coefficients revealed a medium-to-strong correlation. A cointegration analysis, i.e. a GC model incorporated in the VAR, confirmed reciprocity between Moroccan phosphate and wheat prices. VAR predictor indicated a constant trend in phosphate values correlating with final values of the time series, showing a decline in wheat rates. The findings revealed no relationship between the geopolitical deadlock (linked to the war in Ukraine), complicated extraction of Moroccan phosphate and potential heteroscedasticity on the commodity markets in the first half of 2023. We fulfilled our research aim.

The article suffers from a too-narrow specialisation, reflecting only conventional fertilisers and wheat prices. Further research might explore other crops, including corn etc. Employing more prediction models to compare the results would also go a long way.

A future inquest might also observe the use and link between unconventional fertilisers (e.g. urea) and the final product or conventional phosphates, including other essential crops (e.g. corn).

The fluid geopolitical situation might make our findings appealing to national policymakers and state, private and non-profit agrarian organisations. An uncertain exogenous environment should not prevent shareholders from investing in a relatively steady market.

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Predispositions and challenges of agriculture from areas particularly facing natural or other specific constraints in Poland in the context of providing environmental public goods under EU policy

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Abstract: The study's main objective is to determine the predisposition and challenges of agriculture to provide environmental public goods to society in areas particularly facing natural or other specific constraints (ANCs) established within their current delimitation in Poland. Its organisational features, economic situation, and the degree of interest in measures specifically serving the protection of the natural environment under the Common Agriculture Policy (CAP) EU were indicated. Statistically significant factors determined farmers' willingness to participate in these measures. It turned out that farms from ANCs communes with particularly difficult conditions significantly contribute to the total production potential of agriculture in Poland. However, compared to farms with better natural conditions, they are characterised by a lower income per 1 ha of utilised agriculture area (UAA) and a higher share of subsidies, including those for participation in environmental measures, which were implemented to a greater extent. Based on the logistic regression model, it was found that in ANCs communes with particularly difficult conditions, the most important factor of farmers' greater willingness to implement environmental measures was their higher level of education. On the other hand, this inclination was negatively affected by the higher income adjusted for operating subsidies per 1 ha of UAA.

Keywords: agri-environment-climate measure (AECM); environmental public goods; logistic regression model; New Institutional Economics (NIE); organic farming measure

It is widely believed that humanity has never been so close to causing a global crisis resulting from the current scale of violation of key boundaries defining the safe functioning of the natural environment (IPBES 2019; Dasgupta 2021). Despite its efforts to stop this process, the degradation of many of its ecosystems continues, including those of exceptionally high natural value and used for agriculture (Stoate et al. 2009; Chu and Karr 2017; Pe'er et al. 2020). The state of affairs, therefore, prompts an urgent strength-

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ening of the existing institutional actions taken to protect it even more strongly (Bradley 2021). First, they should be concerned with improving the condition of soils used for agriculture. They are one of the basic resources of the natural environment, necessary for the survival of humanity because the good condition is of fundamental importance for the effective fight against climate change, the production of healthy food and human health, the preservation of biodiversity and ensuring food security (Orgiazzi et al. 2016, Brevik et al. 2020). It should be emphasised that agriculture, by properly caring for the quality of soils, can provide society with a wide range of public goods, as is increasingly expected from it (Nilsson et al. 2017).

In the European Union (EU), there is a great readiness and will of the European Commission (EC) to take action to protect agricultural soils. They are demonstrated in the currently most important EU strategic document, the European Green Deal (EGD) strategy of 2019, and in its thematic strategies for 2020–2022. As a priority, areas where agriculture operates under disadvantaged conditions, with low-quality soils and low natural organic matter content, require urgent remedial action. We are talking about areas facing natural or other specific constraints (ANCs), whose new delimitation – according to the same criteria – was recommended by the EC to all EU Member States under the Common Agriculture Policy (CAP) 2014–2020 (European Comission 2016). In addition, this delimitation also applies under CAP 2023–2027. In the EU, these areas currently account for 57.9%, and in Poland for 58.7% of the utilised agricultural area (UAA) (European Comission 2019). In Poland, some are ANCs with particularly difficult conditions for farming (Zielinski et al. 2022).

The presence and durability of appropriate rules (institutions) that can foster the formation of desired behaviours are a prerequisite for agriculture operating in ANCs with particularly difficult conditions to provide environmental public goods at the level society expects continuously. In this context, a significant achievement is brought by the New Institutional Economics (NIE) trend, where the fundamental role is played by formal institutions treated as forms of public order and informal institutions, which are socially acceptable standards of conduct and values nurtured by the human individual, influencing routine in the way it thinks and behaves in economic reality (North 1990; Williamson 2000; Menard and Shirley 2008; Richter 2015). In this trend, both institutions identify and direct several of their internal motivations, which, apart from the desire to achieve personal economic well-being, also strengthen a sense of honesty, justice and social responsibility when making decisions, including those regarding protecting the natural environment.

The study is designed to contribute to filling the research gap regarding assessing the predisposition and challenges of agriculture from ANCs with particularly difficult conditions in the context of providing society with environmental public goods in Poland. In the international literature, there is still a need for results of this type of analysis conducted about these areas currently of particular concern by the EC as part of the EGD strategy.

The study's main objective is to determine the predisposition and challenges of agriculture from ANCs with particularly difficult conditions in the context of providing society with environmental public goods in terms of communes in Poland. The aim is also to indicate its condition and direction of development, including assessing its economic situation against the background of agriculture with better farming conditions. In addition, it is also important to determine the factors that have a statistically significant impact on farms from these communes on their willingness to better adapt to the existing restrictions by participating in the agri-environment-climate (AECM) and/or organic farming measure under the EU CAP.

Theoretical background

Role of agriculture in providing society with environmental public goods. Society expects agriculture to fulfil its objectives related to providing it not only with market goods but also, to an increasing extent, with a wide range of public goods associated with protecting the natural environment (FAO 2017; Leduc et al. 2021; EEA 2022). Therefore, the question of how to better motivate farmers to manage the natural environment institutionally becomes crucial. To remedy the situation, society is currently introducing many environmental regulations in agriculture, offering additional payments, and expanding the range of forms of information transfer that promote better protection. This process is carried out in the EU mainly under the CAP, where measures to deliver environmental public goods are gaining increasing attention (Louhichi et al. 2018). The agri-environment-climate (AECM) and organic farming measures represent this state of affairs.

In the international literature, there is scientific evidence that agriculture is more likely to carry out these measures in areas with poorer farming conditions resulting from lower-quality soils (Wynn et al. 2001; Harvey

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2003; Defrancesco et al. 2008; Hynes and Garvey 2009; Uthes and Matzdorf 2013; Batary et al. 2015; Defrancesco et al. 2018; Velten et al. 2018; Lakner et al. 2020; Wąs et al. 2021; Coyne et al. 2022; Kujala et al. 2022). It should be noted that one of the strengths of these areas is the frequent presence of diverse and valuable natural landscapes, with a large share of permanent grasslands, forests, watercourses and other areas not subjected to strong anthropopressure, including often belonging to the Natura 2000 network, which can effectively support the provision of a wide range of public goods related to the protection of the natural environment to the society (Schmidtner et al. 2012; Früh-Müller et al. 2019, Zieliński et al. 2022). It is also worth emphasising that farms with extensive organisation of agricultural production operate in these areas much more often than in other areas (Zimmermann and Britz 2016). Therefore, the additional payments received by these farms for the implementation of AECM and/or organic farming measures may be economically satisfactory enough to make them a permanent alternative to conventional agricultural practices used so far (Keenleyside et al. 2011, Früh-Müller et al. 2018; Wittstock et al. 2022).

MATERIAL AND METHODS

In the first part of the resulting study, agriculture from ANCs with particularly difficult conditions was characterised by other areas' backgrounds regarding Poland's communes. The analyses used the currently applicable delimitation of ANCs, which was carried out in Poland in 2019 at the request of the Ministry of Agriculture and Rural Development (MARD) and the EC by the Institute of Soil Science and Plant Cultivation State Research Institute (ISSPC SRI), as part of biophysical criteria, and Institute of Agricultural and Food Economics National Research Institute (IAFE NRI) – as part of the fine-tuning procedure [Regulation (EU) No. 1305/2013 of the European Parliament and of the Council of December 17, 2013 on Support for Rural Development by the European Agricultural Fund for Rural Development (EAFRD) and Repealing Council Regulation (EC) No. 1698/2005; European Comission (2016)]. In Poland, ANCs communes with particularly difficult conditions are characterised by a low agricultural production area valorisation index (APAV) set by the ISSPC SRI. It should be emphasised that the Ministry of Agriculture and Rural Development (MARD) and the EC have accepted the index to determine the current ANCs zones in Poland. The average value of the APAV index for a community in Poland is currently 66.6 points out of 120 points achievable.

Three groups of communes were selected for this analysis. From now on, the first had an average APAV index lower than 52 points out of 120 points possible to be achieved, referred to as communes with particularly difficult conditions under ANCs. The second group consisted of communes remaining with ANCs. The third one is without ANCs (Figures 1 and 2).

In the selected groups of communes, attention was first paid to the natural value of their landscape. It was assessed by the share of Natura 2000 areas in their total area. They also indicate the state of agriculture characterised by extensive organisation of agricultural production carried out in the vicinity of valuable components of the natural environment and meeting the requirements of the EC under the concept of agriculture from High Nature Value farmlands (HNVf) areas (European Comission 2017). The 2018 delimitation of these areas, established on behalf of MARD by the ISSPC SRI and the Institute of Agricultural and Food Economics – National Research Institute (IAFE NRI), was used to achieve this goal. As part, three variants of UAA HNVf of moderate, high, and exceptionally high natural value were designated in Poland (Prandecki et al. 2021; Zieliński and Jadczyszyn 2022).

After determining the management conditions and the value of the landscape, and the condition of agriculture meeting the HNVf criteria in selected groups of communes, an analysis of its organisational features was carried out based on data from the Agency for Restructuring and Modernization of Agriculture (ARMA), which acts in Poland as a public institution implementing payments under the EU CAP.

Next, the economic situation of field and milk farms from separate groups of communes was assessed based on data from farms continuously keeping accounts for the Polish Farm Accountancy Data Network (FADN)

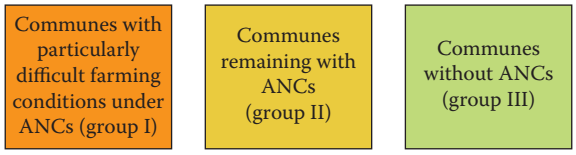

Figure 1. Schematic diagram of the analysis of agriculture within selected groups of communes due to the fact and nuisance of ANCs in Poland

ANCs – areas facing natural or other specific constraints
Source: author's own elaboration

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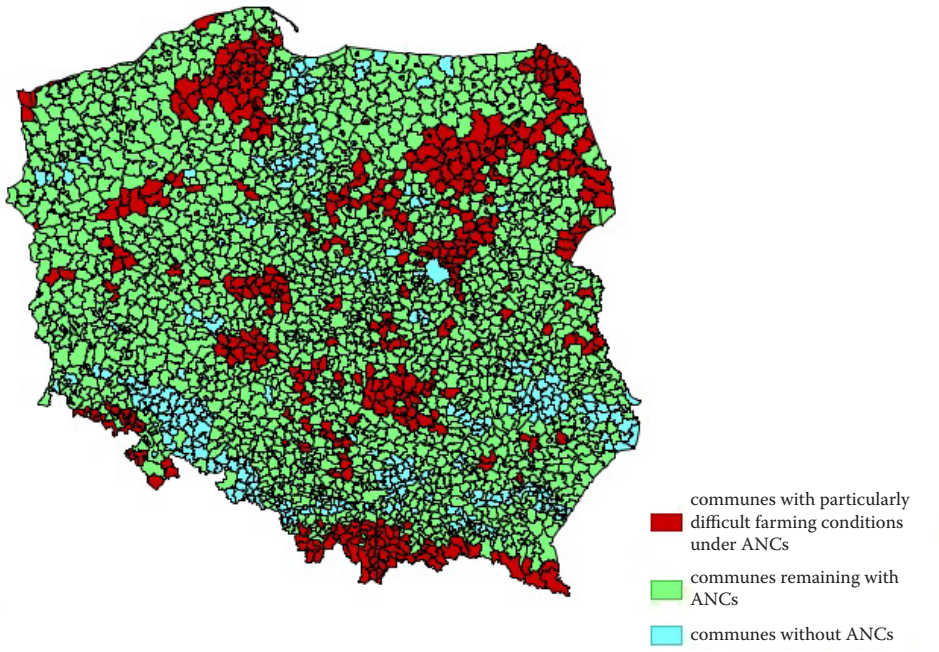

Figure 2. Distribution of communes in Poland due to the fact and nuisance of ANCs in Poland

ANCs – areas facing natural or other specific constraints

Source: Zieliński et al. (2022)

in 2016–2021. When separating farms according to their type of farming, their high importance in the structure of farms in Poland was considered.

In the final part of the study, the factors underlying the decision of farms from ANCs communes with particularly difficult conditions to implement the AECM and/or organic farming measures were identified. For this purpose, a logistic regression model was used, based on data from farms participating in these measures (158 farms) and other farms (795 farms), which continuously kept accounts for the Polish Farm Accountancy Data Network (FADN) in 2016–2021. It should be noted that in the international literature, these models are commonly used to identify factors determining the willingness of farmers to participate in the activities indicated here (Vanslembrouck et al. 2002; Lakner et al. 2020; McGurk et al. 2020; Paulus et al. 2022).

In the logistic regression model, the probability (P) of the occurrence of the expected situation (1) for the binary dependent variable is described by the function being the distribution function of the logistic distribution and finally takes the form (Christensen 1997; Fahrmeir et al. 2013) [Equation (1)]:

$$P\left(y=1|\ x_1,x_2\ldots x_k\right)=\frac{e^{\beta_0+\sum_{i=1}^{k}x_i\times\beta_i}}{1+e^{\beta_0+\sum_{i=1}^{k}x_i\times\beta_i}} \quad (1)$$

where: $P\ (y = 1|x_1, x_2 \ldots x_k)$ – probability that the variable y will take the value equal to 1 for the values of the independent variables in quantitative (continuous) or qualitative (binary) terms ($x_1, x_2 \ldots x_k$); β_i for $i = 0, \ldots, k$ – regression coefficients

The model parameters were estimated using Statistica, version 13.3. The Likelihood Ratio test and the Wald test assessed the quality of the obtained logistic regression model. In addition, Cox and Snell's pseudo-R^2 measure and its modification proposed by Nagelkerke were used.

