Development of the price of selected metals used in the circular economy

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Abstract

The article aims to identify the development of the prices of steel, copper, silver and gold used in the circular economy. The monitored period is 2009-2023. For clarity, the monthly price development on world stock exchanges is used. The time horizon 2009-2023 is divided into three described periods. The economic crisis of 2009-2010, the COVID-19 pandemic in 2020-2021 and the Russian invasion of Ukraine in 2022-2023. The average price and mean for each metal in the observed period are always used for better clarity. During this time, the price of copper, gold and silver rose, while the price of steel tended to fall. Gold and silver rise because they are seen as a haven for investment, so their price rises in times of uncertainty. Furthermore, there is an increase in the demand for electronics, which increases the price of copper even during crisis periods. Adverse effects on the economy mainly cause a drop in the price of steel, as its consumption has mostly stayed the same in recent years. The prices of selected metals are essential because they influence the prices of goods, and we can also observe the current development of the world economy on them.

Keywords: Economic crisis, COVID-19 pandemic, Russia-Ukraine conflict, price developments, metal commodities

Introduction

The development of the price of metals is significant for the circular economy because metals are easily recycled (Horák, Machová & Krulický, 2019). At the same time, they are essential, especially in the production of electronics and the construction industry. We will monitor the development of steel, copper, gold and silver prices. The prices of these commodities depend on the prices on the stock exchange (Machová, Krulický & Horák, 2020).

Among the most commonly used metals is steel. This metal is a typical long-term successful illustration of the circular economy (Horák, Pavlová, 2022). Recycling has been a part of steel production since the beginning of its production. The price depends on scrap and the "new" steel itself. At the same time, due to constant high demand, there are frequent price increases (Fischer, 2021).

Another frequently used metal is copper. It is used to manufacture pipes and electronics. Because copper is easy to process, it was used in ancient times and recycled here for the first time (Bartoš, Vochozka & Šanderová, 2022). The price of copper is essential for producers' plans and for its forecast; for example, a three-factor stochastic model is used, which uses the forecasts of the Bloomberg agency, as well as the COMEX and LME exchanges (Cifuentes et al., 2020).

The most frequently mentioned metals are gold and silver. These raw materials were previously used mainly for producing jewellery, coins and various decorative items. Currently, however, they have found another use: electronics production. They are easy to process, and their recycling has been common since the beginning of their processing times (Horák, Dušek, 2022). However, compared to copper and steel, the development of their prices is also influenced by the fact that gold and silver are considered investment metals (Sadorsky, 2021). During various crises in the market, there is an increased demand for these metals and a subsequent increase in the price. Therefore, in their predictions, the manufacturer must consider difficult-to-predict price fluctuations in the market (Baur, Beckmann & Czudaj, 2020). Apergis, Apergis (2019) used an empirical analysis that uses the ARDL model and combined cointegration to estimate the price of silver. The goal of combining these methods is to express the relationship between the production of solar panels and the price of silver.

An effort to find the best method to predict the three most essential metals in the market - gold, silver and copper - appeared in 2017 by Kristjanpoller, Hernández (2017). ANN-GARCH model with regressors was the best model for forecasting the price return volatility of these significant metals. Due to the heteroskedasticity of the financial series, the loss function HMSE (Heteroskedasticity-adjusted Mean Squared Error) is used, and the Confidence Set model is used to test the superiority of the models.

Nowadays, when all sectors of the economy are heavily influenced by the circumstances that have happened or are still happening, it is appropriate to determine to what extent these circumstances affect the metal markets. Looking back not too far, we can see the economic crisis and uncertainty related to the COVID-19 pandemic (Rydell, Šuleř, 2021). We have been dealing with the Russian-Ukrainian conflict for over a year, affecting us all, not only beyond the borders. It is a question of how these events affect metal prices and their development. To this day, understanding the impact of an infectious disease pandemic on stock market volatility is of great concern to investors and policymakers (Bai et al., 2021), especially after the recent experience each of us, which persists in certain parts of the world. Research from 2020 in Vietnam shows significant changes, especially in the financial sector and stock markets, which showed opposite values than expected (Anh, Gan, 2020). After the outbreak

of war in Ukraine, companies and countries had to adapt their activities to the consequences of this conflict strongly (Matasova, Vochozka & Rowland, 2022). It shows that the European financial system is still fragile to external shocks, which can be seen in the result of research showing that after the outbreak of the war in Ukraine, the value of the euro was devalued in correlation with the exchange rate to the ruble (Aliu Hašková & Bajra, 2023).

The thesis aims to identify the development of the prices of steel, copper, silver and gold used in the circular economy. The monitored period will be 2009-2023. To achieve this goal, the following research questions are defined:

RQ1: How did the economic crisis in 2009 affect metal prices?

RQ2: How did the COVID-19 pandemic affect the development of metal prices?

RQ3: How did the Russian invasion of Ukraine affect the price of metals?

