Empirical Paper

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The “autumn effect” in the gold market—does it contradict the Adaptive Market Hypothesis?

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Abstract:
The present study aims to verify the autumn effect in the gold market, first presented 10 years ago by Dirk Baur in the paper “The autumn effect of gold” and to investigate the calendar effects occurring for other precious metals. This empirical research is presented in a way to place the results obtained in the context of the Efficient Market Hypothesis (EMH) and the more current Adaptive Market Hypothesis (AMH). The study was conducted as an extended reproduction of the Baur study. The main conclusion is that, the autumn effect on the gold market has been reversed and replaced by the winter effect, which is linked to the AMH. An equally interesting calendar effect was observed for silver. Platinum and palladium saw an increase in prices in January, but given the patterns in the gold market, it is very likely that this phenomenon will also change over time.

Keywords: investing, calendar effect, precious metals
JEL Classification: G11, G12, G14

1 Introduction

Gold is, in comparison to other investments, a frequently addressed topic in academic research. In recent years, the number of academic publications incorporating the phrase “investing in gold” has not stopped declining. This is evidenced by the results of searches in browsers for scholarly literature such as EBSCO, Elsevier, and Google Scholar. The following article is part of this trend of intensive investigation into the properties of gold and, more broadly, precious metals as an investment.

The inspiration for writing this paper comes from the publication, nearly 10 years ago, of one of the often-cited academic papers on gold market investing. The work in question is by Dirk Baur and is entitled “The autumn effect of gold” [Baur, 2013]. In his work, Baur demonstrated the existence of the so-called “autumn effect” of gold, which manifests itself in an increase in the price of gold and thus in the returns on this investment in the two autumn months, September and November. The above regularity was obtained from monthly observations from 1980 to 2010. As an explanation for the rise in gold prices during the autumn months, the author offers the following arguments. Firstly, Baur links this situation to the fact of increasing demand in order for investors to hedge against the so-called “Halloween effect” occurring in the stock market. Secondly, the rise in gold prices in autumn, according to Baur, is influenced by the increased demand for gold in jewellery, triggered mainly by the wedding season in India, but also by the

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pre-Christmas shopping season in many developed economies. Lastly, the increasing demand for gold, which can be seen as a substitute for the decreasing number of daylight hours in autumn, was identified as an explanation for the indicated phenomenon.

Today, it is a necessity to check whether the pattern observed 10 years ago is still existing in the market under study. This is because the fact that the autumn effect was described should, according to the Efficient Market Hypothesis (EMH) [Fama, 1970], contribute to a reduction in the above-average autumn returns observed 10 years ago in the gold market. As Fama [1970] points out, such calendar effects according to the EMH should be short-lived and disappear once they become public, which is also in line with the so-called Adaptive Market Hypothesis (AMH) [Lo, 2004]. The fact that periods of efficiency and inefficiency coexist in the financial market is highlighted by the same author in another of his papers [Lo, 2005] as a key element of AMH.

Therefore, the verification of the effect under study will, on the one hand, from a scientific point of view, provide a further verification of the EMH and, from a utilitarian point of view, provide guidance to investors who place their funds in the gold market. So, the target group for this text is investors, market analysts, portfolio managers, and researchers involved in analyzing markets and researching their performance, as well as those involved in the management of precious metals companies.

This topic is all the more important because, as the report by Knight Frank Research [2022] indicates, gold in its various investment forms (coins, bars, or investment funds) is very popular and the prices of, for example, selected collector coins are breaking new records. The main sources of investment demand for gold that determine its prices are the physical bar, official coin, medals coin, or demand from ETFs [World Gold Council, 2022]. Moreover, between Q3 2018 and Q3 2020, there was a significant increase in the price of bullion analyzed from a level of US$1,213.2/oz to a value of US$1,908.6/oz [LBMA Prices and Data, 2022]. Since this record level, gold prices have remained relatively stable. Such a dynamically changing situation in the gold market creates the need to investigate whether the calendar effect diagnosed nearly a decade ago is still present. It is also worth noting the growing role in the investment market of other precious metals, namely silver, platinum, and palladium. In this context, it is equally important to answer whether the same calendar effects that have been diagnosed for the gold market are also present in these markets.

2 Literature review and research questions

The need to verify the autumn effect in future research is indicated in a summary in the article by Baur [2013]. As nearly 10 years have passed since the publication of the article that inspired the analyses carried out in this thesis, verification of the effect described seems justified. The autumn effect is one of a number of calendar effects that have so far been described in academic research, mainly on the example of capital markets [Plastun et al., 2019, 2020; Chatzitzisi et al., 2021; Fuksiewicz, 2021; Shanaev et al., 2022]. Similar work on seasonal effects in the alternative investment market, of which gold investment is one, is less common, but examples of such publications can also be provided [Kumar, 2016; Kinateder and Papavassiliou, 2021; Plastun et al., 2022; Qadan et al., 2019, 2022]. The topic of seasonal effect in the gold market is next to the safe haven properties of gold [Baur and Lucey, 2010; Baur and McDermott, 2010; Potrykus, 2015; Baur and Glover, 2016; Baur et al., 2020; Akhtaruzzaman et al., 2021; Naeem et al., 2022] very often the subject of scientific research.

The occurring calendar effects on the precious metals market are referenced in the study [Qadan et al., 2019] by the aforementioned authors. This study investigated whether the market for 9 commodities, including gold, silver, platinum, and palladium, exhibits any of the 25 defined calendar effects. As a final conclusion, it was stated that effects such as day-of-the-week, Halloween effect, SAD effect, January effect, within-the-month effect, and turn-of-the-month effect occur in the commodities market, including metals and energy commodities. The paper also highlights that these results are not affected by the different lengths of the study periods. The position that the occurrence of calendar effects in the current century is increasingly rare can be found in the work of Plastun et al. [2019]. In their study, the authors used daily, weekly, and monthly data from 1986 to 2018. However, this work did not assess the previously defined autumn effect in the gold market.