RESULTS AND DISCUSSION

Characteristics of communes with ANCs with particularly difficult conditions, compared to other communes in Poland. A new delimitation of ANCs has been in place in Poland since 2019. As mentioned, it aimed to adapt Poland to the new criteria EC for their determination, identical for all EU-27 countries (European Comission 2013, 2016). In Poland, the share of ANCs currently accounts for 58.7% of the total UAA. This share is close to the EU-27 average of 57.9% (Figure 3).

In Poland, in ANCs communes with particularly difficult conditions, natural constrains are caused by poor soil quality and unfavourable climatic and topographical conditions. As a result, the average APAV index in these communes is 46.0 points, while in communes remaining with ANCs – 66.0 points, and without ANCs – 86.5 points. The frequent presence of diverse and valuable natural landscapes is one of their

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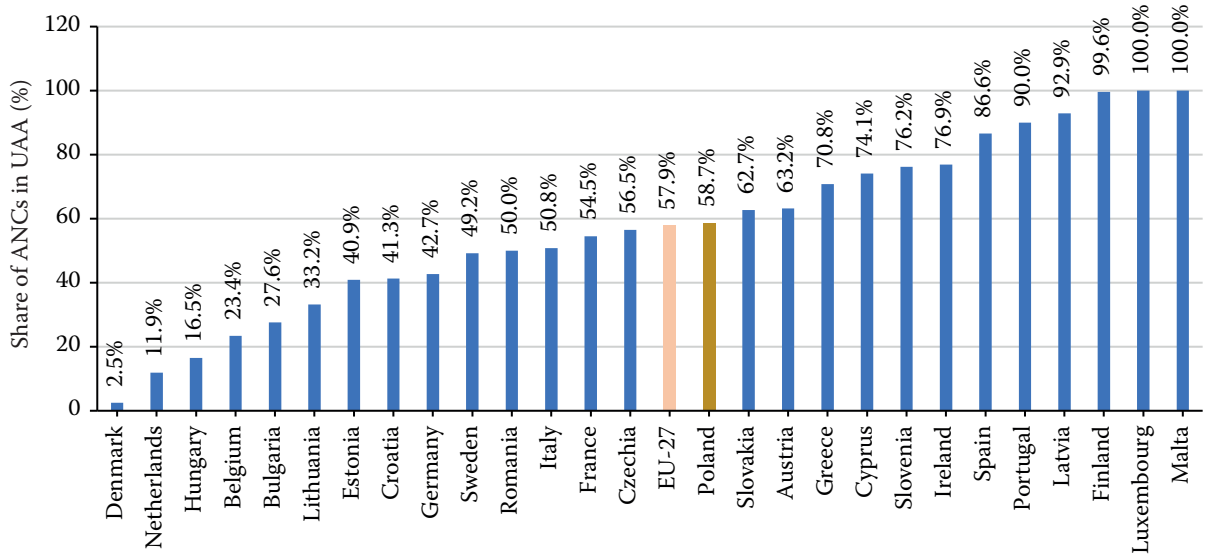

Figure 3. Share of ANCs in the total UAA in EU-27 in 2019

ANCs – areas facing natural or other specific constraints; UAA – utilised agriculture area; CAP – Common Agriculture Policy

Source: author's own elaboration based on the data of European Comission (2019), CAP Context Indicators – 2019 update

strengths compared to comparative communes. They are characterised by a much greater share of extensive UAA HNVf of moderate, high, and particularly high natural value. In addition, their very high natural values are also evidenced by a clearly greater share of Natura 2000 sites in the total area (Table 1).

Agriculture in ANCs communes with particularly difficult conditions co-decides on the total production potential of agriculture in Poland. In 2016 and 2022, there were 15.6% and 15.7% of the total number of farms in these communes. In both analysed years, they used 13.2% of the total UAA each (Table 2).

In 2022, in ANCs communes with particularly difficult conditions, the share of the total area supported under the AECM and organic farming measure in the total UAA was the highest and amounted to 16.6%. On the other hand, in the communes remaining with ANCs and without ANCs, it amounted to 11.2% and 5.3%, respectively (Table 3, Figure 4).

Economic situation of farms from ANCs communes with particularly difficult conditions, as compared to other farms in Poland. Based on the Polish FADN data from 2016–2021, it was established that farms in the type of farming field crops and dairy cows, from ANCs communes with particularly difficult conditions, as compared to farms from communes being the reference point, achieved lower ag-

Table 1. Management conditions and environmental values of communes separated due to the fact and nuisance of ANCs in Poland

Variable	Communes		
	ANCs with particularly difficult conditions	remaining with ANCs	without ANCs
APAV index (points)	46.0	66.0	86.5
Share of UAA HNVf in the total UAA with (%):			
Moderate natural value	48.9	25.9	10.4
High natural value	29.7	15.7	4.3
Particularly high natural value	24.2	12.4	3.3
Share of Natura 2000 areas in the total area	34.0	21.9	9.6

ANCs – areas facing natural or other specific constraints; APAV – agricultural production area valorisation index; UAA – utilised agriculture area; HNVf – High Nature Value farmlands

Source: author's own elaboration based on the data – Institute of Soil Science and Plant Cultivation State Research Institute and Institute of Agricultural and Food Economics National Research Institute for 2018

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Table 2. Number of farms and UAA in communes separated due to the fact and nuisance of the ANCs in Poland in 2016 and 2022

Variables	ANCs with particularly difficult conditions		remaining with ANCs		without ANCs	
Year	2016	2022	2016	2022	2016	2022
Number of farms (thousands)	210.1	199.1	968.7	914.3	166.4	153.7
UAA (thousands ha)	1 881.1	1 874.5	10 579.4	10 575.6	1 756.9	1 758.9

ANCs – areas facing natural or other specific constraints; UAA – utilised agriculture area; ARMA – Agency for Restructuring and Modernization of Agriculture
Source: author's own elaboration based on ARMA data

Table 3. Share of the area covered by the AECM and organic farming measure supported under the CAP 2014–2020 in the total UAA in communes with different saturation and specificity of ANCs in Poland in 2022

Variable	Communes		
	ANCs with particularly difficult conditions	remaining with ANCs	without ANCs
Area of AECM measure (thousands ha UAA)	220.4	831.9	78.7
Area of organic farming measure (thousands ha UAA)	91.4	352.2	13.7
Share of the area covered by the AECM and organic farming measure in the total UAA (%)	16.6	11.2	5.3

ANCs – areas facing natural or other specific constraints; UAA – utilised agriculture area; AECM – agri-environment-climate measure ; CAP – Common Agriculture Policy; ARMA – Agency for Restructuring and Modernization of Agriculture
Source: author's own work based on ARMA data

ricultural income. If these farms were hypothetically deprived of subsidies, including those received under the AECM and organic farming measures, their ability to generate agricultural income would be limited. This unfavourable economic situation would occur, especially in the years of exceptionally low prices on agricultural markets and the effects of climate change, including droughts, which in Polish conditions, especially in ANCs with particularly difficult conditions, are characterised by increasingly longer duration and increasing intensity of occurrence. It is worth adding that in the event of high intensity of these events, farms with field crops even recorded a loss (Tables 4 and 5).

Evaluation of factors influencing farms' willingness to participate in AECM and/or organic farming measures in ANCs communes with particularly difficult conditions in Poland. The results of the estimation of the logistic regression model are included in Table 6. where its parameter values, odds ratios, and the statistics of the Wald test, the likelihood ratio (LR) test, Cox Snell's and Nagelkerke's pseudo-R^2 are included.

The factor whose increase by one unit determined the probability of farm participation in the AECM and/or organic farming measure to the greatest extent was the farmer's transition to a higher level of education (it was a continuous variable, where 1 – primary education, 2 – basic agricultural or non-agricultural education, 3 – secondary agricultural or non-agricultural education and 4 – higher agricultural or non-agricultural education). In this situation, the chance of his participation in these measures increased by 84.6% [exp(β) = 1.845792]. The greater age of the farmer also positively impacted the increase in this chance. It was found that the occurrence of this circumstance was, in turn, able to increase the probability of participation in them by 4.2% [exp(β) = 1.041899]. Another important variable in the model was the share of ANCs in the total UAA and the total share of permanent grasslands, forests, and waters in the total area of a given community. An increase in their share by another 1% meant an increase in the probability of participation in these measures by 14.7 and 2.4%. respectively [exp = 1.146816; exp(β) = 1.024179]. The increase in the chance of farms participating in these measures was also influenced by the greater presence of the surrounding local community of farmers who had joined them earlier and the greater share of the population living in rural areas in the total population of a given community.

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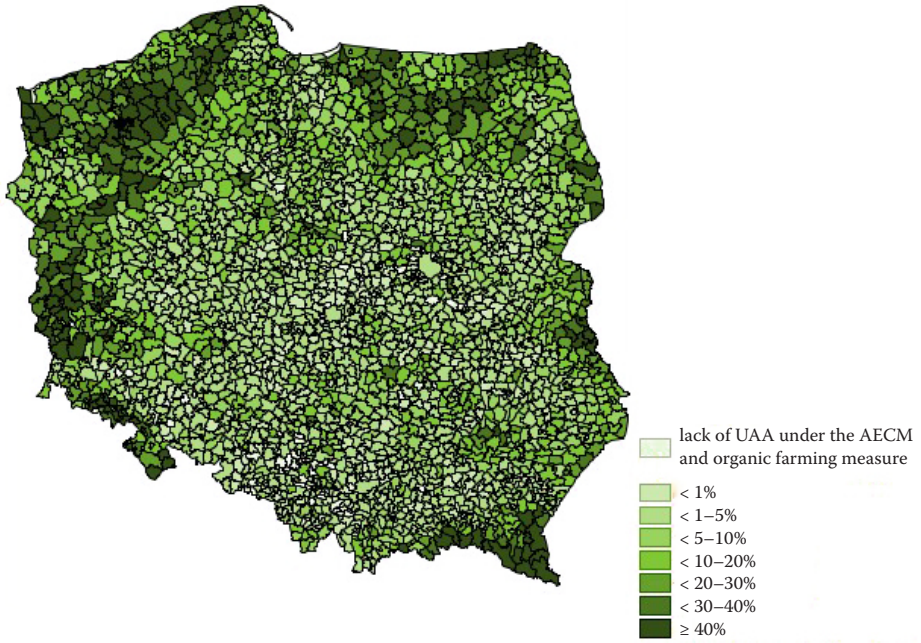

Figure 4. Share of the UAA covered by the AECM and organic farming measure under the CAP 2014–2020 in the total UAA of communes in Poland in 2022

ANCs – areas facing natural or other specific constraints; UAA – utilised agriculture area; AECM – agri-environment-climate measure; CAP – Common Agriculture Policy; ARMA – Agency for Restructuring and Modernization of Agriculture

Source: author's own elaboration based on ARMA data

Table 4. Economic situation of farms with field crops in 2016–2021

Farms from communes	Variable	Year					
		2016	2017	2018	2019	2020	2021
ANCs with particularly difficult conditions	income (EUR/ha)	349.1	363.4	263.6	355.8	395.3	520.4
	including the share of subsidies (%)	112.2	83.4	129.2	82.4	82.4	60.0
Remaining with ANCs	income (EUR/ha)	467.2	452.1	435.7	440.2	495.3	724.8
	including the share of subsidies (%)	77.9	62.6	49.5	67.4	57.4	36.4
Without ANCs	income (EUR/ha)	503.4	527.0	571.6	479.8	556.5	909.4
	including the share of subsidies (%)	69.1	52.0	47.2	55.4	46.4	27.5

ANCs – areas facing natural or other specific constraints; FADN – Farm Accountancy Data Network
Source: author's own elaboration based on Polish FADN data

Table 5. Economic situation of dairy farms in 2016–2021

Farms from communes	Variable	Year					
		2016	2017	2018	2019	2020	2021
ANCs with particularly difficult conditions	income (EUR/ha)	816.3	1 027.7	933.6	934.9	968.2	1 154.8
	including the share of subsidies (%)	60.0	35.2	38.5	38.0	37.9	30.3
Others with ANCs	income (EUR/ha)	855.5	1 112.4	1 035.0	1 038.4	1 093.7	1 316.0
	including the share of subsidies (%)	54.3	30.6	32.6	31.8	32.3	24.6
Without ANCs	income (EUR/ha)	813.5	1 160.6	1 039.4	1 091.6	1 090.1	1 444.3
	including the share of subsidies (%)	60.9	28.3	32.3	31.2	33.8	23.3

ANCs – areas facing natural or other specific constraints; FADN – Farm Accountancy Data Network
Source: author's own elaboration based on Polish FADN data

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Table 6. Estimated parameters of the logistic regression model; pseudo-R^2 Coxa Snella = 0.262987085; pseudo-R^2 Nagelkerke' a = 0.411092417

Variable	β	SE	Wald test	Confidence intervals (95%)		ρ	exp(β)	Confidence intervals (95%):		ρ	Likelihood ratio test		
				upper	lower			upper	lower		lnL	Chi-squared	ρ
Free expression	−23.3387	4.548265	26.33074	−32.2532	−14.4243	0.000000	–	–	–	–	−374.158	–	–
Number of farms participating in the AECM and/or organic farming measure in a given commune	0.0240	0.002512	91.06051	0.0191	0.0289	0.000000	1.024265	1.019233	1.029321	0.000000	−307.628	133.0589	0.000000
Share of population living in rural areas in the total population of a given commune (%)	0.0222	0.007369	9.09249	0.0078	0.0367	0.002567	1.022469	1.007808	1.037344	0.002567	−303.982	7.2925	0.006924
Share of UAA ANCs in the total UAA in a given commune (%)	0.1370	0.042768	10.25974	0.0532	0.2208	0.001360	1.146816	1.054604	1.247090	0.001360	−289.516	28.9315	0.000000
Share of permanent grasslands. forests and waters in the total area of a given commune (%)	0.0239	0.008120	8.65696	0.0080	0.0398	0.003258	1.024179	1.008008	1.040609	0.003258	−285.103	8.8270	0.002968
The fact that the farmer has a higher level of education	0.6129	0.162798	14.17404	0.2938	0.9320	0.000167	1.845792	1.341556	2.539548	0.000167	−278.404	13.3973	0.000252
Farmer age (years)	0.0410	0.012717	10.41789	0.0161	0.0660	0.001248	1.041899	1.016252	1.068194	0.001248	−271.155	14.4984	0.000140
UAA on the farm (ha)	0.0103	0.004204	6.03677	0.0021	0.0186	0.014011	1.010382	1.002092	1.018742	0.014011	−268.728	4.8539	0.027584
Income adjusted for operating subsidies per 1 ha of UAA (EUR,00/ha)	−0.1283	0.044268	8.39540	−0.2150	−0.0415	0.003762	0.879619	0.806517	0.959347	0.003762	−262.931	11.5950	0.000661
The fact that the farmer has a successor	0.0188	0.135111	0.01928	−0.2461	0.2836	0.889577	1.038230	0.611337	1.763220	0.889577	−262.913	0.0346	0.852359
Farmer's involvement in work on his farm	0.1622	0.147994	1.20159	−0.1278	0.4523	0.273004	1.383274	0.774396	2.470887	0.273004	−262.320	1.1857	0.276203

SE – standard error; β – regression coefficient; ρ – precise P value; lnL – maximum likelihood logarithm; ARMA – Agency for Restructuring and Modernization of Agriculture; UAA – Utilised Agriculture Area; AECM – agri-environment-climate measure; ANCs – areas facing natural or other specific constraints; FADN – Farm Accountancy Data Network

Source: author's own elaboration in Statistica version 13.3 based on Polish FADN and ARMA data for 2016–2021

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Each additional farm participating in them increased the chance for the next farm to undertake them by 2.4% [exp (β) = 1.024265]. On the other hand, a 1% increase in the share of the population living in rural areas increased this chance by 2.2% [exp = 1.022469]. To a lesser extent, this propensity was positively influenced by the fact that the farm had a larger UAA, each increase of which by 1 ha increased it by 1.0% [exp(β) = 1.010382]. The chance of participation of farms in the AECM and/or organic farming measure was negatively affected by the increase in agricultural income adjusted for operating subsidies per 1 ha of UAA [exp(β) = 0.879619] (Table 6).