Metal commodities are used as investments in industry and other sectors. An example can be steel, which is mainly used in the engineering industry, for the production of car bodies, but also in the construction industry, where it is primarily used as reinforcement for concrete structures. The largest producers and consumers of steel are located in China. Therefore, the development of steel prices is highly dependent on prices in this country. Ma (2021) used the analysis of iron ore prices, carbon emission allowances, and shipping to predict the price. Specifically, they analyzed price spillovers, dependency structure and spillover risk between iron ore, steel scrap and carbon dioxide emission allowances. The authors' results show that since China's policy to reduce excess capacities in steel production, Chinese prices are mainly subject to iron ore prices. To forecast steel prices in the Czech Republic, Zapletal, Chytilová (2016) used a method that can also be used in other EU member countries. Here, companies are under the influence of carbon trading, which can be an advantage on the one hand, but rather a threat on the other. The method focuses on assessing the effectiveness of steel companies' emissions management and examines the influence of two critical factors of this process. These are emission prices and banking options (transfer of unused allowances to the following period). According to Saniuk, Saniuk (2018), Industry 4.0 technology, which is attracting more and more attention worldwide, can also be used to determine the global price of steel in the future. These new technologies are intended to increase efficiency and performance. Also, this method identifies the main benefits and threats resulting from introducing the Industry 4.0 concept. Much research is emerging in the framework of reuse in steel production. Lupu et al. (2021) comment on how the current legislation requires the search for solutions for converting wastes stored or generated during current production flows into by-products that can be used in industry. It also represents the possibility of increasing the capacity of small and powdered iron wastes generated in the steel industry by converting them into by-products in agglomerate. Similarly, Budiul & Berghian (2021) research investigated the use of iron sludge generated in the steel industry in the context of a circular economy.

Copper is also widely used in industry to produce electronics or pipes. Also, in the case of copper, China is the largest exporter; we assume that international copper price shocks affect China's producer price index (PPI). When testing this method, Wen, Zhao & Hu (2019)

used a time-varying parametric structural vector autoregression model with stochastic volatility to analyze the impact of a copper price shock, which is divided into a supply shock, an aggregate demand shock, and a specific copper demand shock. The results show that the impact of international shocks on China's PPI is time-varying. Price shocks significantly affect PPI in the short and medium term, and the aggregate demand shock is the most pronounced. Another interesting method of determining the price of copper was used by Ardente, Beylot & Zampor (2023) when they addressed the degree of damage to sources of this metal. The authors used this method for conditions in the EU. He states that 90% of the loss in value is due to poor final disposal of tailings, not to mention the environmental impact. A system that tries to effectively and accurately predict the development of the copper price was developed by Liu et al. (2017). They used a machine learning algorithm based on a decision tree. This method can accurately and reliably predict copper prices in both the short-term (days) and long-term (years), with an average absolute percentage error of less than 4%. Furthermore, the method is assumption-free, robust, and not susceptible to human bias. This method is quickly and effectively used to forecast the prices of other metals and other commodities. Even Khoshalan et al. (2021) recognize that metal price is one of the most critical and influential parameters in assessing various projects such as industry and mining. In this regard, price changes can play a vital role in the correct decision-making by managers on the development or limitation of mining activities. Khoshalan et al. (2021) used gene expression programming (GEP), artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS) and ANFIS-ACO (ant colony optimization algorithm) to predict copper price. In this study, the ANN model was selected as the best model for predicting copper prices, but overall, all the mentioned methods were acceptable. The development of the price of copper from 1959 to 2022 was addressed by Vochozka et al. (2021). They focused on the forecast of development in 2022 and analyzed the impact of the COVID-19 pandemic on this commodity. Citing increasing demand after the outbreak of the pandemic and reporting an accelerated trend, daily historical closing prices of copper from the COMEX commodity exchange were analyzed into a time series, which was then processed by artificial intelligence using neural networks. Vochozka et al. (2021) propose, taking into account the limits of the work, its improvement – an effective combination of traditional methods with advanced artificial intelligence techniques.

Other metals important for the circular economy include silver, which is used in producing photovoltaic panels but is also considered an important investment metal (Brabenec et al., 2020). An interesting method for determining the price of silver was proposed by Phitthayanon, Rungreunganun (2019). This method is interesting because it examines price developments for small jewellery manufacturing businesses in Thailand. This method relies on historical price data since small companies cannot access relevant oil prices and other economic data. This model can provide an RMSE (root mean square deviation) prediction of 0.00765, comparable to other methods. The advantage of this prediction is mainly in the simplicity of the model, and a large amount of data is unnecessary. Another approach to determining the price of silver was using a mathematical method devised by Korotkov, Korotkova (2017). The approach aims to detect latent periodicity in the presence of deletions or insertions in the analyzed data if the omissions or insertions' sites are unknown. The

developed method uses dynamic programming and random matrices. It can also be used to determine the price of silver and gold, company shares or stock market indices.

