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An Analysis of the Linkage Between PV Expansion and Silver Prices—Evidence from Monthly Data, 2018–2025

Zheng Liu

School of Business, Macau University of Science and Technology, Macau, China
1230002130@student.must.edu.mo

Abstract. Against the backdrop of the ongoing energy transition, whether the expansion of the photovoltaic (PV) industry affects silver prices through the channel of industrial demand is an important question for understanding the dual attributes of silver. Using monthly data from February 2018 to December 2025, this paper constructs indicators for price levels, relative prices, monthly returns, and year-on-year changes based on cumulative PV installed capacity, the monthly average gold price, and the monthly average silver price. OLS regressions are employed, supplemented by HAC/Newey-West robust standard errors. The results show that, in price-level regressions, the PV variable is significantly and positively associated with silver prices. However, after controlling for gold prices, this effect becomes insignificant, indicating that silver prices are still mainly driven by the common movement of gold. Under specifications based on relative prices, relative returns, and year-on-year measures, the PV variable likewise fails to exhibit robust significance. Overall, PV expansion and silver prices display a clear linkage, but the existing evidence lends more support to a co-movement relationship reinforced by the demand background than to the claim that PV has already exerted an independent pricing effect on silver.

Keywords: PV expansion, silver price, gold, linkage, relative price

1. Introduction

Amid the sustained global energy transition and the rapid expansion of PV installations, silver, as a key raw material in photovoltaic silver paste, has increasingly been discussed within a dual framework of "precious metal" and "industrial metal." Existing studies, starting from the relationship between solar energy production, solar installed capacity, and silver prices, suggest that the expansion of PV demand may exert an important influence on silver prices [1-3]. At the same time, studies on material supply, supply-chain risk, and long-term demand forecasts show that the dependence of the PV industry on silver is not a short-term phenomenon, but one of the structural constraints embedded in the energy transition [4-6].

However, silver is not an asset that can be discussed independently of gold. Research on the long-run relationship between gold and silver and on quantile cointegration indicates that the two have long exhibited a strong linkage [7-9], while evidence on volatility transmission suggests that in many periods the relationship can be characterized as "gold-leading and silver-following" [10]. Meanwhile, the literature on hedging and safe-haven assets generally holds that gold performs the

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financial safe-haven function more consistently than silver, while silver more often behaves as a hybrid asset combining financial and industrial attributes [11-13].

Although existing studies have separately examined the industrial effects of PV expansion on silver and the financial linkage between gold and silver, research directly testing whether the PV variable can provide additional explanatory power for silver prices—especially for silver's performance relative to gold—after controlling for gold remains limited. Against this background, this paper focuses on three monthly indicators, namely cumulative PV installed capacity, gold prices, and silver prices, to test whether a significant linkage exists between PV expansion and silver prices, and whether that relationship remains robust after controlling for gold.

2. Literature review and research hypotheses

2.1. PV expansion and industrial demand for silver

The English-language literature on the relationship between PV and silver can be broadly divided into two strands. The first strand directly examines the relationship between solar energy production or PV capacity and silver prices. Apergis and Apergis find a significant link between solar energy production and silver prices [1]. Subsequent studies based on long-memory and fractional cointegration methods, however, show that this relationship does not necessarily correspond to a stable long-run equilibrium, but may instead take the form of short-run effects or more complex dynamic responses [2]. In addition, Dutta approaches the issue from the perspective of silver-price uncertainty and shows that volatility in the silver market affects the stock performance of solar energy firms, suggesting that silver has become a key cost variable in the PV supply chain [3].

The second strand places greater emphasis on materials and supply-chain perspectives. Relevant studies point out that the PV industry's dependence on silver may amplify industry risk through channels such as supply-chain concentration, rising material demand, and potential supply-demand gaps [4-6]. Taken together, these studies indicate that, from the standpoint of industrial logic, PV has indeed provided the silver market with a new long-term demand background.

2.2. Gold-silver linkages and the financial attribute of silver

Despite the continuous rise in PV demand, silver remains part of the precious metals market system. Baur and Tran find a long-run relationship between gold and silver, with gold playing the stronger leading role in that relationship [7]. Yaya et al. further show, from the perspective of fractional cointegration, that gold and silver prices and their related market indicators exhibit a strong long-run linkage [8]. Quantile cointegration studies find that silver's short-run response to changes in gold prices is more pronounced in the tail quantiles, indicating that silver prices are still deeply influenced by the state of the gold market [9]. From the standpoint of volatility transmission, spillovers from gold to silver are markedly one-directional [10]. This means that, if a study intends to discuss whether PV has altered the pricing of silver, gold must be treated as an indispensable control rather than allowing conclusions to be drawn merely from a simple co-directional movement between silver and PV.