Discussion of the results. In the current economic reality characterised by high turbulence and complexity of the processes, effectively operating formal and informal institutions are needed by agriculture from ANCs with particularly difficult conditions for better protection of the natural environment. In this context, the set of standards, regulations and incentives contained in the EGD strategy from 2019, in its thematic strategies from 2020–2022, as well as in the CAP, revised every few years, plays an important role in this context, in which more and more emphasis is placed on above all, the importance of the AECM and organic farming measure as those mainly serving the provision of environmental public goods. However, it should be emphasised that effective protection of the natural environment by agriculture in areas with special natural constraints is not possible without the simultaneous shaping of values and motivating farmers to apply the activities in a sustainable manner and at the level expected by society (Jones et al. 2016; Valujeva et al. 2022).

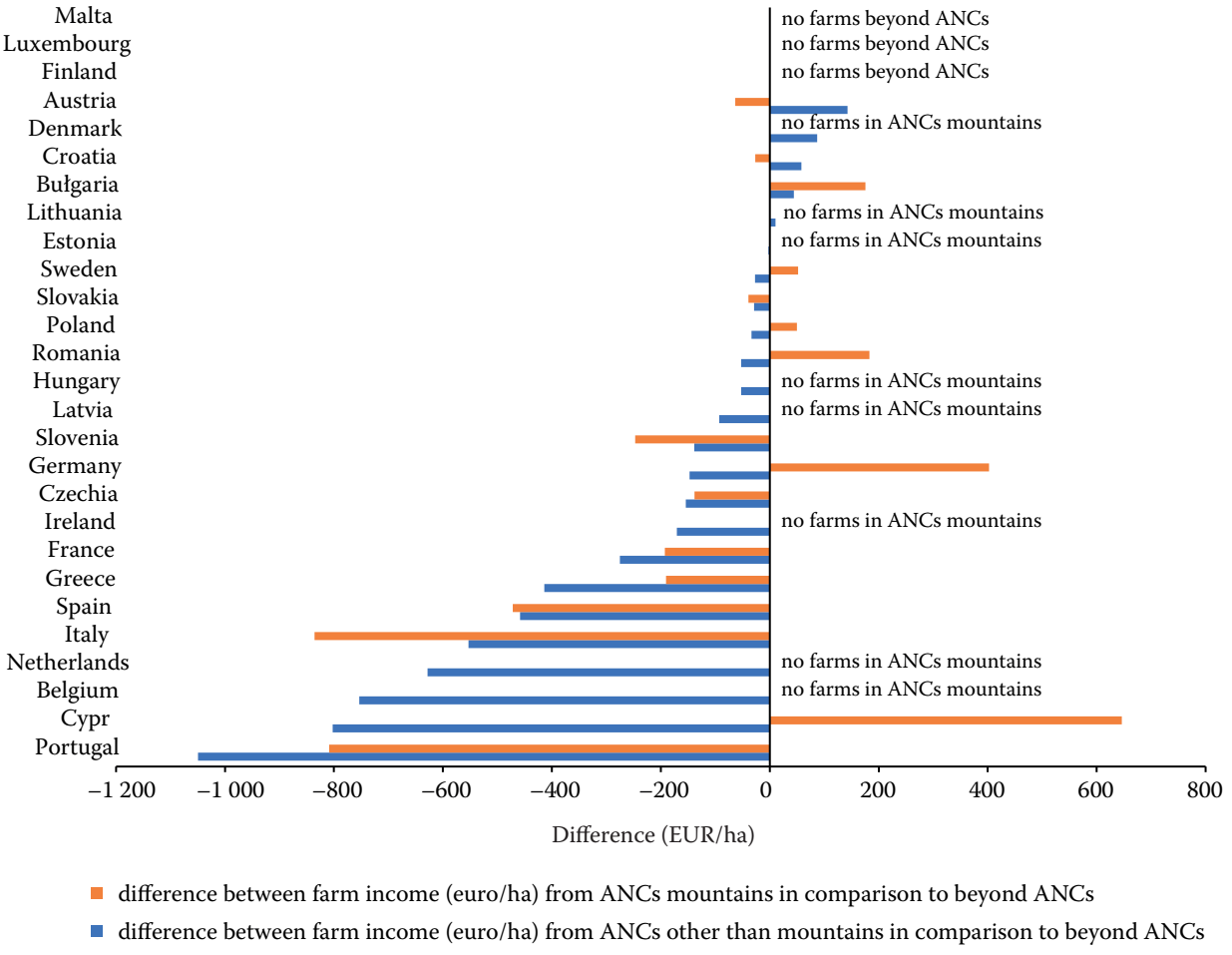

Figure 5. Decrease (–) or increase (+) of income per 1 ha of UAA (EUR/ha) in farms with ANCs compared to farms without ANCs in the EU-27 on average in 2004–2020

ANCs – areas facing natural or other specific constraints; UAA – Utilised Agriculture Area
Source: European Comission (2023)

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Formal and informal institutions should be required to constantly search for more and more new tools that will encourage agriculture from the ANCs with particularly difficult conditions to undertake environmental activities to an even greater extent in the conditions of constantly growing competitive pressure. In this context, the role of institutions is important in finding a balance between providing environmental public goods and ensuring satisfactory income from agricultural activity. It must be borne in mind that the simultaneous improvement of economic and environmental efficiency is the most cost-effective way of protecting the natural environment by agriculture, as it is accompanied by the concurrent maintenance or improvement of its competitiveness (Sidhoum et al. 2023). However, based on the European FADN data, it turned out that, on average, in 2004–2020, the income per 1 ha of UAA in farms with mountains and other than mountains ANCs compared to farms beyond ANCs was significantly lower in many EU-27 countries (Figure 5).

CONCLUSION

The study tried to justify that for effective protection of ANCs with particularly difficult conditions, the presence of sustainable and stable institutions essential that would be able to regulate and motivate agricultural activities in them and would foster the formation of behaviours expected by the society, including those related to providing it with a wide range of environmental public goods. The NIE trend has a lot to offer in this research area. It supplements neoclassicism with an additional scope and research methods. including by attributing special importance to institutions in shaping the market management framework desired by society. For agriculture from ANCs with particularly difficult conditions, well and carefully designed public actions are needed, which, through regulation and financial incentives, can play an important role in the success of environmental protection. The presence of informal institutions is also required since formal rules can only be implemented in agriculture sustainably and stable if they are trusted, promote generally desirable behaviour in farmers, and sustainably and stably enable communication and cooperation within local communities. With this synergy, both institutions can ensure that agriculture achieves personal economic benefits and benefits to society through greater concern for the state of the natural environment.

The research results indicate a significantly lower production potential of ANCs with particularly difficult conditions in areas without ANCs measured by the APAV index. At the same time, it was found that there is a much higher share of UAA HNVf and Natura 2000 areas.

Farms from communes with ANCs with particularly difficult conditions, as compared to farms from communes without ANCs, there was lower income per 1 ha of UAA also a significantly higher share of operating subsidies in income, including those received under the AECM and organic farming measure. This situation is not surprising because a real chance for these farms to continue and develop is participation in these measures, because especially in these areas, they can support uncertain agricultural income related to difficult conditions for agricultural production.

Based on the logistic regression model, it was found that in the communes with ANCs with particularly difficult conditions, older farmers and those with a higher level of education were more likely to implement the AECM and/or organic farming measure. The increase in the share of ANCs and permanent grasslands, forests, and waters in each community, the presence of other farms involved in their implementation in the immediate vicinity, and a greater share of people living in rural areas in a given community also turned out to be a contributing factor. Larger UAAs on farms were also significant. On the other hand, less willingness to implement the AECM and organic farming measures was shown by farms obtaining higher income adjusted for subsidies per 1 ha of UAA.

It should be noted that maintaining agricultural production in ANCs with particularly difficult conditions and their rational and multifunctional development remains one of Poland's priorities under the EU CAP 2023–2027.

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Analysis of the perception and presence of design in the fruit and vegetable cluster: The case of southeast Spain

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Abstract: Companies must provide economic, environmental and social added value based on innovation strategies, design and creative thinking in a globalised and competitive world characterised by rapid change and constantly evolving technologies. In this context, this paper analyses the role of design practice in companies in the agri-food sector (i.e. what is the design component present like; what are its relevance and importance?) An exploratory, descriptive study was conducted with 30 companies in southeast (SE) Spain's fruit/vegetable sector. The findings reveal that all the surveyed companies make financial investments in design and positively value this (7.6 out of 10), which indicates they recognise its strategic and operative importance. However, integration, training and design promotion in the agri-food sector remains somewhat limited. Most companies lack an in-house design department or design professionals as staff members and perform mainly design activities limited to the visual and communication tasks related to marketing initiatives. These results unveil opportunities for enhancing design incorporation and appreciation in the agri-food sector, which could boost its competitiveness and differentiation in the market. Finally, this study can be considered a starting point for future development in line with the horticultural sector's theory, practice, and design management policies.

Keywords: agri-food; design-driven innovation; organizations competitiveness; strategy making; value creation

Since the beginning of the 21st century, society has required more sustainable approaches to design and develop products and services. (Coley and Lemon 2009). Companies increasingly identify design as a multidisciplinary system and a holistic process that involves different dimensions (economic, sociocultural, technological, environmental). Design is also considered an important source of innovation in any business activity (Perks et al.et al. 2005). Moreover, the design component generates a design-business symbiosis that translates into a positive correlation between the introduction of design and business results (Roy 1994; Hertenstein et al. 2001, 2005). In line with this, Gemser and Leenders (2001) show that industrial design positively impacts profits, sales, and exports. In the 1980s, Kotler and Rath (1984) pointed out design as a power-

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ful strategic tool that would play an increasingly important role in companies' constant search for a sustainable competitive advantage.

As an approach to the design concept, it should be noted that it includes all activities associated with creating a design as a specification for a solution, product, service, system, or organisation. It refers to making something primarily tangible (Hertenstein et al. 2013). The definition itself may vary according to use situations (e.g. industrial, graphic, product, service) because it is a broad and multidimensional concept (Walsh 1996; Nixon 1999). In agriculture, Prost (2017) defines design as the process concerned with devising entities to attain goals following Simon (1969). This definition supports the notion that various objects have been designed in agriculture to achieve specific objectives (plant varieties, animal breeds, cropping, farming systems, landscapes, decision support systems, agricultural implements, or inputs) (Prost et al. 2017). Thus, for this study, design is understood as the structured multidisciplinary work process that aims to create products (Raudberget et al. 2022; Roxas et al. 2023), images, spaces (Trubetskaya et al. 2023), services (Brinkman et al. 2023) and digital/multimedia content (Liu et al. 2019).

In the agri-food innovation field, since this century began, the vectors introduced into the industry have been based on food quality and safety, sustainability and, in recent years, organic production (Galdeano-Gómez et al. 2013). So one of the strategic actions that arouse the most interest of traditional actors is innovation related to environmental aspects and their relation to profitability (Kemp 2013). However, it is not enough for crops of origin to be organic because the entire agri-food chain must be holistically considered. For example, in the life cycle assessment (LCA) of the production and marketing of fruit and vegetables, packaging represents the most significant overall impact and is related to environmental problems that arise from the generation of plant and industrial waste, such as plastics (Galdeano-Gómez et al. 2013). Hence the need for greater literacy in this area involves eco-conscious product designers and engineers to design, redesign and develop more sustainable eco-efficient packaging (Pérez-Ortega et al. 2021). Research suggests opening innovation networks like incorporating design theories into agriculture to foster sustainable transitions and to improve current agricultural models from a socio-environmental viewpoint (Prost et al. 2017; Berthet et al. 2018). Design, as a differentiating element with a high added value, is present directly or indirectly in all agri-food sector activities, from the planning of agri-food farms to the marketing and sale of final fruit and vegetable products (González-Yebra 2019a, b) (Figure 1).

In a round table held with professionals from the design sector and the agri-food industry with a higher innovation level, the five determined priority lines of action for design development in this sector were: *i*) promotion of design knowledge depending on companies; *ii*) design as a dynamising element of the new bioeconomy paradigm (González-Yebra et al. 2019b).