Similar to silver, gold is used not only for production but also for investment. The price of gold is very susceptible to crises in the world. Baur (2013) also found that gold is subject to the so-called "underground effect". This effect lies in statistics that show that in September and November, the price of gold achieves positive and statistically significant changes every year. Baur (2013) explains this anomaly by investors' hedging demand in anticipation of the "Halloween effect" in the stock market, demand for gold jewellery during the wedding season in India, and negative investor sentiment due to the shorter summer time. Bentes Gubareva, Teplova (2022) also confirmed the existence of the autumn effect. During the COVID-19 pandemic, this autumn effect's disappearance and subsequent reverse behaviour were noted (November 2020). On the contrary, the unusual behaviour of gold volatility and seasonal effects were not identified. The results also confirm the positive asymmetric impact of gold fluctuations. Baur, Beckmann & Czudaj (2020) tried to evaluate whether the price of gold is overvalued or undervalued. So, they analyzed gold prices concerning commodity prices, consumer prices, stock prices, dividends and bond yields. The authors prove that when there is an increase in market confidence, the relative price decreases, while in the case of increasing distrust, the relative price increases. Immanuvel, Lazar (2020) sought to determine how the arrival of information in the market affects gold prices. They analyzed information spillovers and leverage transferred from countries that are the largest consumers of gold. A multivariate exponential generalized autoregressive conditional heteroskedasticity model was used here. Research has shown that price movements are significantly influenced by information from India and the US. Immanuvel, Lazar (2022) also conducted another follow-up research showing that although India is the largest gold market in the world, it takes prices from other world exchanges, such as the London Stock Exchange. The authors suggested that Indian gold bullion producers take initiatives that would enable India to become a global gold price maker.

Methods and Data

The development of stock exchange prices will be used, from which the prices of contracts concluded outside the stock exchange also depend. The data will be drawn from the website tradingeconomics.com, which publishes the development of price indices. First, the time series of data from 2009 to 2010, when the economic crisis affected the price of commodities, will be described. Next, data from 2020 to 2021, when the COVID-19 pandemic hit the world, will be examined. The next examined period will be 2022 to 2023 when the Russian invasion of Ukraine began. To compare the price development in these periods, formulas will be used to calculate the average price (formula number 1), which is given in Chinese yuan per ton for steel, dollars per pound for copper, and dollars per ounce for silver and gold.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{1}$$

Furthermore, the formula for calculating the mean (formula number 2) will be used here, which is not distorted by extreme values compared to the average and better expresses the mean value during the monitored period. Prices will again be quoted for steel in Chinese yuan per ton, copper in dollars per pound, and silver and gold again in dollars per ounce.

$$ME(X) = x_{(N+1)/2} \qquad (2)$$

Therefore, the primary method used for the research will be the analysis of the time series of the development of the prices of steel, copper, silver and gold. Price indexes from the already described years and events that impacted the development of these indexes will be used. These events are the economic crisis from 2009 to 2010, the COVID-19 pandemic from 2020 to 2021 and the war in Ukraine, which directly followed the pandemic from 2022 to 2023. Using Excel, tables and graphs will be created to describe the findings as results. Monthly data will be used for each metal in the given periods. It will be interesting to see how quickly the market reacts to information shocks and how much the price of the monitored metals will rise or fall. Thus, the comparison method will be used to monitor the differences and fluctuations in the time series of individual tracked metal commodities.

Results

The data comes from tradingeconomics.com, which records price developments in stock markets. Graph 1 shows the prices in individual months so that we can easily observe the effect of prices. Each chart shows data from 2009 to 2010 when the economic crisis affected the markets. Next, data from 2020 to 2021, when the COVID-19 pandemic took place, and data from 2022 to 2023, when the Russian invasion of Ukraine affected the markets.

Graph 1: Steel price development
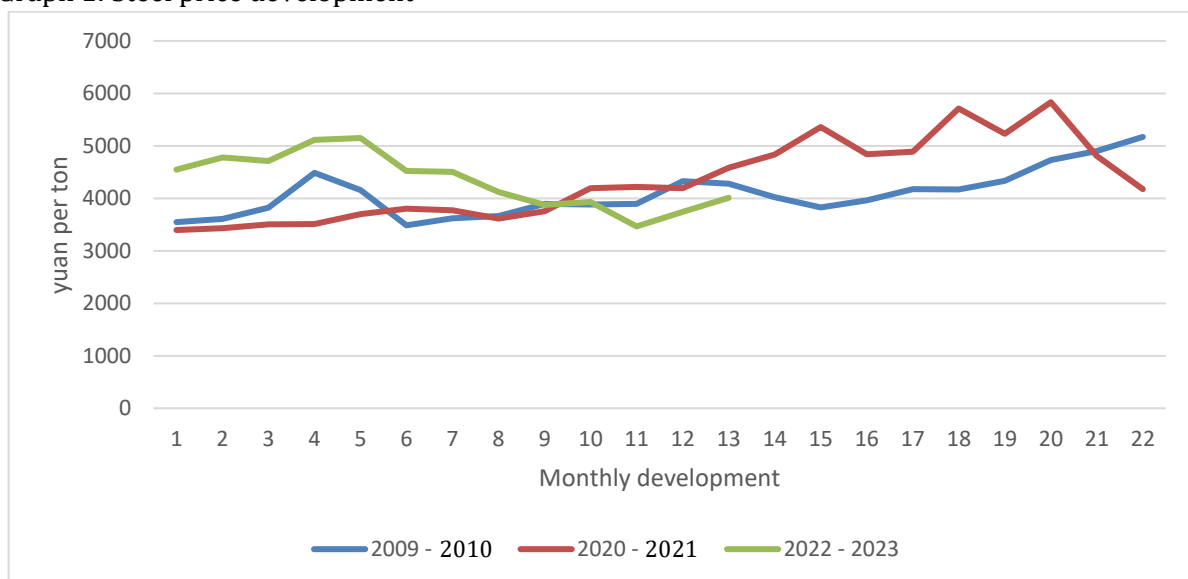
Source: Author.