Another paper attempting to assess the incidence of calendar effects in the precious metals market is by Borowski and Łukasik [2019]. In this work, it has been proven that the calendar effects cannot be confirmed for the months under study for gold, silver, and platinum. In turn, the occurrence of the “September effect” for palladium was confirmed. The period analyzed in this work is January 1, 1998–December 31, 2015 for palladium and January 1, 1995–December 31, 2015 for the other metals studied. This study also did not attempt to verify the autumn effect in the markets studied.

The following article, which is an interesting compendium of published articles on “market efficiency” and “commodity markets,” is by Chhabra and Gupta [2020]. The authors divided the studies collected from three databases (EBSCO, Google Scholar, and Elsevier) into those that address the efficiency of financial markets and those that examine commodity markets for the presence of calendar anomalies. Twenty studies were identified within the second group, of which 10 papers focused on the study of the gold market, with an additional five also covering the silver market. Of these five studies, two also examined the platinum market and the palladium market in addition to the gold and silver market. The papers were by Górska and Krawiec [2014] and the above-cited study is by Borowski and Łukasik [2019]. Chhabra and Gupta [2020] conclude that there are day-of-the-week and month-of-the-year effects in the precious metals market (within the framework of the studies indicated, the markets to be assumed are gold and silver). However, no study indicates that the autumn effect is being verified.

The study by Górska and Krawiec [2014] also does not include the verification of the autumn effect on the precious metals market. However, in this work, the “Friday effect” and the “September effect” were found to occur in the silver market, based on daily data from 2008 to 2013. In addition, the “September effect” was also confirmed for palladium and platinum. For platinum, the occurrence of the “January effect” was also indicated. No calendar effects (of those studied) were found for gold, which is important in the context of the analyses performed by the authors of this study. Another study referring to the research on the calendar effects in the gold market is the work by Blose and Gondhalekar [2013]. However, the authors limit themselves to examining the weekend effect on the gold market by the “bull market” and “bear market.” The study covers the period from 1975 to 2011. The final conclusion from this work is that during a “bear market,” the return in the gold market achieved on Friday is lower (and statistically significant) than on Monday. The same phenomenon was not observed during the “bull market.”

As demonstrated by the literature studies carried out, the authors of this study have not been able to find any studies that verify the autumn effect in the precious metals market, apart from studies carried out by Baur. Therefore, the following study focuses on examining this calendar anomaly, but not only for gold, but also for investments in silver, palladium, and platinum. In addition, the temporal scope of the analysis performed 10 years ago has been extended. A simplified diagram of the study, which shows the research gap, defined on the basis of the literature survey, research purposes, detailed objectives together with the research questions is presented in Figure 1.

As depicted in Figure 1, the article defines four main research objectives as a result of the adopted research gap. Each of the research questions defined is linked to objectives, which in turn are derived from purposes. Finally, as shown in Figure 1, the research questions were formulated as follows:

- For which months of the analyzed precious metals calendar do effects occur (statistically significant rates of return)?
- Are there any changes in the described effects in the gold market after the publication of Dirk Baur?
- Are the same changes present in other markets (silver, platinum, and palladium)?
- Does the choice of seasons (astronomical [ASTRO] or meteorological [METEO]) affect the results in the case of rates of return in the analyzed markets?