Given the described framework, we pose two research questions at the fruit and vegetable companies level: 1) what is the design component present like?; 2) what importance is attached to design in these organisations? In short, these questions aim to address three specific objectives to: *i*) identify the role of design in the organisation chart of fruit and vegetable companies; *ii*) determine the level of importance and satisfac-

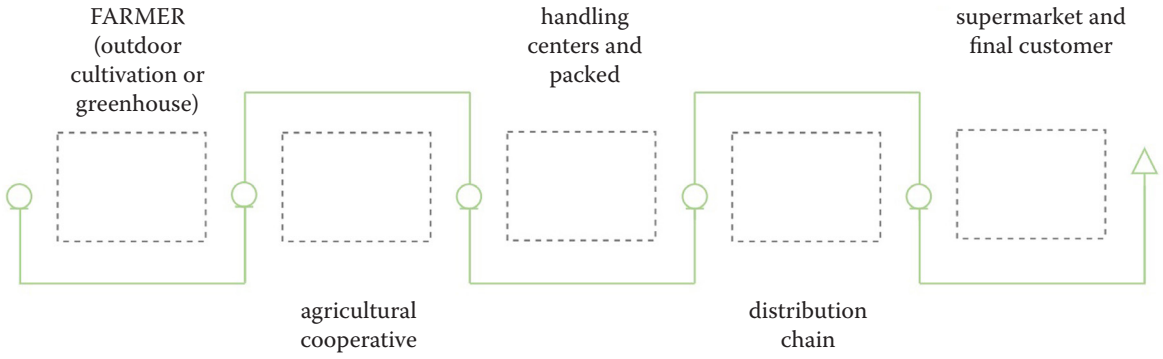

Figure 1. Characterisation of the agricultural production model of southeast Spain

Source: author's elaboration

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tion that companies in the fruit and vegetable sector attach to design; *iii*) establish the tangible and intangible benefits that agricultural organisations obtain from applying design. Another complementary question concerning landscape design and the planning of the productive environment is also explored.

MATERIAL AND METHODS

Study area. For the company selection phase, the contact rounds focused on a study area in Spain (Figure 2), specifically in the southeast. This area comprises four provinces (Almería, Granada, Murcia, Alicante) as the basis for the socio-business mapping of the target population that was consulted. It focuses on the three most everyday design application areas: industrial or product design, graphic design, and the design of spaces or environments.

Methodology. The methodological approach forms part of a broader research project based on mixed research postulates [see Figure S1 in the Electronic Supplementary Material (ESM)]. The complementarity of quantitative and qualitative methods can take research teams closer to a better and more accurate understanding of the study object (Tashakkori and Teddli 2003). The specific stage of the reported project focused on exploratory and descriptive analyses. A panel of companies was selected and received a questionnaire designed *ad hoc*. The study spanned three years and was divided into two phases. The results analysed in this paper correspond to the second phase (field study). In the first phase, research was designed, as was the validity of the proposed measurement instrument: a questionnaire with 15 multiple-choice single-response and two open-ended questions were tested. A rigorous protocol was established in which all the communication and questionnaires were completed via a single corporate email associated with the study. This fact guarantees the traceability and veracity of the data. A copy of all the submissions and obtained responses were recorded.

Figure 2. Location of the companies participating in the survey

A – Alicante; B – Murcia; C – Almeria; D – Granada
Source: author's elaboration

The procedure was as follows: *i*) send an introductory email with a brief description of the study and invite companies to participate; *ii*) send the questionnaire with instructions about filling it into the companies that positively replied. A 15-day deadline was set to complete the questionnaire; *iii*) send up to three reminders if no response is received after the first deadline.

Measurement instrument. The instrument designed *ad hoc* deliberately consisted of five blocks (Table 1) to triangulate the obtained data and information. The first part was introductory and included three central parts with the study questions. The last one contained open-ended comments.

Concerning the structuring of study content, in blocks 3 and 4, questions were asked to assess the design importance and satisfaction on a scale from 0 to 10 (0 – not important at all to 10 – very important) (Tables S3 and S4 in the ESM). Block 3 asked companies about design practices' tangible and intangible benefits. The results rated the highest (with an average of 7 points or more out of 10) were selected. This selection was based on a characterisation previously done by the Delphi method, with a panel of experts

Table 1. Parts of the research questionnaire

Block	Description	Type of question
1	characterisation of the study panel	company data (Table S1, ESM)
2	how is design present in agri-food companies?	multiple choice (Table S2, ESM)
3	level of importance/satisfaction of design in business strategy	Likert – 10 points (Table S3, ESM)
4	tangible and intangible benefits gained from design integration	Likert – 10 points (Table S4, ESM)
5	overall assessment and final contributions (experiences)	Likert – 10 points (open question)

ESM – Electronic Supplementary Material
Source: author's elaboration

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made up of design and agri-food sector professionals (González-Yebra et al. 2019b).

By recapitulation, questions 1–13 from blocks 1–4 appear in Tables S1–S4 (ESM). Questions 14 and 15 (measured on a Likert scale) and two more open-ended questions/comments were included in the last part. Question 14 asked about the landscape design and the planning of the productive environment of the agricultural model in SE Spain. In question 15, a general assessment was made of companies' satisfaction with the usefulness of the design component. Subsequently, in the open questions, they were asked how they could demonstrate the score awarded in question 15 as an organisation. In the last optional question, they were asked about what proposals they considered were necessary for the companies in the sector to incorporate design into their organisation.

Definition of the study population. The study population comprised fruit and vegetable companies as sample units: *i*) companies were established as traders as their only activity; *ii*) traders and producers; *iii*) traders and processors. Panel selection was carried out following the quota sampling method by giving the weight of the Almeria cluster at the national level (70% of the participating companies were from Almeria, with the rest from Granada, Murcia, and Alicante). A coordinating group was set up for the phase in which to select companies, conduct the field study and monitor questionnaires. Research groups and several technicians from the Agri-food Campus of International Excellence (ceiA3) were involved in this work.

Previous publications on the Almeria agri-food cluster were used as valid references to determine the population size. Pérez-Mesa and Galdeano-Gómez (2010) and Galdeano-Gómez et al. (2016) estimate the existence of 200 fruit and vegetable marketing and handling companies. A general email with the questionnaire was initially sent to 150 companies. Personalised contact was made with 50 companies, of which 20 did not complete all the requested questions and were discarded to avoid bias in the conclusions. Some of these companies stated that they could not provide some data requested in the questionnaire due to company privacy policy, which proved a significant handicap. Therefore, the final study sample size was 30 companies.

Data analysis. A data validation analysis was done. To this end, responses to questionnaires were recorded in an Excel database created *ad hoc*. The obtained data were analysed using descriptive statistics. The median (m) and arithmetic mean (μ) were used as central measures. Standard deviation (σ) was employed to test response variability. The coefficient of variation (*CV*), expressed as %, was included to check the results' consistency. The *CV* is the parametric statistics composed of the standard deviation divided by the mean obtained to test the degree of agreement reached in the study panel's responses. In this case, a *CV* of less than or equal to 25% is taken as a reference and indicates a very good agreement (minimal variability). Up to 50% is considered a good agreement with little variability. Data were processed using Excel calculation tools and the Statistical Product and Service Solutions (SPSS) package (version 28).

RESULTS AND DISCUSSION

Characterisation of the participating companies. About 60% were large, while the rest were micro-enterprises, small and medium-sized enterprises (SMEs) (Table 2). In the last 3 years, the average turnover of the participating enterprises was around 68 million EUR, with a minimum of 50 000 EUR (micro-enterprises) and a maximum of 280 million EUR (large enterprises). Of all the companies, 73% were marketers and producer-marketers, and the rest were processors or simply producers. All (100%) of the companies had an international target, 77% shared production with a national destination, and only 27% destined their products for the local market. Practically all the companies (97%) affirmed knowing the difference between 'design and marketing'. Concerning prior knowledge of the design concept, although 63% identified design as a structured work process, 37% considered that design only responded to aesthetic aspects (Table 2). This fact is worrying because design requires knowledge of a series of technical, strategic and market fac-

Table 2. Characterisation of the companies making up the study panel

Size classification		Design concept in business	
Micro-enterprises (< 10 employees)	10%	structured work process	63%
SMEs (10–50 employees)	10%	synonymous with advertising	23%
Medium (50–250 employees)	33%	one-off activity (a style, a fashion)	7%
Large (> 250 employees)	57%	synonymous with modern aesthetics	7%

SME – small and medium-sized enterprises
Source: author's elaboration

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tors and a creative or aesthetic sense. In other words, it is a process that encompasses management (Chiva and Alegre 2007). This can be attributed to the fact that some design interpretations tend to be closer to product development, market research, and even branding. This is why many people think designs relate only to product form, aesthetics, and style (Verganti 2008). Finally, it was concluded from the feedback obtained from some of the companies that did not participate in the study panel that farmer-producers do not have enough resources to include design practices in their small organisations. Thus, marketing companies design brands under which small producer enterprises' products (fruit/vegetables) are marketed.

Presence of design on the organisation chart. Of all the companies, 77% had no design professionals as staff members. Of these, no one was responsible for design functions in 33% of the cases (Figure 3). In the remainder, 44% (17% of organisations), design decisions were made by management, 10% by the sales team and 17% by 'other profiles'. All this indicates that marketing professionals were in charge. As in other sectors like the ceramics industry (Chiva and Alegre 2007), the marketing department had the most significant responsibility for design if there was no design department.

Regarding how design pervades organisations, roughly one-third of the companies (37%) stated that they had integrated design, while another third (34%) had not included it on their company's organisation chart (Figure 4A). Only the remaining third (30%) of the participating organisations had fully integrated design and perceived it as another managerial and business pillar, i.e. with a strategic value for the company.

When asked about the company areas in which design was present (Figure 4C), the reference was marketing (60%), and only 33% had transversally incorporated design into all the areas, and at a similar percentage to those that took design into account as a management tool.

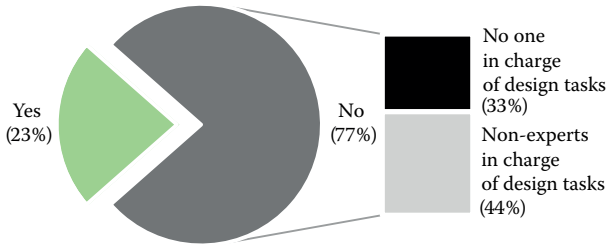

Figure 3. Presence of design professionals in companies in the agri-food sector

Source: author's elaboration

The literature considers design management as the organisational and managerial practices and skills that enable a company to achieve good and effective use of design through a managed process. However, no consensus has been reached about design management's activities (Chiva-Gómez 2004). Therefore, it could be determined that only the companies that took design as a management tool considered it in the definition of company strategies. However, only 13% of the participating organisations had a design department. Design activities were usually integrated into another department supported by external design professionals. In other cases, the company directly relied on external staff (27%). It should be noted that when companies attempted to contemplate design as an essential resource, they seemed to create an internal department which would also favour the development of design management skills (Chiva and Alegre 2007).

Investment and design professionals. All the companies had invested financially in design in the last three years. Obviously, the investment made by SMEs and micro enterprises was lower than that of medium and large companies (and proportional to turnover), with a minimum of 500 EUR (micro-enterprises) and a maximum of 2 000 000 EUR (large companies). The average investment in design was 20 000 EUR and 80% was made in graphic/communication and industrial/product design (Figure 5A). This trend was supported by the fact that 73% of the participating companies have legally protected or registered a brand (graphic/communication dimension) in the last three years. In the industrial domain, fewer companies covered a trademark, with 20% protecting patents and only one protecting an industrial design. These data could be related to the fact that many companies still consider industrial design a cost, not an investment. No company selected the 'copyright' and 'copyleft' questionnaire options.

73% of the companies in the study stated hiring design services only for specific projects, versus the 20% that did so constantly (even several times a month). The remaining 7% required design every 1 or 2 years. In any case, if it was not enough to make a monetary investment in design, design management played an important role in determining the effects of such investment assets on the company's activity and performance (Chiva and Alegre 2009). Only seven companies had design professionals (three medium-sized companies and four large companies). According to an open consultation, four companies had design professionals on their staff. They had other qualified professionals (e.g. technical architecture, audiovisual communication, advertis-

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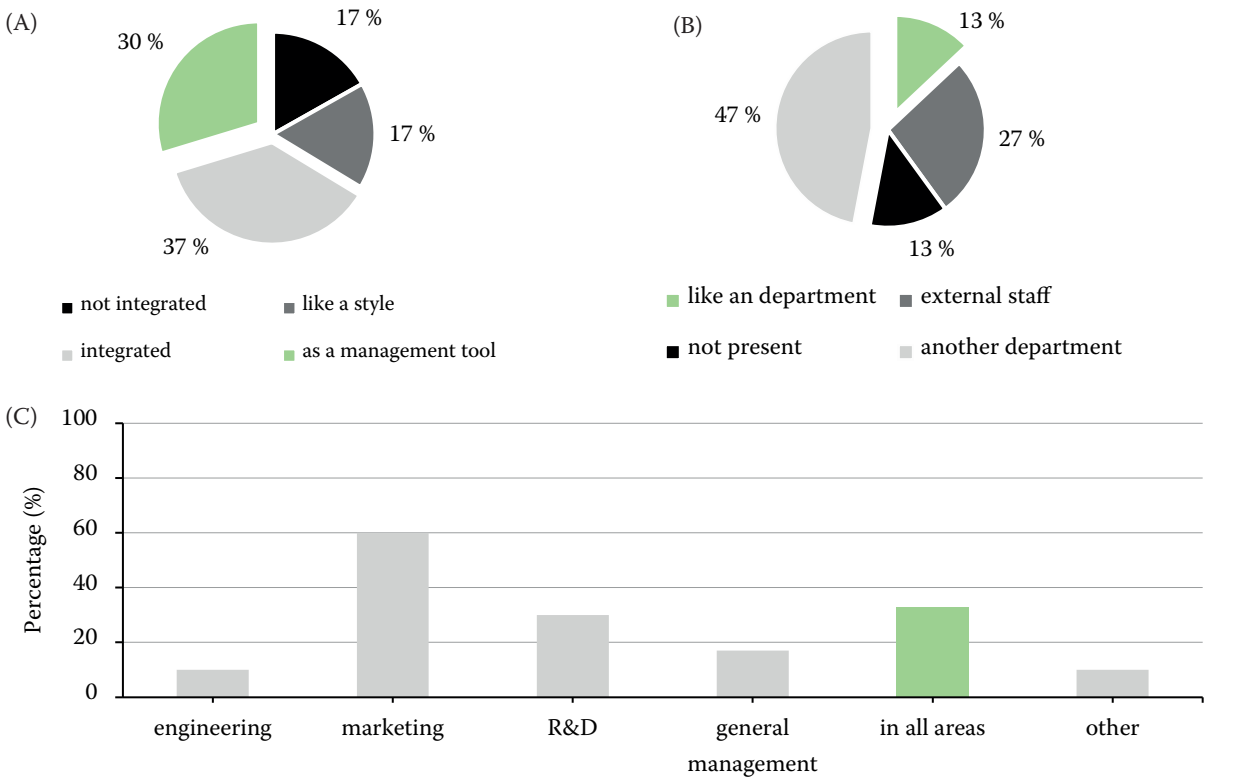

Figure 4. Presence of the design function (A) design in management and business strategy; (B) design within the organisation chart of the companies; (C) company areas in which design is present

R & D – research and development; green – the options towards which it would be desirable for the sector to advance
Source: author's elaboration

ing, and public relations) invested in design training courses. Two of the other three companies had professionals with a higher level of graphic design education. The third one had two industrial design engineers on its staff and was the only company with a professional product design and development profile. This heterogeneity could be related to the fact that no single universally accepted definition of industrial design can be established. Gemser and Leenders (2001) and Verganti (2008) point out the difficulty of defining the industrial design role, which also hinders the visibility of industrial design in companies in general and in the agri-food field in particular.

