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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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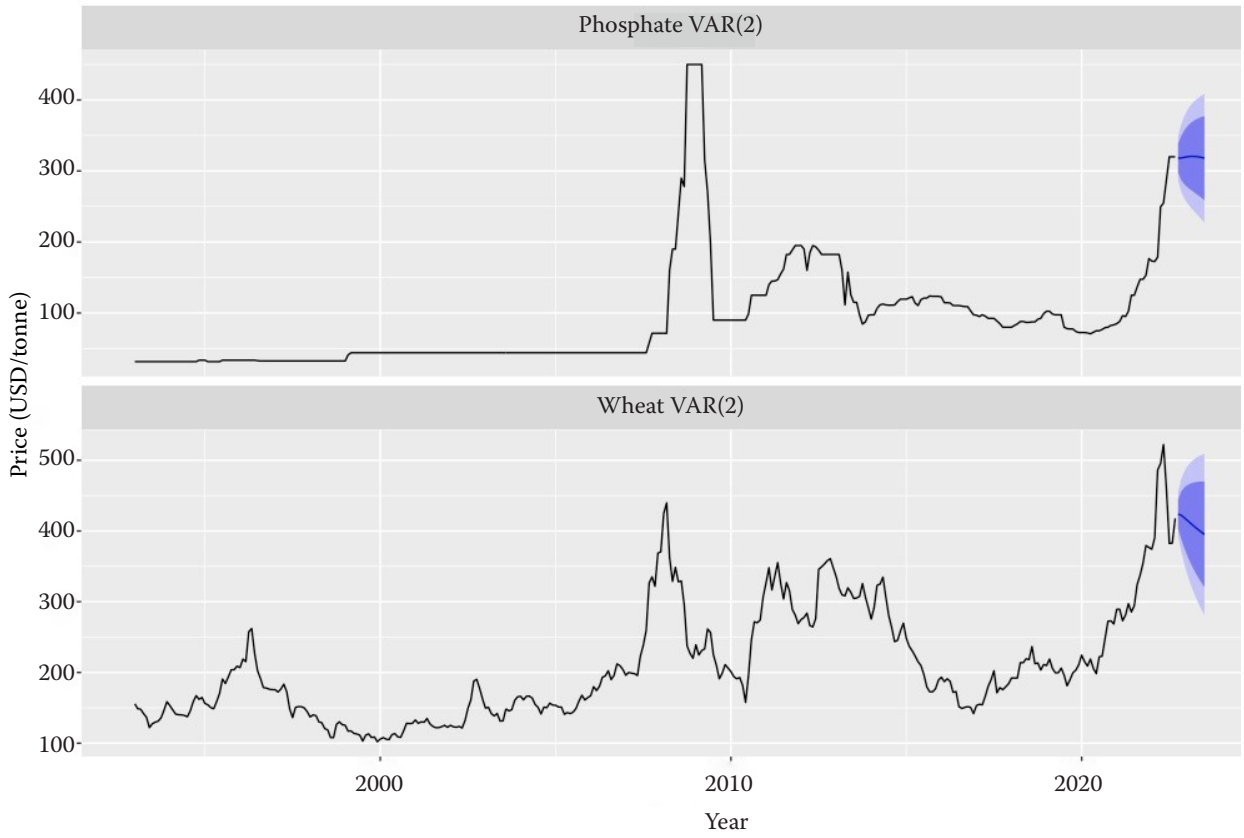

Figure 3. VAR prediction of Moroccan phosphate and wheat

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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