First, we describe the data from 2009 to 2010, which includes prices in 22 months. At the beginning of this period, it can be seen from the development of the curve that there was an optimistic mood in the markets between the 4th and 5th months, but this mood did not last long, and steel prices returned to prices around 3600 yuan per ton. A more permanent increase in steel prices occurred until the end of the economic crisis in 2010. Here, steel prices reached values of 5000 yuan per ton. The average price during this period was 4088.64 yuan per ton, and the mean was $3992.5 per ton of steel.

The following data will be from 2020 to 2021; the graph shows prices for 22 months. It is interesting here that since the steel demand has decreased due to the pandemic, at the same time, steel mills have been closing, especially in China, which is the largest producer, and the price of steel has stabilised at around 3,700 yuan per ton. At the beginning of 2021, the price rose to a value of 5,500 yuan per ton, but due to the re-closure of large cities in China, there was a drop again to a value of around 4,000 yuan per ton. Average steel prices during this period were $4341.81 per ton, and the mean was $4192 per ton.

The following data is from 2022 to 2023; data from 13 months was used here. The data from 2022 shows that steel prices were relatively stable. They were around 5,000 yuan per ton. This relative stabilisation was also due to the impact of COVID-19, as the widespread closures in China were lifted, which caused the economy's relaunch. However, towards the end of 2022 and the beginning of 2023, the uncertainty in the markets caused by the Russian invasion took full effect, and steel prices fell to values of 3500 yuan per dollar. The observed prices during this period averaged 4,345 yuan per ton, and the mean value was 4,504 yuan per ton of steel. See Graph No. 2.

Graph 2: Cooper price development
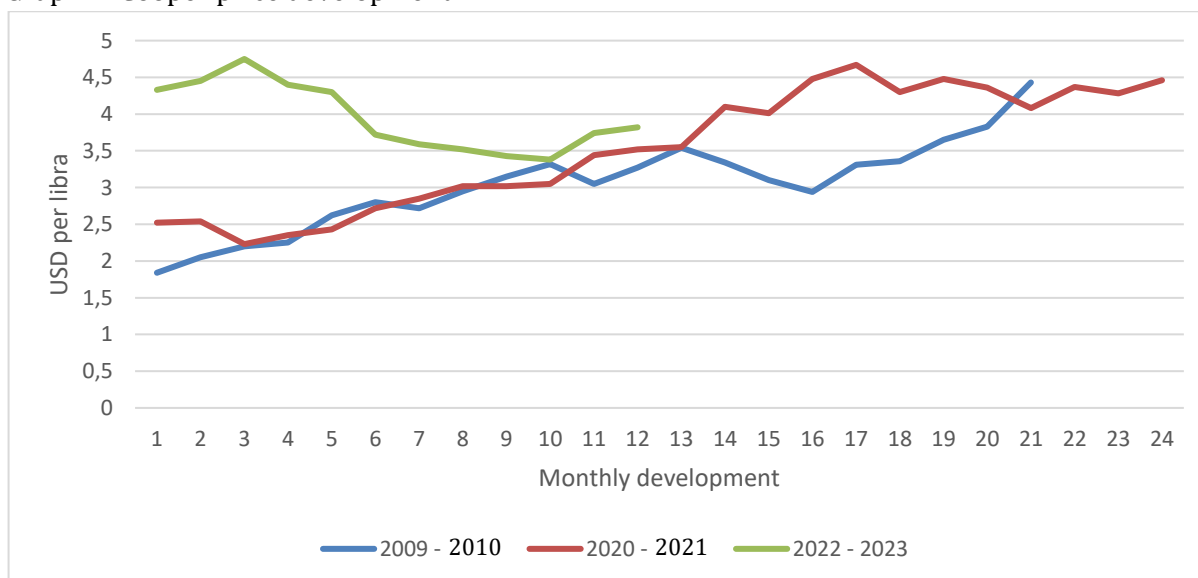
Source: Author.

First, we will describe the data from 2009 to 2010. During this period, we are monitoring data for 22 months. What is interesting about these data is that although the economic crisis affected the markets, the price of copper more than doubled during this period, namely from a value of 1.84 dollars per pound to a value of almost 4.5 dollars per pound. The average price during this period was $3.03 per pound, and the mean was $3.1 per pound of copper.

The following monitored data is from 2020 to 2021; we are tracking the price development in 24 months. During this, despite the COVID-19 pandemic, the price of this metal rose again. This growth was mainly due to increased demand for electronics. Since copper is one of the essential production metals in electronics, there has been an increase in the market for this metal. The already mentioned COVID-19 closures in China also impacted the price increase because China, like steel, is the largest copper processor in the world. The average price during this period was $3.53 per pound, and the mean was also $3.53 per pound of copper.