Regarding hiring techniques, 47% of the companies indicated that they used professional relations to find design professionals, compared to only two companies that resorted to universities. None showed art schools (Figure 5B). Those who chose the other option indicated they engaged professional assistance from advertising agencies. This could be related to a lack of matching between the design competencies provided by universities and industry demands. In line with this, Alonso-García et al. (2020) concluded that only around 20% of the contents taught in Industrial Design Engineering degrees align with companies' current demands.

Level of importance/satisfaction with the design. The only design type with a lower rating (average lower than 7 points) was service design in terms of both importance (Figure 6A) and satisfaction (Figure 6B). The graphic and digital/multimedia design stood out with an average rating of 8 points (Figure 6A). All the different design types obtained good ($CV \leq 50\%$) or very good ($CV \leq 25\%$) agreements, i.e. little, or very little variability in responses. These data were corroborated by triangulating the results (background González-Yebra et al. 2019a, b), quantitative data and qualitative feedback, and the perception of the agri-food industry and design professionals). It could be stated that the agri-food sector identified design mainly with the graphic dimension (including digital/ multimedia design). No single case stood out for satisfaction with design, with satisfaction levels averaging around

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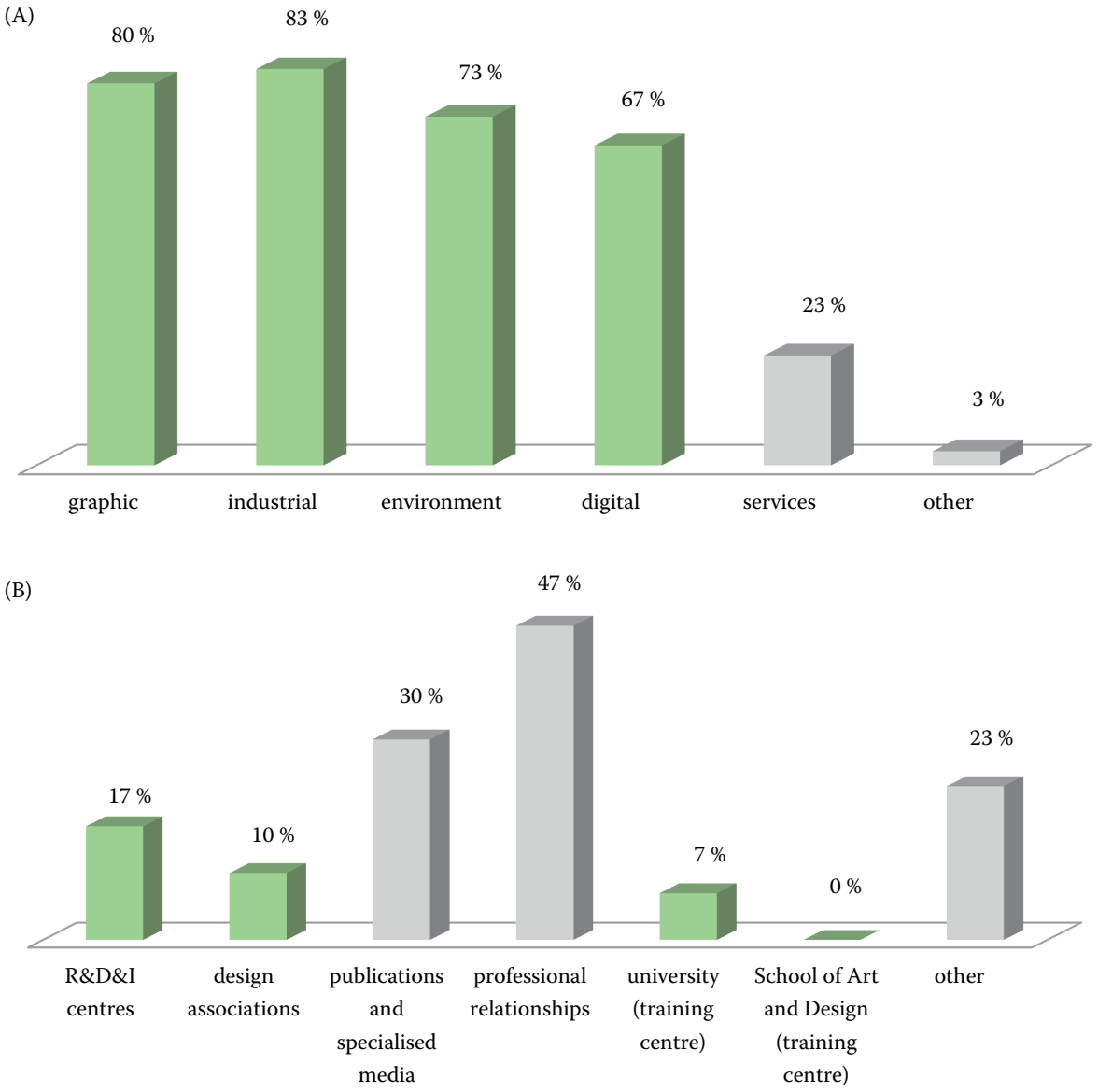

Figure 5. (A) Types of investment in design made in the last 3 years and (B) sources to which companies turn for designers' recruitment

R&D&I – research, development, and innovation; green – options into which responses were expected to be grouped
Source: author's elaboration

7.5 and very high agreement values for graphic, industrial, and service design (Figure 6B).

Tangible/ intangible benefits of design. The least valued tangible benefit was the increased sales volume on the international market (i.e. increased exports) (Figure 6C). The least valued intangible benefit was opening new segments to introduce the company's products (i.e. entry into new markets) (Figure 6D). The most valued benefit, with an average score of 8 points out of 10 and a very high level of agreement between companies ($CV \leq 25\%$), was that related to improving the company's image. Once again, it was associated with the graphic dimension of design. It would seem that fruit/vegetable sector companies focus almost all their efforts on graphic design, compared to industrial/product or environmental design. However, organisations generally consider design an interesting provider of non-technological innovation strategy to explore.

This conclusion was supported by the high scores for its application's tangible and intangible benefits (Fig-

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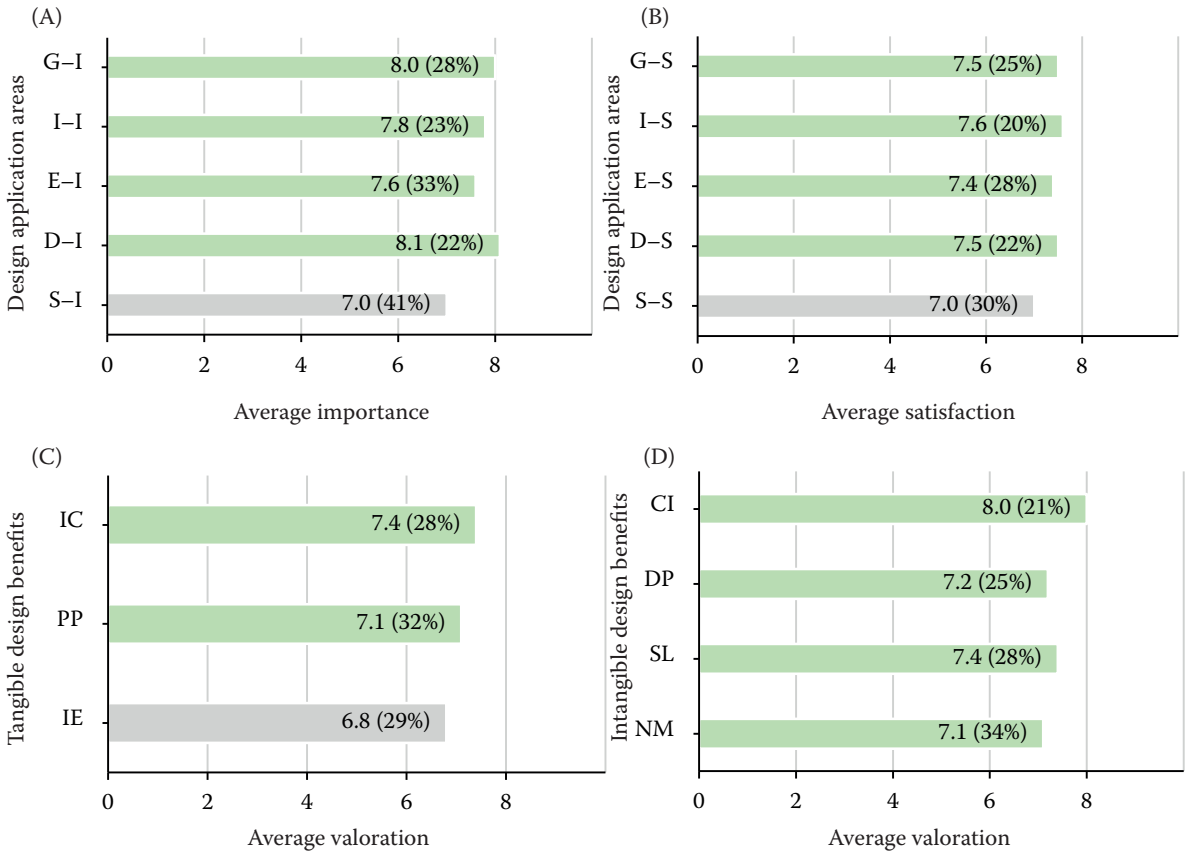

Figure 6. Results of the company evaluations related to the importance/satisfaction of design and the obtained tangible and intangible benefits

(A) G–I – importance that companies attach to graphic design; I–I – importance that companies attach to industrial and product design; E–I – importance that companies attach to the design of spaces; D–I – importance that companies attach to digital and multimedia design; S–I – importance that companies attach to service design; (B) G–S – satisfaction with the graphic/communication design; I–S – satisfaction with the industrial and product design; E–S – satisfaction with the design of spaces; D–S – satisfaction with the digital and multimedia design; S–S – satisfaction with the service design; (C) IC – increased competitiveness; PP – profit-profitability; IE – increased exports; (D) CI – improvement in the corporate image; DP – differentiation and positioning; SL – customer satisfaction and loyalty; NM – entry into new markets; tangible and intangible benefits (Figure 6C and Figure 6D) were surveyed considering the last 3 years; results are expressed using the mean assessment (for Figure 6A 0 – not important at all and 10 – very important) and the *CV* is expressed as % in brackets.

Source: authors elaboration

ure 6C, 6D). These results aligned with the developments in the third edition of the Oslo Manual in terms of incorporating non-technological innovation as a fundamental form of innovative activities (OECD 2005). The results showed the design role in the agri-food sector as non-technological innovation, where managers must be active players who improve how they manage and include design practices in companies to increase their innovation potential.

Design and planning the environment. The environment's design was related to and defined as the space of the company and everything related to it (industrial sites, offices, production areas, common spaces, commercial spaces, exhibition spaces and fairs). In the agri-food sector, previous research highlights that the presence of design in the conception and development of agro-industrial constructions and auxiliary industries (design and production of spaces) is lesser (González-Yebra et al. 2019a, b). The question as to whether improvement in the landscape design and planning of the production environment (greenhouses) could positively influence the image and global position of the fruit and vegetable sector was rated with an average score of 8.2 points out of 10 and a high

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level of agreement for all the participating companies (*CV* – 29%).

Overall rating. Overall, the design was rated positively, with an average of 7.6 points out of 10 and a very high level of agreement for all the participating companies (*CV* – 23 %). Although different studies have analysed the role of design in companies in various industries, for example, the furniture industry, the ceramics industry, or they have focused on the SME sector; there are no previous studies in companies in the fruit/vegetable sector with which to compare the obtained results.

CONCLUSION

This work aims to analyse the role of design and how it is perceived by organisations in the agricultural sector using a triangulation analysis (background, quantitative data, qualitative feedback). Regarding the role of design on the organisation chart, the results show that its practical implementation in the pool of organisations' activities entails two options: outsourcing or in-house development. The former is the more employed alternative. Regarding the level of importance/satisfaction attached to design; the results show that companies generally have a good overall perception of design. All the companies state that they have invested in design; most have invested in graphics/communication in the last 3 years and have legally protected themselves using a registered trademark. From the analysis of design tangible/intangible benefits, the most important benefit is improving the companies' image, and the least important benefit is related to the volume of exports and opening up new markets. The graphic dimension of design is highly valued, but the industrial/product dimension is not so highly valued. Given the particularities of the productive environment related to the fruit and vegetable sector, it is also necessary to work on the design of its spatial/environmental dimension to improve the image and global position of the agri-food cluster's productive model.

The results show a somewhat low level of maturity for implementing the design in the sector. The creative and implicit nature of design leads organisations to underestimate its value and, instead of considering it a strategic pillar of their management, they associate it mainly with brand image and company communication. However, design is doubtlessly essential for business success because of its potential to drive innovation and competitiveness. Nowadays, design has changed not only the strategy of companies but also the way they interpret and inspire consumer behaviour, their approach to new product and service development and, ultimately, the impact on value creation processes at the business level. To remain outside this interpretation of design might lead to a misunderstanding of consumer needs, missing out on the opportunity to capitalise on new technological advances, achieve differentiation from competition, develop innovations, define brand identity, and imbue it with meaning.