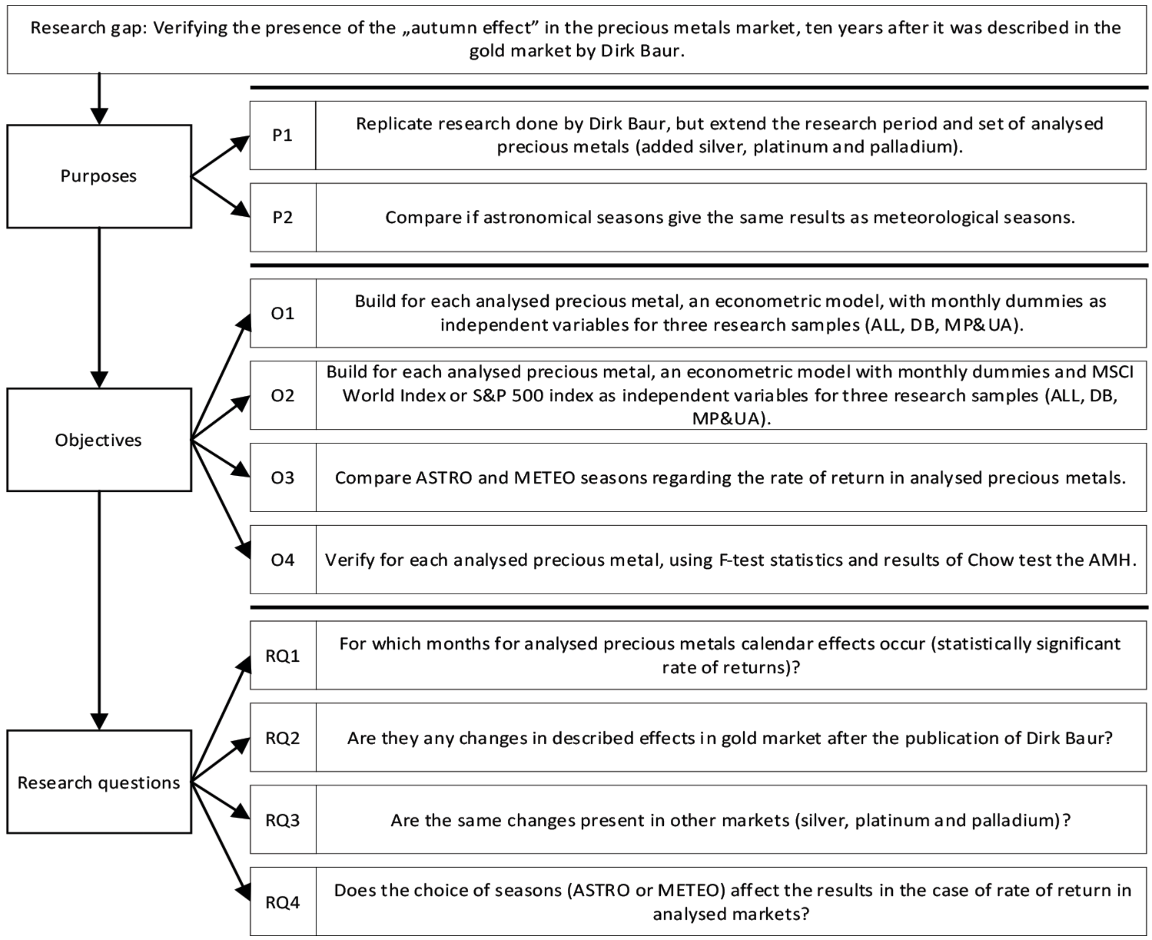

Figure 1. Research gap, purposes, objectives, and research questions. Source: Own elaboration. AMH, adaptive market hypothesis; ASTRO, astronomical; METEO, meteorological.

The answers to the questions posed in this way should be of interest, first and foremost to investors, including traders, the precious metals market, but also to analysts and researchers involved in this market. The second group of stakeholders of the final conclusions of this work are the managers of the companies who consider the analyzed metals as a commodity for their companies. Indeed, on the basis of the research carried out, it will be possible to determine the optimum inventory management strategy, given the timing of the purchase of these commodities. The third group comprises companies in the mining sector to whom the analysis carried out in this work should indicate the optimum moments for selling their product, given the price of the ore mined.

In order to answer the questions posed, the next section of the article presents the data used for the analysis and the methodology of the study. The subsequent section describes the results obtained, and the entire paper concludes with a discussion and conclusions section.

3 Data and methodology

The study was carried out using identical methods to those used in the article, inspiring our own analyses. In addition to investment in gold – (gold bullion spot price [GBSP]), investment in silver, palladium, and platinum was also analyzed. The data for which the logarithmic returns were determined, which are the basis for all calculations related to the precious metals analyzed, were downloaded from LBMA Prices and Data [2022]. In addition, the analysis also used logarithmic returns for the MSCI World Index [MSCI, 2021] and the S&P 500 [Investing.com, 2022]. Analyses were also carried out for gold futures prices (COMEX), but due to the volume of the study and the almost identical results to the GBSP data series, these results are available on request.

The difference between this article and the 2013 article is the temporal scope of the analysis. Indeed, the survey was divided into three samples, which were marked:

- ALL: Covers the period from January 20, 1981 to July 29, 2022 and contains 10,834 observations for gold and silver investments. For investments in palladium and platinum, 8,434 observations were analyzed from April 3, 1990 to July 29, 2022 due to data availability.
- DB (“in-sample”): An identical sample to the survey sample [Baur, 2013] covers the period from January 20, 1981 to December 15, 2010 and consists of 7,802 observations. The results for this sample are presented to reproduce the original study using gold investments as an example.
- MP&UA (“out-of-sample”): A sample covering data from December 16, 2010 to July 29, 2022, consisting of 3,032 observations. The sample contains information that was not examined in the original article, and will also allow an assessment of whether the publication of Baur’s paper contributed to a change in the results obtained, as it includes a period of almost 10 years after the publication of the autumn effect.

Analysis in the context of the division of the seasons is also an important issue. This work adopts two divisions, METEO and ASTRO. In the METEO division, the successive seasons comprise three calendar months in total, spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). In the ASTRO division, the start of spring is most often on March 20th, although there are years when it is on March 21st, the start of summer is usually on June 21st, autumn begins on September 22nd or 23rd, and the start of ASTRO winter is on December 21st or 22nd. Despite only minor shifts in the designated seasons, interesting and surprising results were obtained (only for gold investments), which are presented in the next section of the paper.

To better illustrate the data used, Table 1 shows the basic descriptive statistics, divided into three study samples.

Based on the data presented in Table 1, it can be concluded that the highest average daily returns of each of the studied data series, with the exception of palladium and the S&P500 index, were achieved in the DB sample. In the case of standard deviation, almost identical values were observed for each of the data series studied, regardless of the research sample defined. The minimum and maximum values observed for the DB sample were also, in almost all the cases, the minimum and maximum values for the ALL sample. In addition, Table 1 also shows the value of the skewness coefficient and kurtosis in the studied groups. It is also noted that the highest average return equal to 0.0338% was observed for investments in palladium, only in the MP&UA, a higher (0.0398%) average return than palladium was recorded for the S&P 500 index.

After the determination of descriptive statistics for each analyzed precious metal, a model was determined, with dummy variables for each month as exogenous variables. The form of the model is given by the following equation

$$r_{\text{pm}} = \beta_1 \times D_{\text{January}} + \cdots + \beta_{12} \times D_{\text{December}} + e \tag{1}$$

where,

r_{pm}—the rate of return for the precious metal under study.

D_{January}—dummy variable equal to one for each day of the month (here January), zero otherwise.

B_1—value of the determined regression coefficients (successive numbers indicate months).

e—random variable.