Next, we monitor the data from 2022 to 2023 (see Graph No. 3), and the graph's curve expresses the price development in 12 months. Here, the price of copper fell from $4.75 per pound to $3.38 per pound. This decline was caused by the uncertainty in the markets caused by the war in Ukraine. However, it was not the only factor. Furthermore, there was a decrease in the demand for electronics, and, as I already mentioned, this also harmed the demand for copper. The average price of copper during this period was $3.95 per pound, and the mean was $3.78 per pound of copper.

Graph 3: Silver price development
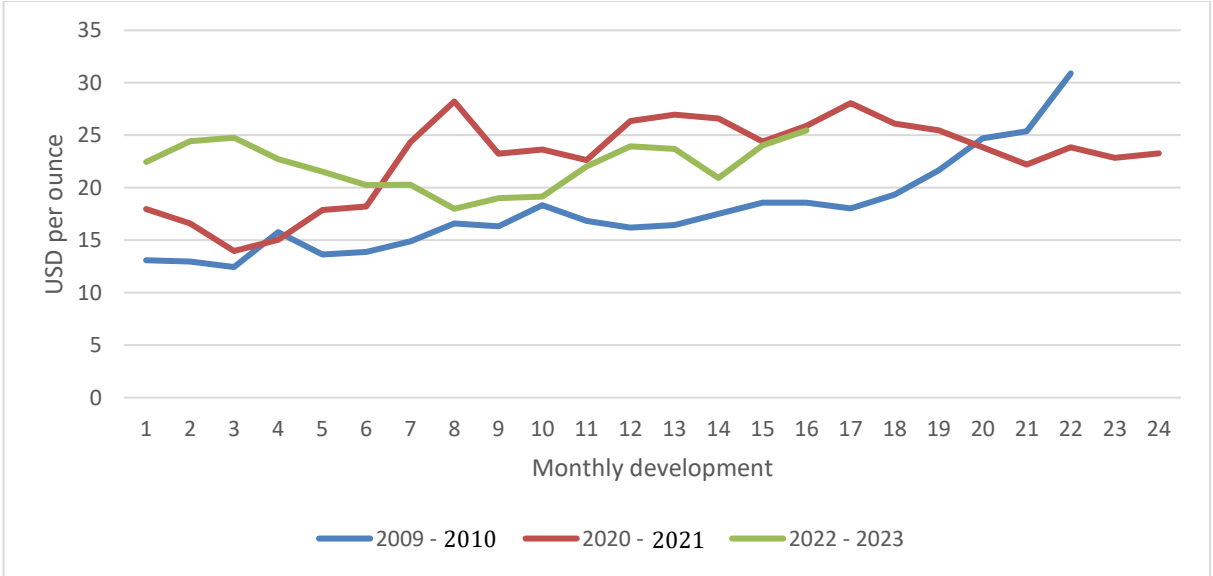
Source: Author.

Again, we will first describe the data from 2009 to 2010, the time horizon of the monitored period is 22 months. This data shows that silver is often used as an investment metal in times of crisis. As a result of the economic crisis, there was a steady increase in the price of silver.

And that from values around 13 dollars per ounce to 30 dollars per ounce. The average price during this period was $17.82 per ounce, and the mean was $16.73 per ounce of silver.

Next, data from 2020 to 2021 are described, data for 24 months is used here. The price development in this period was very turbulent. Due to market uncertainty caused by COVID-19, the price dropped from $17.96 per ounce to $13.97 per ounce at the beginning of this period. However, silver's safe-haven nature became apparent after that, and values rose to $28 per ounce. Towards the end of this period, at the end of 2021, the markets gradually calmed down, and the price of silver stabilized at around $22 per ounce. The average price during this period was $22.81 per ounce, and the mean was $23.74 per ounce of silver.

Between 2022 and 2023, the price of silver fluctuated again, for better clarity, the data for 16 months are shown here. This swing occurred between 2022 and 2023. This dip occurred due to the uncertainty caused by the invasion of Ukraine, and at the same time, there was a decrease in the demand for electronics. Since silver is an essential metal in electronics production, this factor again harmed the price of silver. However, at the beginning of 2023, uncertainty prevailed in the markets again, and prices were renewed up to values of $25 per ounce. The average price during this period was $22.05 per ounce, and the mean was $22.24 per ounce of silver. Graph 4 closely follows the development of the gold price for the given periods.