This work shows the current state of design in the sector by unveiling opportunities for improvement if design application were strategically considered a driver of policies that enables sustainable economic growth driven by innovation. Therefore, this study can be seen as a starting point for future development in line with the theory, practice, and design of management policies in the studied sector.

Limitations and future research lines. Although this research finds no significant differences among company types, at a practical level, a pattern is repeated in the fruit and vegetable cluster in SE Spain in which small production companies (usually run by self-employed farmers) are organised through large cooperatives for the marketing and sale of their products (fruit and vegetables). In this context, it can be inferred that farmers-producers do not have the time or the means to incorporate the design function into their small organisations. Besides, marketing companies design brands under which fruit and vegetable products are marketed. In many cases, a single brand brings together the products of many small producers. All this indicates the need for further research into this issue. As for the scope and development of the field study, they focus on a single industry in a specific geographical area (SE Spain) with a small sample size. Despite providing valuable information on the design conception in the sector, it only allows for a descriptive analysis of an exploratory nature that would need to be confirmed in future studies with larger samples and a more extensive geographical scope. This could be achieved by limiting the measurement instrument to only a few specific questions (five questions), making it easier to enlarge the sample (e.g. 100–150 companies) because one of the main found handicaps is questionnaire length. Moreover, creating an observatory could allow experts in the field to conduct longitudinal analyses, test returns on investment in design, and propose and monitor strategic research projects. Finally, offering training courses about design is recommended as a tool for management and non-technological innovation for entrepreneurs (directors/managers) and public managers.

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Working with all the stakeholders on a plan to introduce design into the policies and strategies of companies in the agri-food sector is also recommended. In this context, moving towards a design conception as a non-technological innovation for creating new business strategies is proposed. To summarise, the findings of this work provide a starting point to explore the contributions of design and its development to the agri-food industry now and in the future.

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Multifrequency downside risk interconnectedness between soft agricultural commodities

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Abstract: In this article, we explore multiscale extreme risk interdependence between four soft agricultural markets – coffee, cocoa, cotton and orange juice. Wavelet correlation and cross-correlation are used to investigate this interlink, and dynamic conditional Value at Risk is used to measure extreme risk. Wavelet correlation results suggest a very weak connection between the markets in the short-term and midterm horizons, which means that investors who operate in the short term or midterm do not have to apply hedging measures against extreme risk. However, the situation is different in the long term, where relatively high correlations are found on the highest wavelet scale in all pairs, except coffee–cocoa. Complementary cross-correlation analysis indicates a lead–lag relationship between the markets. The results are mostly in line with expectations, as bigger markets lead smaller markets. Only in the cases of cocoa–cotton and cocoa–orange juice does the opposite happen.

Keywords: conditional Value at Risk; extreme risk interdependence; wavelet correlation; wavelet cross-correlation

Investing in commodity futures has become popular in the last decade (Árendáš and Kotlebová 2023; Babar et al. 2023) because investors have paid more attention to alternative assets after the equity market crash in 2008. This type of investment is particularly attractive because a different set of factors affects commodities and traditional assets such as stocks and bonds, which produce low correlation between them (Umar and Olson 2022). This essential prerequisite must be met if investors want to construct a portfolio with good diversification characteristics. However, related to the topic of portfolio construction, volatility transmission remains underexplored in the literature, according to Živkov et al. (2022). Gardebroek et al. (2016) argued that second moment interdependence is very important to address because interlinks in variance could provide a better understanding of dynamic price relationships. This happens because the rise of volatility in one market could generate increased volatility in another market because of demand substitution or the joint underlying causes of volatility. Fernández-Avilés et al. (2020) asserted that close volatility connections between markets might lead to missing arbitrage and hedging opportunities for traders and investors, which is accompanied by huge challenges in balancing their portfolios. In this regard, investigating relationships between agricultural commodity futures has become an imperative in re-

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cent years because more investors consider investing in these instruments (Akyildirim et al. 2022).

Given this situation, we hypothesise in this article the situation of an investor who wants to invest in soft agricultural commodities, with the aim of determining risk interdependence between the markets. This knowledge could be valuable for global investors because if there is an intense risk transfer between markets, then assets from such markets are not good candidates to be in the same portfolio. In particular, the goal of this article is the investigation of time-varying risk interdependence between the four soft agricultural futures commodities (coffee, cocoa, cotton and orange juice) traded on the Chicago Mercantile Exchange. To our knowledge, the authors of very few articles have investigated the risk association between agricultural commodities, and none have researched soft agricultural commodities. This lack of research leaves a lot of room for our contribution, which is where we find a motive for this study. Futures are considered rather than cash prices because futures markets have higher trading volumes that process and incorporate new information into prices more quickly, which makes them more appropriate for the analysis (Palanska 2020). In addition, investigation of risk connections between the markets is particularly important in light of the two recent crises – the COVID-19 pandemic and the war in Ukraine (Boscá et al. 2021) – which have caused significant price oscillations on the global agricultural markets in the last few years, as Figure 1 shows. Huge price movements are fertile ground for extreme risk, and the task of this article is to stipulate whether extreme risk is interconnected between the markets and also to determine which market leads and which one lags in this relationship.

The research contributes in the following ways. In the process of risk evaluation, we do not use common variance because variance is a biased measure of risk that can lead to wrong conclusions, which happens because variance does not distinguish positive and negative returns, and investors are only keen to know the risk of negative returns. In this regard, instead of variance, we observe downside risk that takes into account only negative returns. The most famous measure of downside risk is the parametric value at risk (VaR), introduced by J.P. Morgan bank in 1994. VaR overcomes the problem of positive returns, but it is not an ideal risk measure because it cannot measure the losses beyond the threshold amount of VaR, which might lead to underestimation of the risk of losses (Yu et al. 2018). This issue was addressed by Rockafellar and Uryasev (2002), who proposed parametric conditional VaR (CVaR),

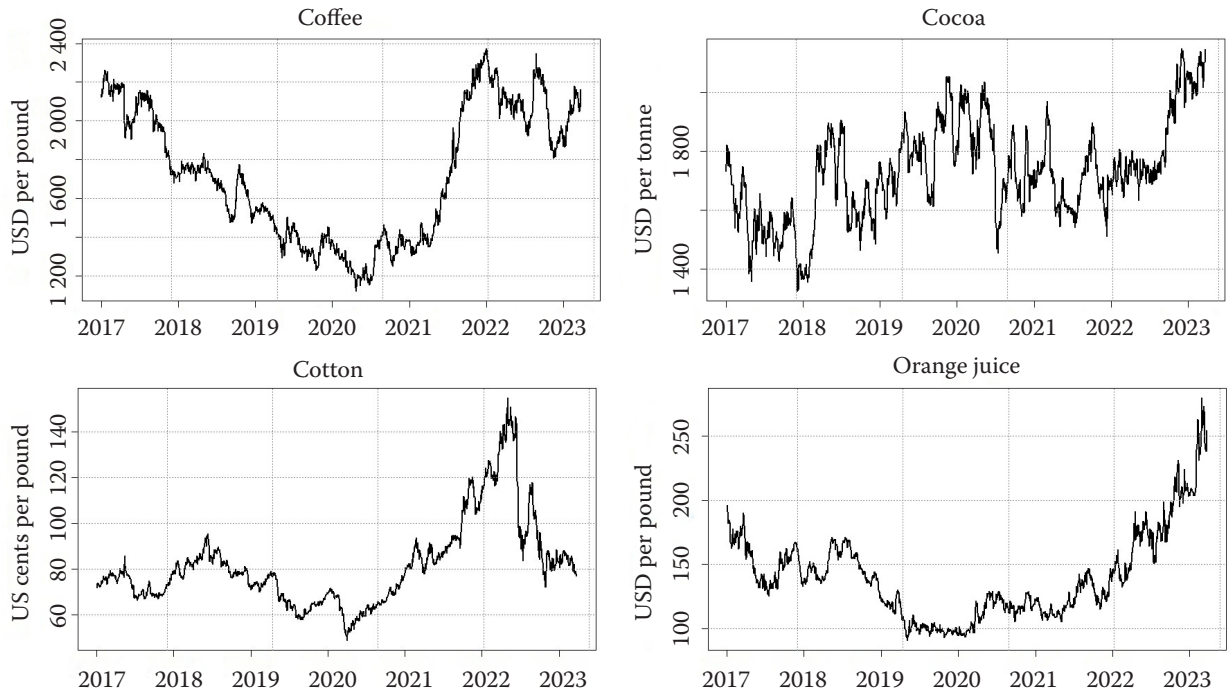

Figure 1. Empirical price dynamics of four soft agricultural commodities

Source: authors' own calculations based on data from investing.com (2023)

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which controls the magnitude of losses beyond VaR. Also, it is relevant to say that calculating VaR is inappropriate in empirical time series because they are not independently and identically distributed (iid). To resolve this problem, we first estimate every agricultural log return time series with the asymmetric Glosten-Jagannathan-Runkle-generalised autoregressive conditional heteroscedastic (GJR-GARCH) model with Student *t*-distribution. In this process, we can generate iid residuals. Because we are researching dynamic risk interdependence, we used created iid residuals for the construction of dynamic CVaR time series of all the selected agricultural commodities.

Another contribution of this article is the use of a multiscale framework in researching the comovement of tail risk between the soft commodities, which has not been done before, to our knowledge. We opted for this approach because different market participants meet their goals in different time horizons, and risk interdependence may vary significantly over frequency domains. Hence, it is important to inspect the strength of risk interdependence in multiple time horizons. This task is performed using two methodologies – wavelet correlation and wavelet cross-correlation. The former method calculates the exact strength of correlation in a multifrequency domain, and the latter shows a multiscale lead-lag relationship between the variables (Almaskati 2022). In particular, created dynamic CVaR time series are embedded in the two wavelet frameworks in a pairwise manner, which produces six pairs of tail-risk interdependencies. Combining these two wavelet methodologies, we can gain a fairly accurate picture of the strength of extreme risk connectedness in multiple horizons among the markets; this method also could indicate from which markets extreme risk transfers and which markets are the recipients of extreme risk. This information can be very valuable for investors in soft commodities because they will avoid combining assets that are highly correlated and assets that are receivers of high risk.

Regarding the existing literature, Fernández-Avilés et al. (2020) studied a number of commodities (including agricultural), showing extreme downside risk comovement maps of these markets during six recent distress periods. They observed no clear risk comovement patterns among the assets. However, they found that financialisation and speculation might have played some role in the dynamics of price and risk only in food commodity markets during the period from 2007 to 2008. Živkov et al. (2022) used VaR to measure a pairwise multiscale extreme risk interdependence between corn, wheat, soybean, rice and oats. They found an absence of high interdependence in the short-term horizons, but at higher wavelet scales, the results indicated stronger connection only in the cases corn–wheat, corn–soybean, wheat–soybean and somewhat corn–rice. Hamadi et al. (2017) examined the level of interdependence across corn, wheat, soybeans and soybean oil in terms of return volatility spillover. They found more significant evidence of bidirectional volatility spillovers, particularly underlining spillovers from soybeans and soybean oil markets to corn and wheat markets, than the inverse. Bonato (2019) investigated the changes in the dynamics of price correlations and spillover effects in the commodity markets, considering the interaction within soft and grain commodities and between these commodities and oil. He reported that soft commodities were segmented before 2008 and became correlated thereafter. However, correlations within grains were significant and positive, and increased only marginally, indicating that this group was affected less by the recent crisis events.

MATERIAL AND METHODS

GJR-GARCH model. To create iid residuals, we estimated all the soft commodities in the GJR-GARCH model with the Student *t*-distribution. In the specification, the first autoregressive term AR(1) is used in the mean equation, which is enough to resolve an autocorrelation problem. The variance equation in the model deals with the problem of heteroscedasticity. Mathematical expressions of the mean and variance equations are presented in Equations (1) and (2), respectively.

$$y_t = C + \Theta y_{t-1} + \varepsilon_t; \qquad \varepsilon_t \sim z_t \sqrt{\sigma_t^2} \tag{1}$$

$$\sigma_t^2 = c + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \gamma\varepsilon_{t-1}^2 I_{t-1};$$
$$I_{t-1} = \begin{cases} 1 \text{ if } \varepsilon_{t-1} < 0 \\ 0 \text{ if } \varepsilon_{t-1} > 0 \end{cases} \tag{2}$$

where: C, c – constants in the mean and variance equations, respectively; y_t – log returns of the particular soft commodity; Θ – autoregressive parameter, ε_t – iid residuals; $\sigma^2{}_t$ – conditional variance where $\alpha \geq 0$ and $\beta \geq 0$ (α measures the autoregressive conditional heteroscedasticity effect, and β gauges the persistence of volatility); γ – measures asymmetric response of volatility to positive and negative shocks, where the dummy variable (I_{t-1}) activates only if the previous shock (ε_{t-1}) is negative; z_t – independently and identically distributed process.

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If $\gamma > 0$ then negative shocks increase the volatility more than positive shocks do, and the reverse applies if $\gamma < 0$. We estimated all the GJR-GARCH models by using a quasi-maximum likelihood technique.

CVaR. Dynamic extreme risk was measured with the parametric *CVaR*, which indicates an average amount of loss that an investor might experience in a single day at a certain probability. *CVaR* is an integral of *VaR* [Equation (3)], where *VaR* is calculated every single day as $VaR_\alpha = \hat{\mu} + Z_\alpha \hat{\sigma}$, creating a dynamic *CVaR* time series. The variables $\hat{\mu}$ and $\hat{\sigma}$ denote an estimated mean and standard deviation, respectively, of a particular soft commodity, and Z_α is a left quantile of the normal standard distribution.

$$CVaR_\alpha = -\frac{1}{\alpha}\int_0^\alpha VaR(x)dx \tag{3}$$

where: $CVaR_\alpha$ – conditional Value-at-Risk; *VaR* – Value-at-Risk.