Table 1. Descriptive statistics for the analyzed time series

Research sample	Descriptive statistic	Gold	Silver	Palladium	Platinum	MSCI	S&P 500
ALL *N* = 10834 (for palladium and platinum *N* = 8434)	Mean (x100)	0.0104	0.0028	0.0332	0.0075	0.0263	0.0316
	Std. dev.	0.0106	0.0193	0.0205	0.0139	0.0091	0.0112
	Min.	−0.1290	−0.2575	−0.1786	−0.1728	−0.1044	−0.2292
	Max.	0.1048	0.1828	0.1696	0.1173	0.0910	0.1096
	Skewness	−0.2456	−0.4978	−0.3481	−0.5072	−0.6925	−1.1612
	Kurtosis	8.4797	12.1038	7.6754	8.9385	13.3391	26.3539
DB *N* = 7,802	Mean (x100)	0.0115	0.0086	0.0328	0.0238	0.0265	0.0284
	Std. dev.	0.0108	0.0192	0.0206	0.0138	0.0090	0.0113
	Min.	−0.1290	−0.2575	−0.1786	−0.1728	−0.1036	−0.2292
	Max.	0.1048	0.1828	0.1584	0.1173	0.0910	0.1096
	Skewness	−0.1574	−0.3917	−0.1765	−0.5800	−0.5139	−1.2561
	Kurtosis	8.8449	11.0447	6.7748	10.7002	12.1150	29.6646
MP&UA *N* = 3,032	Mean (x100)	0.0077	−0.0122	0.0338	−0.0214	0.0257	0.0398
	Std. dev.	0.0098	0.0193	0.0202	0.0143	0.0095	0.0109
	Min.	−0.0960	−0.1959	−0.1568	−0.1442	−0.1044	−0.1277
	Max.	0.0513	0.1736	0.1696	0.0934	0.0841	0.0897
	Skewness	−0.5484	−0.7663	−0.6706	−0.3862	−1.0850	−0.8803
	Kurtosis	6.7287	14.7832	9.4061	6.2049	15.8141	16.1195

Source: Own elaboration.

In the next step, the above models were estimated again by including as an exogenous variable, the value of the logarithmic return, first for the MSCI World Index and then for the S&P 500 Index. The models estimated in the next step can be written as:

$$r_{\mathrm{pm}} = \beta_1{}^{*}D_{\mathrm{January}} + \ldots + \beta_{12}{}^{*}D_{\mathrm{December}} + \gamma_1{}^{*}r_{\mathrm{MSCI}} + e \tag{2}$$

$$r_{\mathrm{pm}} = \beta_1{}^{*}D_{\mathrm{January}} + \ldots + \beta_{12}{}^{*}D_{\mathrm{December}} + \gamma_2{}^{*}r_{\mathrm{SP}} + e \tag{3}$$

where,

y_1 and y_2—estimated parameter values.

r_{MSCI}—logarithmic return of the MSCI World Index.

r_{SP}—logarithmic return of the S&P 500 index.

The next stage of the study shows how average returns have changed over the seasons (both METEO and ASTRO), in the three different research samples adopted. The final stage of the study is to verify the AMH. For that purpose, for all investments, the restricted model vs. the full (unrestricted) model were calculated. The restricted model is built with only the constant parameter, while the full model, as an explanatory variable, includes dummy variables for months or seasons. Finally, the *F*-statistic is calculated as follows:

$$F = \frac{(\mathrm{RSS}_R - \mathrm{RSS}_{\mathrm{UR}})/q}{\mathrm{RSS}_{\mathrm{UR}}/\left(n-k-1\right)} \tag{4}$$

where,

$\mathrm{RSS}_{\mathrm{R}}$ is the *restricted* sum of squared residuals,

$\mathrm{RSS}_{\mathrm{UR}}$ is the un*restricted* sum of squared residuals,

q is the number of restrictions,

(n–k–1) are the degrees of freedom of the unrestricted model.

Having tested the null hypothesis, it can be stated that the constraints imposed by the restricted regression are correct. In other words, it can be said that monthly or season variables help explain the analyzed investments’ rates of return and can be helpful to predict the prices of the analyzed investments. For our research, we also use the Chow test to verify if Baur’s work can be a source of a structural break in the analyzed markets.

Throughout the paper, a standard way of marking the statistical significance of the estimated parameters was also adopted. If the statistical significance for the determined parameters was equal to 0.1, they were marked with “*”; for a significance of 0.05, “**” was used, and for 0.01, “***.” Parameters that were not statistically significant were not marked in any way, leaving the value in the “sig” column blank, in such a case.

4 Research results

In the first step of the study carried out in accordance with Eq. (1), the value of the parameters for each month was estimated. Models were built for each precious metal and divided into three defined test samples. To include the parameter values from 12 months, a constant was eliminated from the equations. The estimated parameter values should be interpreted as the average daily return on the investments for each month. In below Tables 2–4, only the statistically significant variables are presented.