2.3. Safe-haven literature and research hypotheses

The literature on safe-haven properties has arrived at a relatively clear view: gold generally serves as a hedge or safe-haven asset more consistently than silver, whereas silver's performance depends more heavily on the specific market environment and sample period [11-13]. This body of work

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offers an important implication for the present study: if PV demand has truly altered the relative pricing logic of silver in a significant way, such a change should be reflected not only in the level of silver prices but also in silver's price or return performance relative to gold.

Based on the foregoing literature, this paper proposes two testable hypotheses. H1: At the price-level dimension, PV expansion is significantly and positively associated with silver prices. H2: If PV expansion exerts an effect on silver that is independent of gold, then after controlling for gold prices, or when using indicators of silver relative to gold, the PV variable should remain significant.

3. Data sources, variable construction, and research design

3.1. Data sources and sample selection

Table 1. Variable definitions

Variable	Definition	Role	Description
PHO	New installed PV capacity: cumulative value (within-year cumulative, 10,000 kW)	Core explanatory variable	Measures the intensity of PV industry expansion
GOLD	Monthly average spot price of gold (CNY/gram)	Control variable	Represents the traditional financial anchor of precious metals
SILVER	Monthly average spot price of silver (CNY/kg)	Dependent variable	Captures the level of silver prices
log_ratio	ln(SILVER/GOLD)	Relative-price variable	Tests the performance of silver relative to gold
log_pho_add	ln(monthly PV additions)	Robustness variable	Mitigates trend bias caused by cumulative reporting
rel_ret	Monthly return on silver minus monthly return on gold	Robustness variable	Tests relative returns rather than absolute prices
pv_yoy	Log growth of year-on-year cumulative PV capacity	Robustness variable	Tests the relationship from the perspective of annual changes

This paper uses monthly observations from December 2012 to December 2025 and includes three core variables: cumulative PV installed capacity (PHO), the monthly average spot price of gold (GOLD), and the monthly average spot price of silver (SILVER). Given that PHO is reported on a within-year cumulative basis and that the early sample contains many missing values, an OLS framework is adopted to conduct tests based on price levels, relative prices, returns, and year-on-year indicators.

As shown in Table 1, cumulative PV capacity is treated as the core explanatory variable. In the subsequent robustness tests, additional indicators are constructed, including monthly PV additions, year-on-year PV growth, the silver-to-gold relative price, and silver returns relative to gold. Sample diagnostics are reported in Table 2. The original sample spans from December 2012 to December 2025 and contains 132 observations, but as many as 25 months are missing. Missing observations are especially frequent in 2013–2017, and January is generally absent in each year. To reduce the interference caused by early missing values, the paper sets February 2018 to December 2025 as the main sample period, while the year-on-year model uses the 2019–2025 sample.

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Table 2. Sample diagnostics

Item	Result
Original sample period	2012-12-31 to 2025-12-31
Number of original observations	132
Number of missing months	25
Main sample period	2018-02 to 2025-12
Number of main-sample observations	88
Whether February-December of each year in 2018-2025 is complete	Yes
ADF p-value：log(SILVER)	0.9985
ADF p-value：log(GOLD)	0.9990
ADF p-value：log(PHO)	0.7873
ADF p-value：log_ratio	0.0180
ADF p-value：rel_ret	8.741e-07

Note: The ADF test results indicate that, in the main sample, the level series of log(SILVER), log(GOLD), and log(PHO) are non-stationary, whereas the relative-price and relative-return indicators are closer to stationary series.

3.2. Variable construction

Because PHO is in fact a within-year cumulative measure rather than a strict measure of monthly new installations, regressing it directly on the level of silver prices is susceptible to the influence of common trends. For this reason, in addition to the main model, this paper constructs three classes of auxiliary variables. The first is the relative-price variable, namely log(SILVER/GOLD), which is used to test whether silver has systematically strengthened relative to gold. The second consists of monthly returns and relative returns, which are intended to remove price trends as much as possible. The third is the year-on-year growth variable for PV, which is used to examine whether the relationship remains stable from the perspective of annual changes.

This treatment preserves the core information contained in PV expansion, gold prices, and silver prices, while also helping to avoid the problem of spurious regression caused by trend components, thereby allowing a more accurate identification of the marginal explanatory power of the PV variable for the silver market.