Wavelet correlation. After creating the dynamic *CVaR* time series, we embedded them in the pairwise wavelet correlation and wavelet cross-correlation frameworks. Wavelet correlation calculates the average value of correlation across wavelet scales, assuming a bivariate stochastic process $[Z = (x_t, y_t)]$ of the two time series, *x* and *y*, where each wavelet coefficient is obtained by applying a maximal overlap discrete wavelet transform process of Z_t. In computing wavelet correlation, wavelet variance needs to be calculated for the scale *j* of *x* and *y* time series: $\sigma^2_{x,j,t} = VaR\left(\hat{D}_{x,j,t}\right)$ and $\sigma^2_{y,j,t} = VaR\left(\hat{D}_{y,j,t}\right)$. $D_{j,t} = \left(D_{x,j,t}, D_{y,j,t}\right)$ is a particular wavelet detail at scale *j*. Accordingly, the scale-dependent average wavelet covariance is then $COV\left(\hat{D}_{x,j,t}, \hat{D}_{y,j,t}\right)$. Combining the average wavelet covariance and two wavelet variances in the same equation results in calculating scale-dependent average wavelet correlation coefficients ($\rho_{x,y,j,t}$), as in Equation (4):

$$\rho_{x,y,j,t} = \frac{COV\left(\hat{D}_{x,j,t}, \hat{D}_{y,j,t}\right)}{\left[VaR\left(\hat{D}_{x,j,t}\right)VaR\left(\hat{D}_{y,j,t}\right)\right]^{\frac{1}{2}}} \tag{4}$$

where: *COV* – wavelet covariance.

Wavelet cross-correlation. Wavelet cross-correlation indicates the direction of the spillover effect—that is, it determines which extreme risk leads and which one lags in different time horizons. In this way, researchers can learn from which markets extreme volatility shocks originate and which markets are the recipient of these shocks. Wavelet cross-correlation also couples two time series, as in the case of wavelet correlation, but it calculates a lagged correlation function (ρ_τ) with lag τ. In this way, wavelet cross-correlation has a symmetric lagged correlation function ($\rho_\tau = \rho - \tau$). However, when deviations between ρ_τ and $\rho - \tau$ become significant, this symmetry is interrupted, which creates an asymmetry in the information flow. When asymmetry occurs, the leading asset has predictive power over the lagging asset. The maximal overlap discrete wavelet transform cross-correlation equation for scale *j* and lag τ can be written as follows [Equation (5)]:

$$\rho_{x,y,j,t,\tau} = \frac{COV\left(\hat{D}_{x,j,t}, \hat{D}_{y,j,t+}\right)}{\left[VaR\left(\hat{D}_{x,j,t}\right)VaR\left(\hat{D}_{y,j,t+}\right)\right]^{\frac{1}{2}}} \tag{5}$$

where: *VaR* and *COV* have the same meaning as in Equation (4), and cross-correlation takes the value $-1 \leq \rho_{x,y,j,t} \leq 1$.

Data set and descriptive statistics. In this article, we used the daily near maturity futures prices of four soft agricultural commodities – coffee, cocoa, cotton and orange juice – which are all traded in the Chicago Mercantile Exchange. Sugar is omitted from the sample because the GJR-GARCH model does not fit the returns of sugar, so appropriate dynamic *CVaR* time series cannot be created. The sample covers the period from January 2017 to March 2023, including the COVID-19 pandemic and the war in Ukraine. These two crisis events inevitably created high risk, and the task of this article is to determine the scale-dependent connections between downside risks in these neighbouring markets. All the time series are collected from the investing.com website. Each empirical time series is transformed into log returns ($r_{i,t}$) according to the expression $r_{i,t} = 100 \times \log(P_{i,t} / P_{i,t-1})$, where P_i is the daily price of a particular asset. Also, each time series is synchronised with the other three, making in this way the six pairs of assets.

Table 1 contains descriptive statistics of the selected soft commodities, showing the results of the first four moments, the Jarque-Bera test, the Ljung-Box tests for level and squared log returns and the Dickey-Fuller generalised least squares unit root test. According to the results, orange juice has the highest volatility (0.914), but it has relatively low kurtosis, which means that extreme values are not that frequent in the orange juice market. However, cotton has a relatively high second moment but also very high kurtosis (14.745), which indicates that extreme values are relatively common in this market. Ljung-Box test results showed that the cocoa and orange juice time series have a problem

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Table 1. Descriptive statistics of the selected soft agricultural commodities

Soft commodities	Mean	SD	Skewness	Kurtosis	*JB*	LB(Q)	LB(Q^2)	DF-GLS
Coffee	0.000	0.575	0.188	3.863	58.164	0.818	0.000	–5.817
Cocoa	0.006	0.695	0.317	5.950	598.782	0.024	0.044	–4.014
Cotton	0.002	0.768	–0.677	14.745	9 167.339	0.303	0.000	–4.719
Orange juice	0.007	0.914	–0.206	4.911	249.576	0.005	0.000	–34.860

JB – Jarque-Bera coefficients of normality; LB(Q), LB(Q^2) – *P*-values of Ljung-Box Q-statistics of level and squared log-returns of 10 lags, 1% and 5% critical values for the Dickey-Fuller generalized least squares test with 5 lags, assuming only constant, are –2.566 and –1.941, respectively; DF-GLS – Dickey-Fuller generalized least squares

Source: Authors' own calculation based on data from investing.com (2023)

with autocorrelation, and all the assets showed heteroscedasticity, which means that the AR(1)-GJR-GARCH model might be appropriate to resolve these issues. All of the time series had no problem with the unit root, as Dickey-Fuller generalised least squares test results suggested, which is a necessary precondition for GARCH modelling.

Table 2 shows the estimated GJR-GARCH parameters, which indicate that past shocks affected conditional variance in the coffee, cotton and orange juice markets and that the persistence of volatility was present in all the markets. An asymmetric effect occurred only in the cocoa market, where the γ parameter was positive, and the orange juice market, where the γ parameter was negative. This finding means that negative shocks have a stronger effect than do positive shocks on the conditional variance of the cocoa market, whereas in the orange juice market, the reverse applies. All ν parameters were highly statistically significant, meaning that empirical distribution was recognised well by the Student *t*-distribution. Autocorrelation and heteroscedasticity problems were resolved in the models according to the diagnostic test results, which means that all models created reliable residuals and that this is a good basis for the creation of dynamic *CVaR* time series.

Figure 2 plots the estimated residuals of the soft commodities and the two dynamic extreme downside risks (*VaR* and *CVaR*) calculated at 95% probability. Cotton had the highest downside risk in 2022, which is likely due to high price growth and a steep decline in 2022 (Figure 1). However, the pandemic did not have a significant effect on the soft commodity markets, except to some extent for orange juice. To inspect extreme risk interdependencies between the markets, we used lower blue lines and embedded them in the wavelet correlation and cross-correlation methodologies. Multiscale interdependence occurred across six wavelet scales, where the scales represent the following time horizons: scale 1 (2–4 days), scale 2 (4–8 days), scale 3 (8–16 days), scale 4 (16–32 days), scale 5 (32–64 days) and scale 6 (64–128 days). The first four scales cor-

Table 2. Estimated GJR-GARCH parameters

Estimated parameters	Coffee	Cocoa	Cotton	Orange juice
Panel A: GARCH parameters				
α	0.044**	0.001	0.048***	0.080***
β	0.852***	0.831***	0.932***	0.951***
γ	0.033	0.133***	0.009	–0.082***
Panel B: Distribution parameter				
ν	11.049***	5.621***	4.743***	8.852***
Panel C: Diagnostic tests				
LB(Q)	0.785	0.898	0.325	0.192
LB(Q^2)	0.404	0.972	0.974	0.275

**, ***statistical significance at the 5% and 1% level, respectively; LB(Q), LB(Q^2) – *P*-values; GJR-GARCH – Glosten-Jagannathan-Runkle-generalised autoregressive conditional heteroscedastic model; α measures the autoregressive conditional heteroscedasticity effect; β measures the persistence of volatility; γ measures asymmetric response of volatility to positive and negative shocks; ν – shape parameter of Student t-distribution

Source: Authors' own calculation based on data from investing.com (2023)

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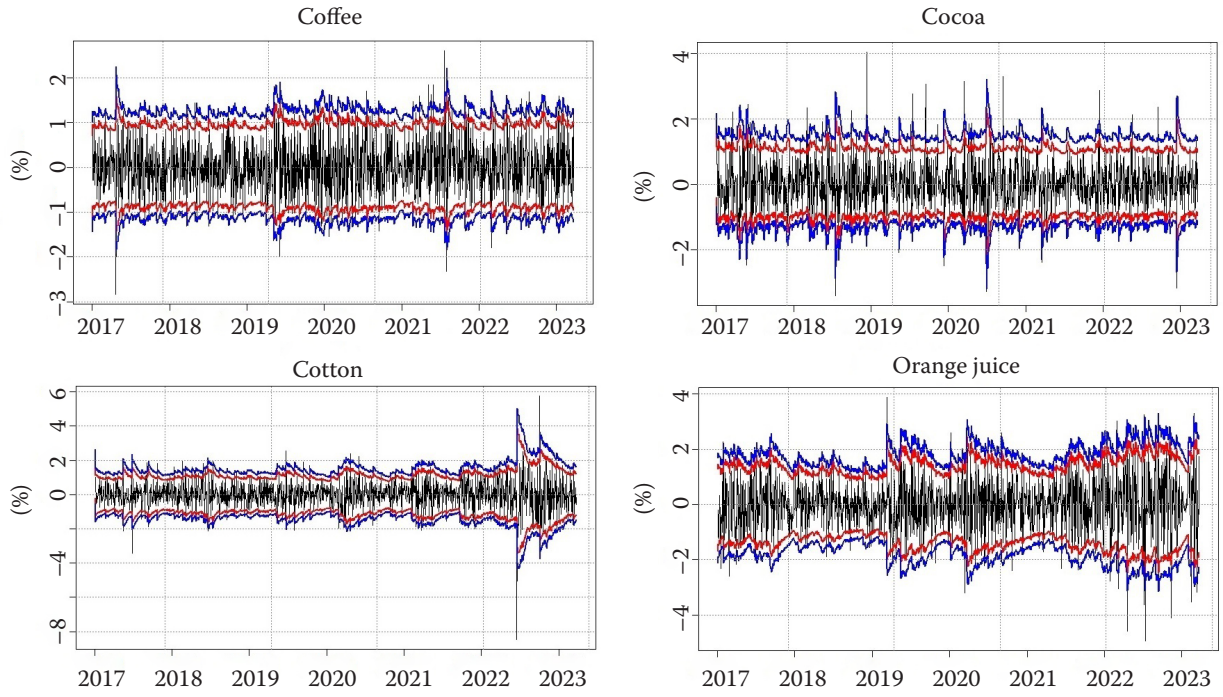

Figure 2. Created dynamic downside risk time-series of the soft commodities

Blue (red) lines denote upper and lower dynamic *VaR* (*CVaR*) time-series; *VaR* – Value-at-Risk; *CVaR* – condtional *VaR*
Source: authors' own calculation based on data from Investing (2023)

respond to the short-term horizon, and the fifth and sixth scales are regarded as midterm and long term, respectively. Frequency scales can also be called wavelet details, and the label of wavelet details is the capital letter D.

RESULTS AND DISCUSSION

Wavelet correlation findings. This section presents the results of pairwise wavelet correlations, where Figure 3 contains the plots and Table 3 shows the exact values of scale-dependent correlations. According to the results, wavelet correlations were very low up to the fifth scale, which means that soft agricultural markets were mostly segmented in the short-term and midterm horizons. These results are in line with those of Živkov et al. (2022) who researched multiscale interdependence between five cereal markets and found lower wavelet correlations in short time horizons, particularly between smaller markets. These authors also asserted that in the cases when one asset is the largest market (corn), higher correlations can be found even at lower wavelet scales. Our results coincide with these findings because very low or even negative correlations were found between smaller markets (cocoa, cotton and orange juice), whereas in the cases when one asset in the combination was the largest market (coffee), higher correlations were found at lower wavelet scales. Table 4 shows the average daily trading volumes in the four markets, where coffee is the largest market, according to this parameter.

For example, in the coffee–cocoa combination, a relatively high correlation exists in the D4 scale (0.142); in the coffee–cotton pair, the higher correlation is in the D3 scale (0.123); and in the coffee–orange juice pair, the higher correlation is in the D4 scale (0.246). These results could indicate that smaller markets follow the largest market to some extent, but these correlations are still relatively small. The smaller markets do not have higher correlations whatsoever at lower wavelet scales. These results indicate that strong connections between high risks do not exist among soft agricultural markets in the short term and midterm, which is good news for market participants who operate in these time horizons. In other words, investors do not have to worry too much that high risk from another market will have an effect on their market in the short term and midterm.

However, the situation is totally different in the long-run, in the sense that five out of six pairs have high corre-

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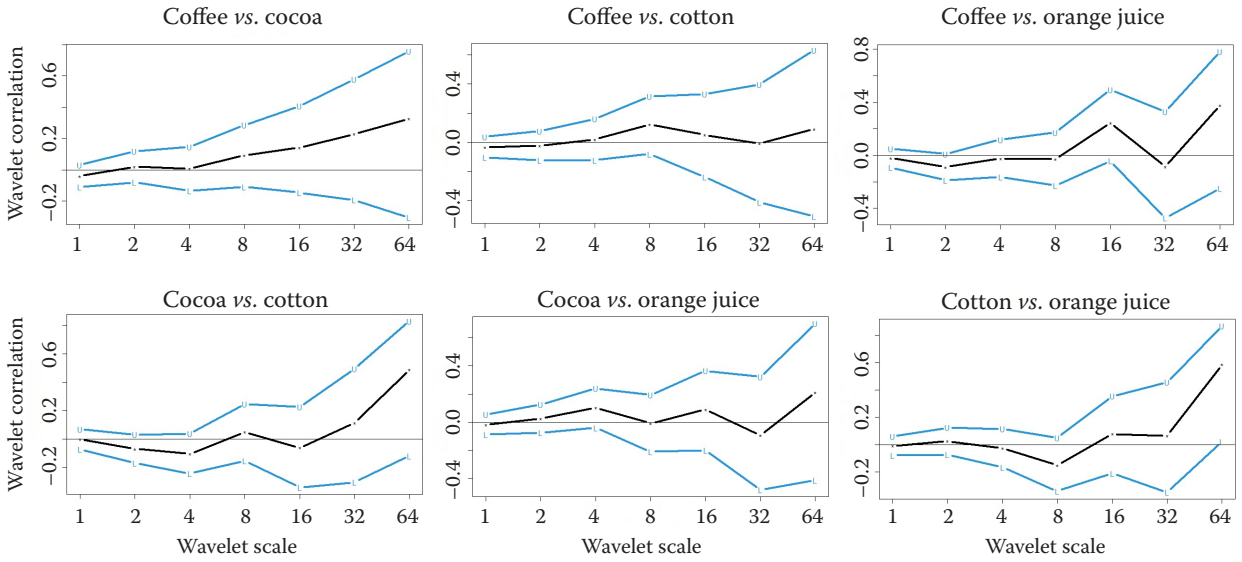

Figure 3. Pairwise wavelet correlations between the selected soft agricultural commodities

Source: Authors' own calculation based on data from Investing (2023)

lation in the long-term horizon (D6 scale). These results are not unusual in commodity markets (Tiwari et al. 2023) and probably occur because time series lose idiosyncratic features in the long-run while being affected by the same external factors. As a result, high correlation occurs even between smaller markets, meaning that market participants have to consider some type of protection against extreme risk from another market in the long-run.