Based on the data presented in Table 2, it can be concluded that there have been significant changes in the gold market for months that record statistically significant returns. Firstly, there was no month effect in

Table 2. Regression results—only monthly dummies

		ALL			DB			MP&UA		
Dependent variable	**Month independent variable**	**Coef.**	***t*-Stat.**	**Sig.**	**Coef.**	***t*-Stat.**	**Sig.**	**Coef.**	***t*-Stat.**	**Sig.**
Gold	Jan	0.0504	1.44		0.0149	0.35		0.1376	2.28	**
	Aug	0.0522	1.49		0.0309	0.73		0.1102	1.75	*
	Sep	0.0493	1.38		0.1128	2.64	***	−0.1247	−1.94	*
	Nov	0.0410	1.15		0.0936	2.19	**	−0.1022	−1.60	
Silver	Jan	0.1084	1.70	*	0.1013	1.34		0.1258	1.06	
	Jun	−0.1543	−2.41	**	−0.1695	−2.24	**	−0.1163	−0.97	
	Jul	0.1036	1.64		0.0617	0.83		0.2087	1.76	*
	Sep	−0.0040	−0.06		0.1058	1.40		−0.3051	−2.42	**
	Nov	−0.0084	−0.13		0.0688	0.91		−0.2186	−1.74	*
Palladium	Jan	0.2232	2.90	***	0.2244	2.29	**	0.2210	1.78	*
	Feb	0.1957	2.43	**	0.2000	1.95	*	0.1884	1.45	
	Jul	0.1002	1.32		0.0373	0.39		0.2109	1.70	*
	Aug	−0.1073	−1.40		−0.1628	−1.70	*	−0.0019	−0.01	
Platinum	Jan	0.1738	3.32	***	0.1320	2.02	**	0.2436	2.79	***
	Feb	0.1369	2.50	**	0.1696	2.47	**	0.0825	0.90	
	Mar	−0.0586	−1.12		0.0252	0.38		−0.1980	−2.27	**
	Sep	−0.1190	−2.24	**	−0.0581	−0.90		−0.2356	−2.54	**

Notes: ***, **, and * denote the results significance at 1%, 5% and 10% levels, respectively.
Source: Own elaboration.

the gold market in the entire study sample, which confirms the EMH. Instead, in the sample marked “DB,” the results obtained by Baur, i.e., positive and statistically significant returns for September and November, were confirmed. Interestingly, these results were not confirmed in the “MP&UA” sample. The statistically significant month in this sample with a positive rate was January, suggesting a shift in the effect described. Also a statistically significant, at the level $\alpha = 0.1$, positive rate of return was also observed in August. In contrast, September, which had previously recorded a statistically significant positive rate of return, now recorded a negative value of the estimated parameter with statistical significance at the level of $\alpha = 0.1$. Changes in the estimated coefficient values after December 16th, 2010 are also confirmed by the Chow structural shift test (the *p*-value for the Chow test is equal to 0.027).

For silver investments, on the other hand, a negative statistically significant interest rate was recorded in June. This was confirmed for the “ALL” and “DB” samples, but not for the “MP&UA” sample, which includes the most recent data, because in this sample, the value of the estimated parameter is also negative, but not statistically significant. Surprisingly, in this research sample, a negative and statistically significant return for silver was observed in September ($\alpha = 0.05$) and November ($\alpha = 0.1$), the months that Baur indicated as months in which there were average positive returns in the gold market. Changes in the estimated coefficient values for the silver market after December 16th, 2010 are also confirmed by the Chow structural shift test (the *p*-value for the Chow test is equal to 0.038).

For palladium investments, January proved to be a statistically significant month, with a positive return in all three research samples. In the “ALL” sample, the statistical significance of this result was the highest of those considered, while in the “MP&UA” sample, the level of statistical significance was $\alpha = 0.1$. More months with a statistically significant value of the estimated parameters are found for platinum. For this metal, it is worth noting the positive average return values in January, for each research sample. In addition, in the “ALL” and “MP&UA” samples, as in the case of silver, the value of the estimated average daily return was also negative in September. For palladium and platinum, the conducted Chow test *p*-values indicate that there is no structural break point after December 16, 2010.

Table 3 shows the results of the average daily returns of the precious metals studied with an additional exogenous variable representing interest rates for the capital markets.

The data in Table 3 show that the value of the estimated coefficient, representing the average capital market return, is, for all the precious metals investments studied, statistically significant and positive. This means, as shown in the study inspiring the analyses carried out, that the returns of the analyzed metals are positively related to capital market returns, as represented by the world index. In order to further explore this relationship, Table 4 presents the regression results, but using the S&P 500 index quotations instead of the MSCI World Index as an additional exogenous variable.

Following this change in the group of exogenous variables, the results of which are shown in Table 4, there was no change in direction or change for statistical significance between the estimated coefficient value for the S&P 500 index and platinum or palladium. This means that the prices of these precious metals and the index under study are positively correlated, and their hedging properties for the investment portfolio should be questioned in the long term. The results presented show the strengthening of this relationship, as the values of the estimated coefficients are higher in the “MP&UA” sample than in the “DB” sample. For the return on investment in silver, in the entire sample and in the “DB” sample, no statistical significance was confirmed for the estimated parameter of the S&P 500 variable. This means that returns on investment in silver should be treated as a potential source of diversification for an investment portfolio based on US capital market values. However, this conclusion is contradicted by the results obtained from the last research sample “MP&UA,” as for it a statistically significant and positive value of the analyzed coefficient was found. The situation is similar for the gold market in relation to the S&P 500 index. In the entire research sample, the value of the coefficient for the S&P 500 variable was not found to be statistically significant, which already contradicts the conclusions of Baur’s publication. In the “DB” sample, the value of the estimated coefficient was negative and statistically significant, which confirms the validity of using gold investments as a hedge for a portfolio based on the US capital market. However, this property has been reversed and is statistically significant for the latest “MP&UA” research sample.