Graph 4: Gold price development
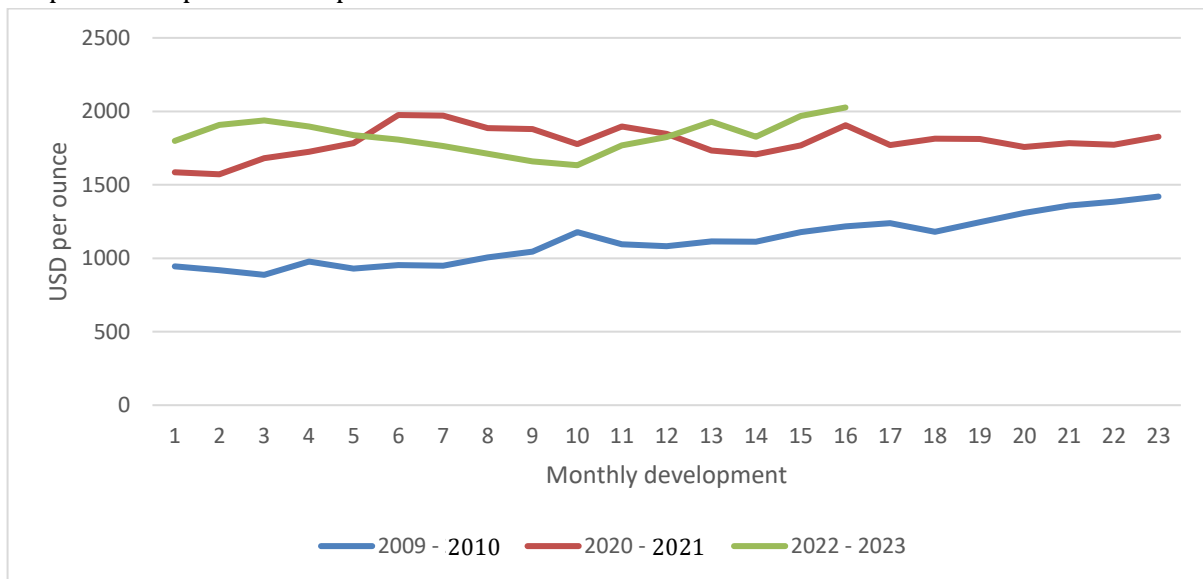
Source: Author.

Again, we will first start with the development of the data in the period 2009 to 2010, the presented development shows the prices for 23 months. Here again, as with silver, confidence in gold was shown. Again, this metal is therefore considered a safe harbour in times of crisis. We can see the price rise here throughout this period. Prices here ranged from $943.98 per ounce to $1,419.9 per ounce. The average price during this period was $1118.62 per ounce, and the mean was $1112.6 per ounce of gold.

The next period described is again from 2020 to 2021, and the curve of the graph shows the prices in 23 months of this period. Here again, due to the market crisis and the pandemic, the price of gold rose. The initial price in this period was $1,584 per ounce, and at the end of this period, the price was $1,828 per ounce of gold. However, there was no permanent price increase as in the previous monitored period. During 2021, the uncertainty in the markets was higher, and gold prices jumped to 2000 dollars per ounce. Prices fell to $1,828 an ounce due to the positive sentiment in the markets caused by the end of the pandemic. The average price during this period was $1,792.37 per ounce, and the mean was $1,782.5 per ounce.

The last monitored period is 2022 to 2023, for better clarity, the development in 16 months is shown here again. Interestingly, at the beginning of this period, the price of gold reached almost 2000 dollars per ounce due to the Russian invasion of Ukraine. However, as with silver, gold is an essential metal in the production of electronics, and again due to the decline in demand for electronics, the price of gold has fallen at the end of 2022 to $1,633 per ounce. But then uncertainty prevailed on the markets again, and the price rose to values of $2,000 per ounce. The average price during this period was $1,831.16 per ounce, and the mean was $1,826.4 per ounce of gold.

Discussion

RQ1: How did the economic crisis of 2009 affect metal prices?

During the economic crisis, the price of steel fell to 3,600 yuan per ton due to reduced demand and market uncertainty. Prices could overcome these problems only with the end of the economic crisis in 2010 when prices reached 5000 yuan per ton of steel. However, the prices of copper, silver and gold developed differently. Interestingly, there was a steady growth in these metals between 2009 and 2010. For gold and silver, this growth was due to these metals being taken as safe havens in times of crisis. In this period, the price of gold went from 950 dollars per ounce to 1400 dollars per ounce. The price of silver climbed from $19 an ounce to over $30 an ounce. However, the price of copper has more than doubled due to increased demand for this metal. The price here went from $1.84 to $4.4 per pound. The same results were obtained by Fortescue (2013) in his work that examined the evolution of the price of steel.

RQ2: How has the COVID-19 pandemic affected the development of metal prices?

In this period from 2020 to 2021, during the COVID-19 pandemic, there was growth in all the listed metals. For steel, this was mainly due to the COVID-19 closures in China, which is its largest producer. Prices here went from 3,400 yuan per ton to 5,800 yuan per ton. Copper has grown due to increased demand for electronics and the COVID-19 mentioned above lockdowns in China. Due to these factors, the price rose from $2.50 to $4.50 per pound. The prices of silver and gold rose due to the already mentioned understanding of these metals as a safe harbour for investments, but the increased demand for electronics

also supported the growth of their prices. Silver went from $17 per ounce to $23 per ounce, and gold went from $1,580 to $1,828 per ounce. Ahmed, Sarkodie (2021) also reached the same values when they examined the development of stock market prices for steel, copper, gold and silver during the COVID-19 pandemic.

RQ3: How did the Russian invasion of Ukraine affect the price of metals?