Wavelet cross-correlation findings. This section describes complementary cross-correlation findings, which show from which market extreme risk originates and which market is the recipient of extreme risk. Table 5 presents the results, and Figures 4 and 5 show plots of wavelet cross-correlations. This methodology indicates whether any pulling effect exists between the soft agricultural markets at contrasting time lags.

Table 3. Pairwise wavelet correlations

Frequency scales	Coffee *vs.* cocoa	Coffee *vs.* cotton	Coffee *vs.* orange juice	Cocoa *vs.* cotton	Cocoa *vs.* orange juice	Cotton *vs.* orange juice
Raw	–0.040	–0.033	–0.021	–0.001	–0.016	–0.009
D1	0.020	–0.023	–0.089	–0.068	0.027	0.026
D2	0.007	0.020	–0.023	–0.104	0.103	–0.026
D3	0.093	0.123	–0.029	0.049	–0.007	–0.150
D4	0.142	0.051	0.246	–0.061	0.091	0.078
D5	0.229	–0.007	–0.085	0.115	–0.092	0.065
D6	0.327	0.093	0.378	0.489	0.213	0.588

D1–6 – wavelet details (scales)

Source: Authors' own calculation based on data from Investing (2023)

Table 4. Average daily trading volumes of the selected soft agricultural commodities in 2019

Observed category	Coffee	Cocoa	Cotton	Orange juice
Volume	57 652	46 816	31 579	1 698

Average trading volumes, i.e. number of contracts, are observed in 2019 in order to avoid possible biasedness that can be caused by the pandemic and the war in Ukraine in the years 2020–2022

Source: Authors' own calculation based on data from Stooq (2023)

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Table 5. Wavelet cross-correlation results at D6 wavelet scale

Cross-correlation	Wavelet scale	Negative lagged correlations				Positive lagged correlations			
		–20	–15	–10	–5	5	10	15	20
Coffee *vs*. cocoa	D6	0.073	0.135	0.190	0.225	0.185	0.110	0.015	–0.084
Coffee *vs*. cotton	D6	0.001	–0.023	–0.040	–0.045	–0.045	–0.041	–0.038	–0.042
Coffee *vs*. orange juice	D6	0.219	0.182	0.129	0.065	–0.055	–0.101	–0.128	–0.127
Cocoa *vs*. cotton	D6	–0.031	–0.011	0.016	0.049	0.106	0.124	0.132	0.123
Cocoa *vs*. orange juice	D6	0.065	0.072	0.050	–0.003	–0.161	–0.230	–0.266	–0.252
Cotton *vs*. orange juice	D6	–0.003	0.038	0.069	0.083	0.068	0.054	0.048	0.058

Source: Authors' own calculation based on data from Investing (2023)

The names of the pairs in Table 5 suggest which variable enters the computational process first and which comes second. This order is important because negative lag correlations are connected with the first vari-

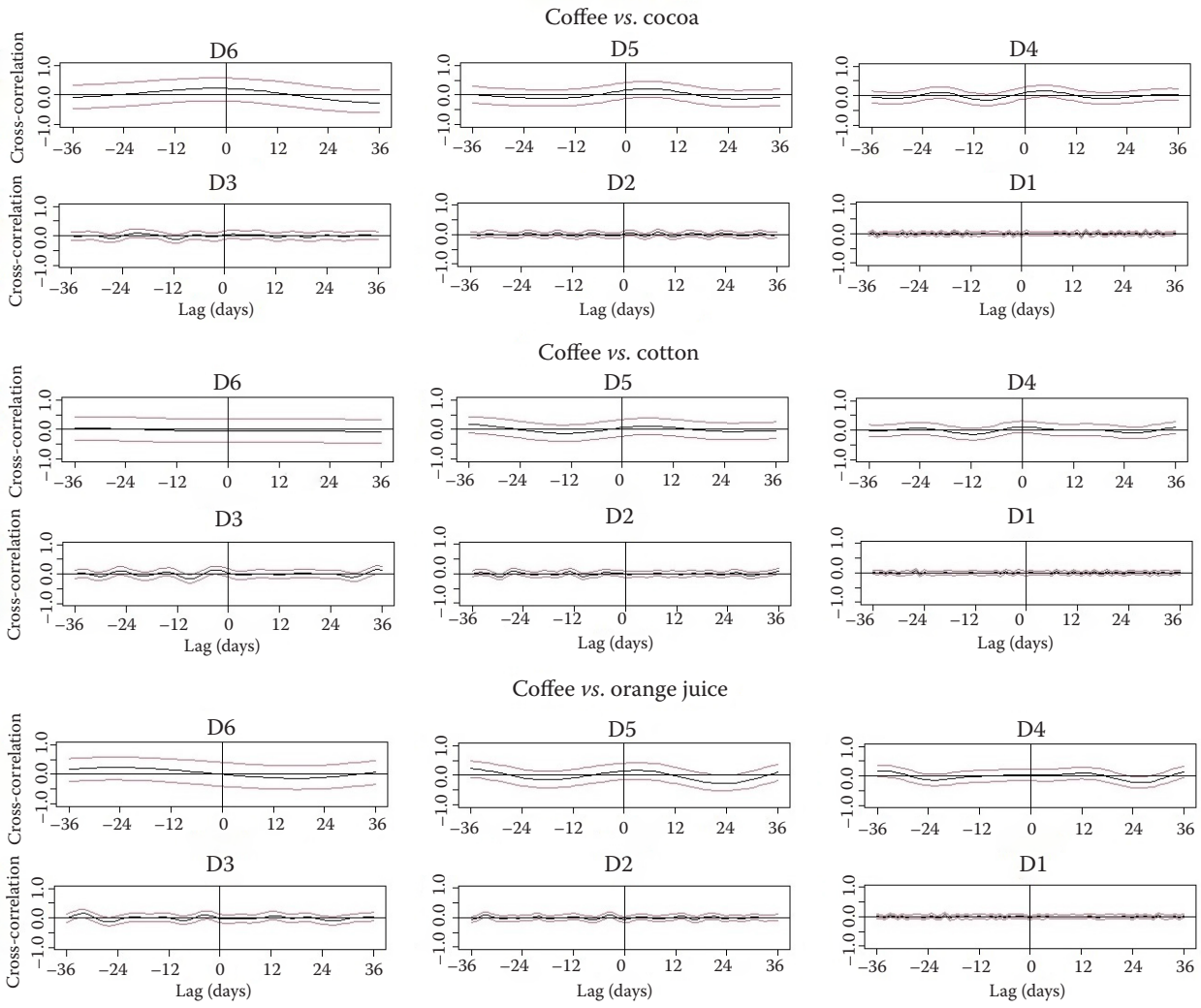

Figure 4. Cross-correlation between the selected soft agricultural commodities

D1–6 – wavelet details (scales)
Source: Authors' own calculation based on data from Investing (2023)

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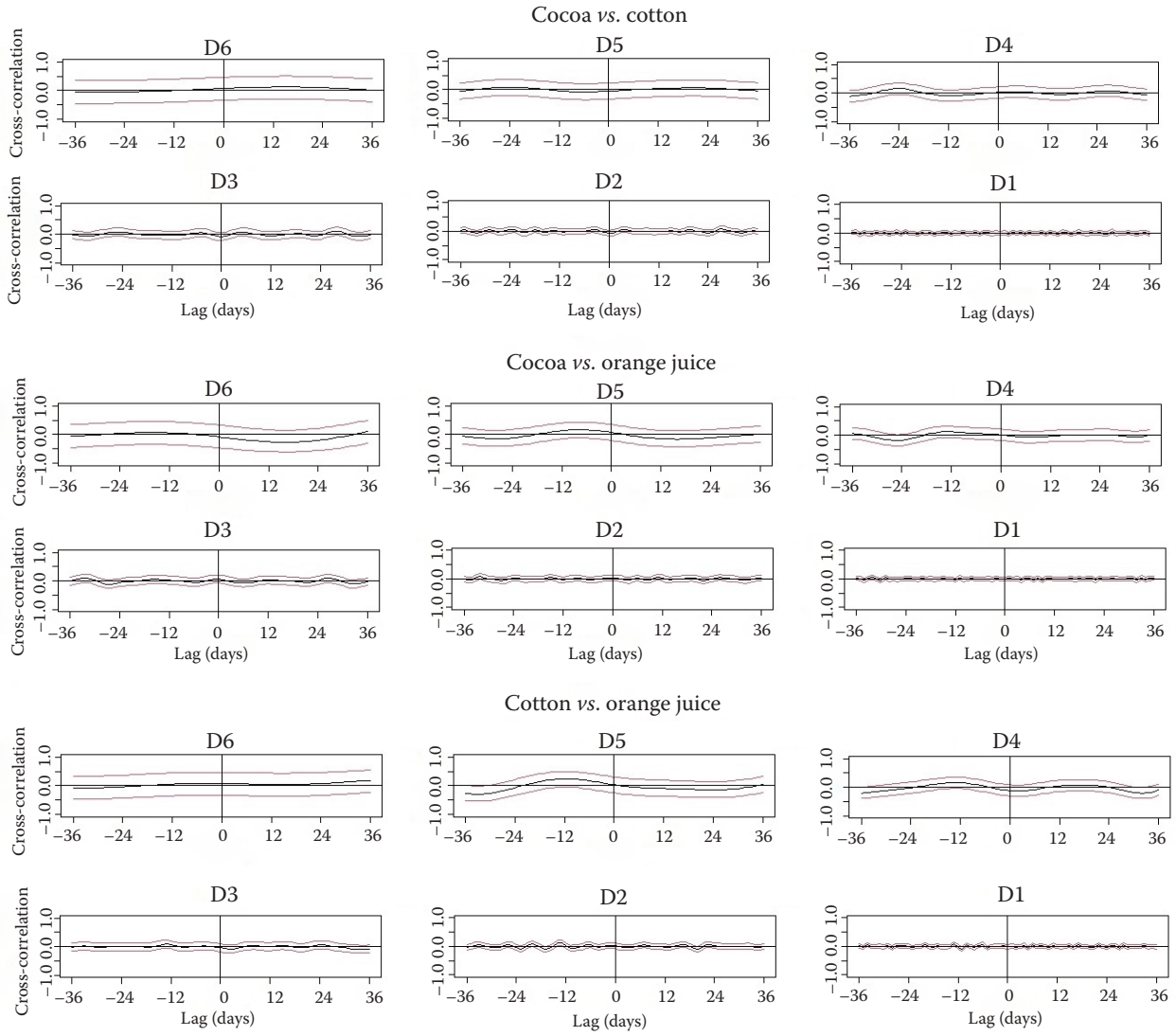

Figure 5. Cross-correlation between the selected soft agricultural commodities

D1–6 – wavelet details (scales)

Source: Authors' own calculation based on data from Investing (2023)

able, and positive lag correlations are connected with the second variable. The lead-lag interlink is determined via skewness of the cross-correlation curve, meaning that the curve being skewed significantly on the left side of the graph implies that the first time series leads the second and vice versa. A significant lead-lag relationship exists only if the correlation between variables is relatively strong, which means that only cross-correlation on the D6 scale is worthy of note because only at the long-term horizon does the strongest interdependence exist. Only cross-correlations at lag 5 are compared and commented.

According to the results, coffee as the largest market leads cocoa and orange juice, which is expected because larger markets usually process new information faster, and smaller markets then follow the developments on the larger market. The situation between coffee and cotton is inconclusive because the cross-correlations are equal. Even if there would be a pulling effect between the two markets, the result would be questionable because these assets have very low correlation on the D6 scale (0.093). Cotton leads orange juice, which also makes sense because cotton is a bigger market. However, in the

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cases of cocoa–cotton and cocoa–orange juice, the larger market does not lead the smaller market, contrary to common knowledge. This finding means that further research needs to be done by using different methodologies to confirm or refute our results between these markets.

CONCLUSION

In this article, we investigated the nature of extreme risk interdependence between four soft agricultural futures markets. We performed the analysis by using a multiscale framework and two wavelet methodologies—wavelet correlation and wavelet cross-correlation. Extreme risk was measured via *CVaR*, and the dynamic *CVaR* time series were computed using the asymmetric GJR-GARCH model.

Wavelet correlation results indicated that a very weak connection exists between the markets in the short-term and midterm horizons. Only in the cases when coffee was an element in the combination did somewhat higher wavelet correlations occur on some short-term and midterm wavelet scales. These results favour investors who run their businesses in the short term or midterm because they do not have to apply hedging measures to protect themselves against extreme risk. However, the situation is significantly different in the long-run, where relatively high correlations were found on the D6 scale in all the pairs, except coffee–cocoa. This finding means that some hedging measures should be implemented if investors operate in the long-term horizon.

Additional cross-correlation analysis results revealed lead-lag relationships between the markets. The results were mostly in line with expectations, meaning that bigger markets led smaller markets, but only in the cases of cocoa–cotton and cocoa–orange juice did the opposite happen. From this point of view, further research is needed to verify or reject the results for cocoa–cotton and cocoa–orange juice.

These findings could be useful for investors in soft commodities to gain knowledge about extreme risk interdependence between these markets. Short-term market participants can freely invest in soft commodities or construct a portfolio with them without worrying that extreme risk from a neighbouring market will spill over. In the long-term horizon, the situation is somewhat different in the sense that some risk protection is needed because higher correlation exists in this timescale. Besides, long-term cross-correlation results can be useful to indicate to investors in lagging markets how to behave if extreme price swings occur in leading markets.

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