Table 3. Regression results—monthly returns conditional on MSCI World Index

Dependent variable	Month independent variable	ALL			DB			MP&UA		
		Coef.	***t*-Stat.**	**Sig.**	**Coef.**	***t*-Stat.**	**Sig.**	**Coef.**	***t*-Stat.**	Sig.
Gold	MSCI	0.1147	10.34	***	0.1137	8.35	***	0.1156	6.16	***
	Jan	0.0493	1.42		0.0146	0.34		0.1344	2.24	**
	Aug	0.0533	1.53		0.0314	0.75		0.1128	1.80	*
	Sep	0.0543	1.53		0.1173	2.76	***	−0.1187	−1.86	*
	Nov	0.0340	0.96		0.0872	2.05	**	−0.1107	−1.74	*
Silver	MSCI	0.2431	12.06	***	0.2030	8.41	***	0.3337	9.12	***
	Jan	0.1060	1.68	*	0.1008	1.34		0.1164	1.00	
	Jun	−0.1499	−2.35	**	−0.1646	−2.18	**	−0.1154	−0.97	
	Sep	0.0065	0.10		0.1139	1.51		−0.2877	−2.32	**
	Nov	−0.0232	−0.36		0.0573	0.76		−0.2433	−1.96	**
Palladium	MSCI	0.4002	17.31	***	0.3198	10.93	***	0.5429	14.42	***
	Jan	0.2269	3.00	***	0.2345	2.42	**	0.2057	1.71	*
	Feb	0.1933	2.44	**	0.2040	2.01	**	0.1688	1.34	
Platinum	MSCI	0.2678	17.00	***	0.1999	10.21	***	0.3879	14.70	***
	Jan	0.1762	3.42	***	0.1383	2.14	**	0.2327	2.76	***
	Feb	0.1353	2.51	**	0.1720	2.53	**	0.0684	0.77	
	Mar	−0.0648	−1.26		0.0163	0.25		−0.1933	−2.30	**
	Jun	−0.0587	−1.14		−0.0129	−0.20		−0.1430	−1.67	*
	Sep	−0.1065	−2.04	**	−0.0494	−0.77		−0.2154	−2.40	**
	Nov	0.0085	0.16		0.0889	1.38		−0.1509	−1.69	*

Notes: ***, **, and * denote the results significance at 1%, 5% and 10% levels, respectively.

Source: Own elaboration.

Table 4. Regression results—monthly returns conditional on S&P500

		ALL			DB			MP&UA		
Dependent variable	**Month indepependent variable**	**Coef.**	***t*-Stat.**	**Sig.**	**Coef.**	***t*-Stat.**	**Sig.**	**Coef.**	***t*-Stat.**	**Sig.**
Gold	S&P 500	−0.0058	−0.64		−0.0231	−2.13	**	0.0418	2.54	**
	Jan	0.0506	1.45		0.0156	0.37		0.1365	2.26	**
	Aug	0.0522	1.49		0.0309	0.73		0.1101	1.75	*
	Sep	0.0491	1.38		0.1119	2.62	***	−0.1227	−1.92	*
	Nov	0.0414	1.16		0.0949	2.22	**	−0.1067	−1.67	*
Silver	S&P 500	0.0252	1.53		−0.0243	−1.27		0.1622	5.05	***
	Jan	0.1076	1.69	*	0.1021	1.35		0.1212	1.03	
	Jun	−0.1543	−2.41	**	−0.1696	−2.24	**	−0.1184	−0.99	
	Sep	−0.0030	−0.05		0.1049	1.39		−0.2973	−2.37	**
	Nov	−0.0102	−0.16		0.0701	0.92		−0.2362	−1.89	*
Palladium	S&P 500	0.1883	9.60	***	0.1298	5.36	***	0.3047	9.12	***
	Jan	0.2210	2.89	***	0.2243	2.30	**	0.2123	1.73	*
	Feb	0.1964	2.45	**	0.2043	2.00	**	0.1751	1.36	
	Aug	−0.1022	−1.34		−0.1571	−1.65	*	−0.0030	−0.02	
Platinum	S&P 500	0.1099	8.22	***	0.0555	3.42	***	0.2182	9.31	***
	Jan	0.1725	3.31	***	0.1319	2.02	**	0.2374	2.76	***
	Feb	0.1373	2.51	**	0.1714	2.50	**	0.0729	0.81	
	Mar	−0.0631	−1.21		0.0222	0.34		−0.2022	−2.35	**
	Jun	−0.0635	−1.22		−0.0185	−0.29		−0.1468	−1.68	*
	Sep	−0.1157	−2.18	**	−0.0570	−0.88		−0.2251	−2.46	**

Notes: ***, **, and * denote the results significance at 1%, 5% and 10% levels, respectively.

Source: Own elaboration.

In the next step of the study, the value of the average daily returns by ASTRO and METEO seasons was compared. The data for the three study samples, for the four precious metals studied, are presented in Figure 2.

Based on the data presented in Figure 2, some interesting facts can be observed. For gold investments, it can be seen that the METEO division favors the prominence of the autumn effect for the DB sample. One cannot see this phenomenon for the ALL sample, and for the MP&UA sample a trend reversal for the average daily returns can be seen. The MP&UA sample for autumn shows the lowest value of the average daily return, while the neighboring seasons, i.e., summer and winter, show positive returns at a level exceeding the value for the DB sample in autumn.

Surprisingly, no reproduction of the autumn effect can be seen for the DB sample when the ASTRO season division is applied. The observed average daily return for ASTRO autumn is nearly three times lower than for METEO autumn. However, with this division, there continues to be a high and positive rate of return in summer and winter. The ASTRO division also results in symbolic differences in the results obtained, within the spring and summer research samples.

A similar relationship for the MP&UA sample was observed for the silver market. This refers to a high, negative, average daily return for autumn (for both ASTRO and METEO divisions) and high levels of these rates for summer and winter. This pattern is not observed for the DB sample and is not present, due to the length of the samples studied, for the ALL sample. What is typical for palladium and platinum is the highest levels of surveyed returns in winter. The division into seasons used and the research sample defined are not relevant here. In contrast to the gold and silver markets, we found that in the MP&UA sample, the observed winter values were the lowest within the survey samples, indicating the weakening of this phenomenon in recent years. Additionally, for the platinum market, as for the gold and silver markets, the prominent negative returns occur in autumn. This can be seen more clearly for the METEO division for which significant negative rates were also recorded in spring.