From 2022 to 2023, a Russian invasion of Ukraine caused uncertainty in world markets. The price of steel and copper fell during this period. However, this drop was caused by the already mentioned prevailing uncertainty and reduced demand for these metals. Steel prices fell from 4,549 yuan to 4,000 yuan per ton, and copper prices fell from $4.3 per pound to $3.8 per pound of copper. In the case of gold and silver, their prices rose again due to the prevailing uncertainty in the markets. Gold's price rose from $1,798 per ounce to $2,000 per ounce, and silver's price went from $22.45 per ounce to $25.47 per ounce. Gajdzik, Wolniak & Grebski (2022) also achieved the same results when they investigated steel price development in Poland.

Conclusion

The work aimed to identify the development of the prices of steel, copper, silver and gold used in the circular economy. The monitored period was 2009-2023.

The goal was accomplished. The results chapter always described the price development of steel, copper, silver and gold during the period of the economic crisis in 2009-2010, then the period of the COVID-19 pandemic in 2020-2021 was described, and the last monitored period was from 2022-2023 when the Russian invasion of Ukraine was underway. Data from monthly price developments on world stock exchanges were used in each of these periods. The monitored metal's average price and mean were always listed for better clarity. The resulting data then showed that even though there was an increase in uncertainty in the markets in the monitored periods, the price of copper, silver and gold increased, but the price of steel decreased. For copper, this growth was driven by increased demand for the metal. The rise in the price of gold and silver was mainly because gold and silver are considered safe havens for investment. However, there was a decrease in demand for steel, and this caused a drop in its price.

Work limits represent a time limit and, simultaneously, the effect of other influences on prices than those already mentioned. The problem with the time limit is mainly with the Russian invasion of Ukraine. Since there have been no peace negotiations and no end to the conflict, we cannot describe its future effect on the prices of these metals. Other influences on metal prices include the prices of emission allowances in Europe and subsidies to support steel production in China. Even in view of the limits of the work, in the following article, we would like to focus on the influence of the price of emission allowances and subsidies on the development of metal prices.

Acknowledgement

References

AHMED M. Y., SARKODIE S. A., 2021. COVID-19 pandemic and economic policy uncertainty regimes affect commodity market volatility. *Resources Policy*, **74.** doi: doi:10.1016/j.resourpol.2021.102303

ALIU F., HAŠKOVÁ S., BAJRA, U. Q., 2023. Consequences of Russian invasion on Ukraine: Evidence from foreign exchange rates. *Journal of Risk Finance*, **24**(1), 40–58. doi: https://doi.org/10.1108/JRF-05-2022-0127

ANH D. L. T., GAN C., 2020. The impact of the COVID-19 lockdown on stock market performance: Evidence from Vietnam. *Journal of Economic Studies*, **48**(4), 836–851. doi: https://doi.org/10.1108/JES-06-2020-0312

APERGIS I., APERGIS N., 2019. Silver prices and solar energy production. *Environmental Science and Pollution Research,* **26**(9), 8525-8532. doi: doi:10.1007/s11356-019-04357-1

ARDENTE F., BEYLOT A., ZAMPORI L., 2023. A price-based life cycle impact assessment method to quantify the reduced accessibility to mineral resources value. *The International Journal of Life Cycle Assessment*, **28**(1), 95-109. ISSN 0948-3349. doi: doi:10.1007/s11367-022-02102-4

BAI L., WEI Y., WEI G., LI X., ZHANG, S., 2021. Infectious disease pandemic and permanent volatility of international stock markets: A long-term perspective. *Finance Research Letters*, **40**. doi: https://doi.org/10.1016/j.frl.2020.101709

BARTOŠ, V., VOCHOZKA, M., ŠANDEROVÁ, V., 2022. Copper and aluminium as economically imperfect substitutes, production and price development. *Acta Montanistica Slovaca*, **27**(2), 462-478.

BAUR D. G., 2013. The autumn effect of gold. *Research in International Business and Finance*, **27**(1), 1–11. doi: https://doi.org/10.1016/j.ribaf.2012.05.001

BAUR D. G., BECKMANN J., CZUDAJ R. L., 2020. The relative valuation of gold. *Macroeconomic Dynamics,* **24**(6), 1346-1391. doi: doi:10.1017/S1365100518000895

BENTES S. R., GUBAREVA M., TEPLOVA T., 2022. The impact of COVID-19 on gold seasonality. *Applied Economics*, **54**(40). doi: https://doi.org/10.1080/00036846.2022.2033681

BRABENEC T., ŠULEŘ P., HORÁK J., PETRÁŠ M., 2020. Prediction of the future development of gold price. *Acta Montanistica Slovaca*, **25**(2), 250-262. doi:10.46544/AMS.v25i2.11.

BUDIUL BERGHIAN A., LUPU O., SOCALICI A., BIRTOK BANEASA, C., 2021. Harnessing the ferrous sludge resulting from steel industry in the context of the circular economy. *UPB Scientific Bulletin, Series B: Chemistry and Materials Science*, **83**(4), 241–250.

CIFUENTES S., CORTAZAR, G., ORTEGA, H., SCHWARTZ E. S., 2020. Expected prices, futures prices and time-varying risk premiums: The case of copper. *Resources Policy,* **69** doi: doi:10.1016/j.resourpol.2020.101825

FISCHER D., 2021. Korrelieren Stahlpreise und Stahlbaupreise? Eine statistische Untersuchung.

Stahlbau, **90**(7), 542-547. doi: doi:10.1002/stab.202100041

FORTESCUE S. 2013. The Russian Steel Industry, 1990-2009. *Eurasian Geography and Economics,* **50**(3), 252-274. doi: doi:10.2747/1539-7216.50.3.252

GAJDZIK B., WOLNIAK R., GREBSKI W. W., 2022. An econometric model of the operation of the steel industry in POLAND in the context of process heat and energy consumption. *Energies*, **15**(21). doi: doi:10.3390/en15217909

HORÁK J., DUSEK K., 2022. The evolution of gold and silver commodity prices in the circular economy. *Journal of Valuation and Expertness,* **6**(1), 11-27.

HORÁK J., MACHOVÁ V., KRULICKÝ T., 2019. Value generators in metallurgical industry. *Social and Economic Revue*, **2**, 17-23.

HORÁK J., PAVLOVA S., 2022. Capital structure of companies applying principles of circular economy. *AD ALTA: Journal of Interdisciplinary Research*, **12**(1), 60-64.

IMMANUVEL S. M., LAZAR, D. 2020. Does information spillover and leverage effect exist in world gold markets? *Global Business Review*. doi: doi:10.1177/0972150919885472

IMMANUVEL S. M., LAZAR. D., 2022. Does volume of gold consumption influence the world gold price?. *Journal of Risk and Financial Management*, **15**(7). doi: doi:10.3390/jrfm15070273

KHOSHALAN H. A., SHAKERI J., NAJMODDINI I., ASADIZADEH, M., 2021. Forecasting copper price by application of robust artificial intelligence techniques. *Resources Policy*, **73**. doi: https://doi.org/10.1016/j.resourpol.2021.102239

KOROTKOV E.V., KOROTKOVA, M. A. 2017. Study of the periodicity in Euro-US Dollar exchange rates using local alignment and random matrices. *Algorithmic Finance*, **6**(1-2), 23-33. doi: doi:10.3233/AF-170182

KRISTJANPOLLER W., HERNÁNDEZ E., 2017. Volatility of main metals forecasted by a hybrid ANN-GARCH model with regressors. *Expert Systems with Applications* **84**, 290-300.

LIU C., HU Z., LI Y., LIU S., 2017. Forecasting copper prices by decision tree learning. *Resources Policy,* **52**, 427–434. doi: https://doi.org/10.1016/j.resourpol.2017.05.007

LUPU O., ARDELEAN M., SOCALICI A., ARDELEAN, E., 2021. Research regarding the capitalization of the waste resulted from the steel industry. *U.P.B. Scientific Bulletin, Series B*, **83**(1), 187-196.

MA Y., 2021. Do iron ore, scrap steel, carbon emission allowance, and seaborne transportation prices drive steel price fluctuations?. *Resources Policy*, **72**. doi: z: doi:10.1016/j.resourpol.2021.102115

MACHOVÁ V., KRULICKÝ T., HORAK J., 2020. Comparison of neural networks and regression time series in estimating the development of the afternoon price of gold on the New York stock exchange. *Social and Economic Revue*, **1**, 61-72.

MATASOVÁ T., VOCHOZKA M., ROWLAND Z., 2022. Alternative costs of equity of coal mining companies taking into account a context of the Russian invasion into Ukraine. *Entrepreneurship and Sustainability Issues*, **10**(2),394-407.

PHITTHAYANON CH., RUNGREUNGANUN, V., 2019. Material cost prediction for jewellery production using deep learning technique. *Engineering Journal,* **23**(6), 145-160. doi: doi:10.4186/ej.2019.23.6.145

RYDELL L., SULER, P., 2021. Underlying values that motivate behavioral intentions and purchase decisions: lessons from the COVID-19 pandemic. *Analysis and Metaphysics,* **20**, 116-129.

SADORSKY P., 2021. Predicting gold and silver price direction using tree-based classifiers. *Journal of Risk and Financial Management*, **14**(5), 1911-8074. doi: doi:10.3390/jrfm14050198

SANIUK A., SANIUK S. 20198. Current state and future perspectives of steel production. Proceedings of the 27th International Conference on Metallurgy and Materials, 1808-1813.

VOCHOZKA M., KALINOVÁ E., GAO P., SMOLÍKOVÁ, L., 2021. Development of copper price from July 1959 and predicted development till the end of year 2022. *Acta Montanistica Slovaca*, **26**(2), 262–280. doi: https://doi.org/10.46544/AMS.v26i2.07

WEN F., ZHAO C., HU CH., 2019. Time-varying effects of international copper price shocks on China's producer price index. *Resources Policy*, **62**, 507-514. doi: doi:10.1016/j.resourpol.2018.10.006

ZAPLETAL, CHYTILOVÁ., 2016. Influence of the emission prices and banking of allowances on steel companies in the Czech Republic.

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