In the last step of the analysis carried out, the *F*-test was calculated using both restricted and full models. The results of this analysis, divided into monthly, ASTRO, and METEO data, are presented in Table 5.

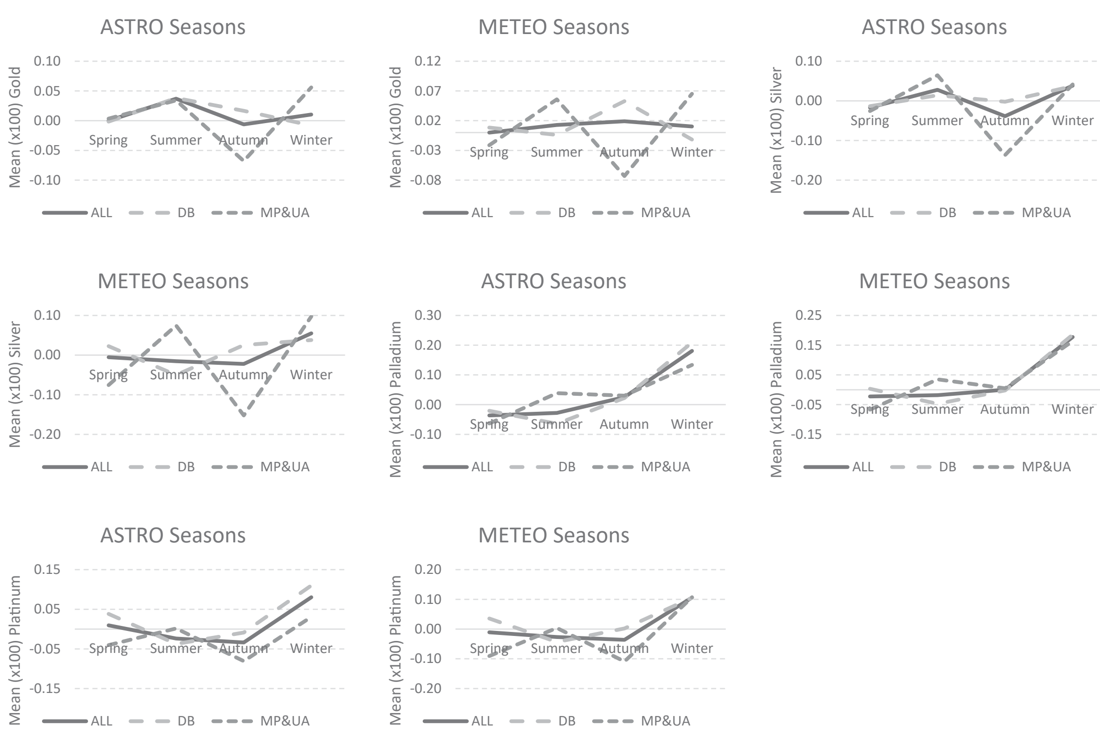

Figure 2. ASTRO vs. METEO seasons mean daily return of analyzed investments.
Source: Own elaboration. ASTRO, astronomical; METEO, meteorological.

Table 5. *F*-test results for the conducted research

Sample		Investment			
		Gold	Silver	Palladium	Platinum
Monthly data	All	*F*-statistic = 0.889 *p*-value = 0.550 n.s.	*F*-statistic = 1.161 *p*-value = 0.308 n.s.	***F*-statistic = 1.920** ***p*-value = 0.032** **	***F*-statistic = 2.374** ***p*-value = 0.006** ***
	DB	*F*-statistic = 1.360 *p*-value = 0.185 n.s.	*F*-statistic = 1.251 *p*-value = 0.247 n.s.	*F*-statistic = 1.372 *p*-value = 0.179 n.s.	*F*-statistic = 1.436 *p*-value = 0.149 n.s.
	MP&UA	***F*-statistic = 1.800** ***p*-value = 0.049** **	***F*-statistic = 1.872** ***p*-value = 0.038** **	*F*-statistic = 1.055 *p*-value = 0.394 n.s.	***F*-statistic = 2.485** ***p*-value = 0.004** ***
ASTRO Seasons data	All	*F*-statistic = 0.890 *p*-value = 0.445 n.s.	*F*-statistic = 0.962 *p*-value = 0.410 n.s.	***F*-statistic = 5.019** ***p*-value = 0.002** ***	***F*-statistic = 2.891** ***p*-value = 0.034** **
	DB	*F*-statistic = 0.717 *p*-value = 0.542 n.s.	*F*-statistic = 0.251 *p*-value = 0.861 n.s.	***F*-statistic = 4.466** ***p*-value = 0.004** ***	***F*-statistic = 2.891** ***p*-value = 0.034** **
	MP&UA	*F*-statistic = 2.190 *p*-value = 0.087 *	*F*-statistic = 1.595 *p*-value = 0.188 n.s.	*F*-statistic = 1.233 *p*-value = 0.296 n.s.	*F*-statistic = 0.863 *p*-value = 0.460 n.s.
METEO Seasons data	All	*F*-statistic = 0.152 *p*-value = 0.929 n.s.	*F*-statistic = 0.900 *p*-value = 0.440 n.s.	***F*-statistic = 4.569** ***p*-value = 0.003** ***	***F*-statistic = 4.659** ***p*-value = 0.003** ***
	DB	*F*-statistic = 1.369 *p*-value = 0.250 n.s.	*F*-statistic = 0.847 *p*-value = 0.468 n.s.	***F*-statistic = 3.295** ***p*-value = 0.020** **	***F*-statistic = 2.762** ***p*-value = 0.041** **
	MP&UA	***F*-statistic = 3.317** ***p*-value = 0.019** **	***F*-statistic = 2.871** ***p*-value = 0.035** **	*F*-statistic = 1.748 *p*-value = 0.155 n.s.	***F*-statistic = 3.670** ***p*-value = 0.012** **

Notes: ***, **, and * denote the results significance at 1%, 5% and 10% levels, respectively.
Source: Own elaboration.

Based on the data presented in Table 5, the restrictions are valuable to explain the gold and silver rates of return in the MP&UA sample. For those investments, the conducted analysis shows at least the p-value for the F-test at the level equal to 0.05. The same conclusion can be given for platinum with an even higher statistical significance level. For the ALL sample, monthly dummy variables are useful to explain the rates of return for palladium and platinum. This is clear evidence that monthly anomaly effects are present on the palladium and platinum markets. However, (and this is true for all the analyzed investments), those effects depend on the time sample which is analyzed, and this is proof of the existence of the AMH on those markets. Similar conclusions are obtained for METEO seasons on the gold and silver markets for the MP&UA sample. The fact that the restrictions help explain the rates of return for two other time samples is not confirmed. This indicates changes in the rates of return for the gold and silver markets after Baur's publication. Data presented in Table 5 also indicate strong season effects in the palladium and platinum markets in the ASTRO and METEO seasons. Those results confirm that monthly or seasonal effects on the precious metals market vary over time; it can be said that one replaces the other effect as a result of finding EMH in the market.

5 Discussion and conclusion

On the basis of the research carried out, the following calendar effects for the precious metals studied were shown to occur. For the sample analyzed over the longest period, from January 20th, 1981 to July 29th, 2022, no month with a statistically significant average daily return was confirmed for gold. This is in contrast to an earlier study by Baur [2013]. It should be noted that the autumn effect analyzed for gold was confirmed for the identical sample that Baur analyzed. Nevertheless, for the data that include the most recent results from December 16th, 2010 to July 29th, 2022, negative returns were recorded in the autumn months of September and November (previously identified as those generating the autumn effect), i.e., a trend reversal was observed for the returns studied. However, a positive and statistically significant coefficient value appeared for January. Therefore, it can be concluded that the autumn effect observed nearly a decade ago in the gold market has been replaced by a winter effect. Importantly, this observation confirms the conclusion that there are calendar anomalies in the gold market that contradict the EMH [Fama, 1970]; however, in the long run, market participants recognize the existence of such patterns and, seeking to maximize profit, reduce the strength of such anomalies, but also create new ones. The authors of this study link such a situation to a more recent theory called the AMH [Lo, 2004]. As highlighted in this study, AMH applies the principles of evolution—competition, adaptation, and natural selection—to phenomena occurring in financial markets, or investment markets. In the light of AMH, it can therefore be considered that the financial market is adapting to the emergence of new information, which explains the disappearance (and even the observed reversal) of the autumn effect that was diagnosed a decade ago. The time-varying nature of calendar effects as a key component of AMH is mentioned by, e.g. Akhter and Yong [2021]. Similar conclusions regarding only the temporal occurrence of selected calendar effects as support for the dominance of AMH over EMH are also reached, among others, by Urquhart and McGroarty [2014], Xiong et al. [2019], and Bassiouny et al. [2023]. However, these works are concerned with capital markets. What distinguishes this study is the confirmation of AMH for the precious metals market. This conclusion is also strengthened for the gold and silver markets, provided in the paper by the Chow test results.

Several months that generate statistically significant interest rates were also noted for the precious metals studied. In the silver market, such a month with negative rates is June, which was confirmed for the ALL and DB samples. However, this effect is no longer observed for the most recent research sample, as for the MP&UA sample, the negative statistically significant value occurs in September. This phenomenon and the shift of the sell-off of silver from June to September, in the opinion of the authors of this study, should be linked to the high correlation of gold and silver prices. In line with this fact, the changes taking place in the gold market were also followed by coinciding changes in the silver market. A similar phenomenon was also observed for platinum. Also for this precious metal in September, for the MP&UA sample, there was a statistically significant and negative value of the estimated coefficient. This is already a strong-enough phenomenon that was also recorded for the ALL sample, but not confirmed for the DB sample. What is also similar for both the platinum and palladium markets is the occurrence of significant price increases at the beginning of the year. Although, in line with the observation made for the gold market, this effect is also expected to be variable over time.

In conclusion, it can be said that the publication of the paper by Baur [2013] resulted in reversing the autumn effect on the gold market. Moreover, statistically significant decreases in that month also appeared in the other precious metals markets studied. These observations were also confirmed when additional exogenous variables were included in the econometric model in the form of the MSCI World Index and the S&P 500. An additional conclusion that emerged from the estimation of these new models is the fact of the variable suitability of precious metals to hedge a portfolio, as also pointed out by Peng [2020] and Naeem et al. [2022].

What was also noticed is that the return rates for days that are classified differently in two season divisions (ASTRO and METEO) should be subject to detailed analyses in the future. Those days are a source of finding different seasonal effects in the analyzed time samples. This means that with the end of each season, investor activity rises and creates surprising temporary effects. That fact was also confirmed by the results of the *F*-test statistic. This is in line with Marquering et al. [2006], Mclean and Pontiff [2016], and Shanaev and Ghimire [2021] and supports the AMH.The conclusions presented in this article should be of particular interest to investors, market analysts, money managers, and executives of companies in the precious metals sector. For all these groups, the conclusions of this study are a valuable indication for the formulation of a strategy (investment, stock management) related to the functioning of the precious metals market.

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