3.3. Model specification

Based on the variables defined above, three groups of models are specified in sequence. The first group is the price-level model:

$$\ln\left(\mathrm{SILVER}_t\right) = \alpha + \beta_1 \ln\left(\mathrm{PHO}_t\right) + \varepsilon_t \tag{1}$$

used to test H1. The second group adds gold as a control on the basis of the first model:

$$\ln\left(\mathrm{SILVER}_t\right) = \alpha + \beta_1 \ln\left(\mathrm{PHO}_t\right) + \beta_2 \ln\left(\mathrm{GOLD}_t\right) + \varepsilon_t \tag{2}$$

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The third group consists of the relative-price and robustness models, including

$$\ln\left(\mathrm{SILVER}_t \,/\, \mathrm{GOLD}_t\right) = \alpha + \beta_1 \ln\left(\mathrm{PHO}_t\right) + \varepsilon_t \tag{3}$$

as well as alternative regressions based on monthly additions, relative returns, and year-on-year indicators. All regressions are estimated by OLS and use HAC/Newey-West robust standard errors.

The logic of this design is straightforward: first, examine whether PV and silver display an apparently significant relationship; second, test whether that relationship still holds after controlling for gold; and finally, assess whether it can be preserved under the more conservative specifications based on relative prices and returns.

4. Empirical results and analysis

4.1. Descriptive statistics and graphical features

The descriptive statistics for the main sample are reported in Table 3, and the correlation matrix is presented in Table 4. Overall, gold and silver prices at the level dimension move highly synchronously: the correlation coefficient between log(GOLD) and log(SILVER) reaches 0.9654, while that between log(PHO) and log(SILVER) is 0.7168. This suggests that silver prices do rise in tandem with PV expansion, but that gold may possess greater explanatory power for silver.

Figure 1 presents the indexed trends of the three variables over 2018–2025. As can be seen, the index of cumulative PV installed capacity rises the fastest and exhibits a pronounced within-year reset pattern, whereas gold and silver both show a smoother and broadly synchronous upward movement. Figure 2 further compares the silver/gold ratio with cumulative PV values and shows that the two do not display a stable one-to-one correspondence. In other words, although PV expansion has been accompanied by greater market strength in silver, silver has not persistently or unidirectionally strengthened relative to gold.

Table 3. Descriptive statistics (main sample)

Variable	Obs	Mean	Std. Dev.	Min	Max
PHO	88	6747.53	7812.31	107.00	31751.35
GOLD	88	446.03	165.66	265.75	973.57
SILVER	88	5606.91	2128.27	3435.00	15390.42
ln(PHO)	88	8.13	1.24	4.67	10.36
ln(GOLD)	88	6.04	0.32	5.58	6.88
ln(SILVER)	88	8.57	0.32	8.14	9.64
ln(S/G)	88	2.53	0.08	2.28	2.76

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Table 4. Correlation matrix

Variable	ln(PHO)	ln(GOLD)	ln(SILVER)	ln(S/G)
ln(PHO)	1.00	0.72	0.71	-0.03
ln(GOLD)	0.72	1.00	0.96	-0.14
ln(SILVER)	0.71	0.96	1.00	0.11
ln(S/G)	-0.03	-0.14	0.11	1.00

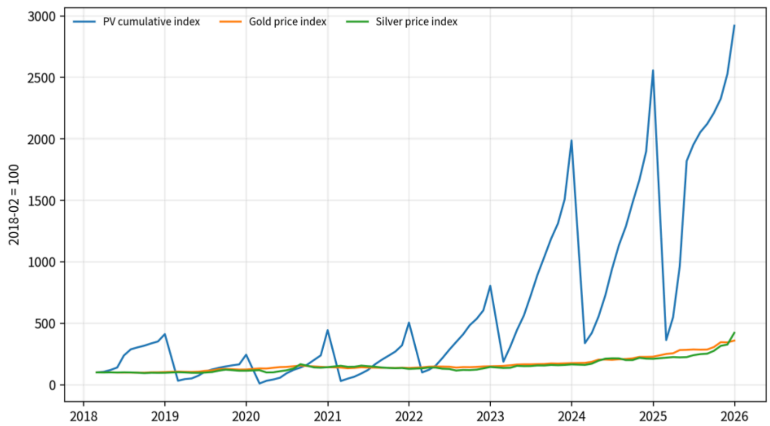

Figure 1. Indexed trends of PV, gold, and silver (2018-2025)

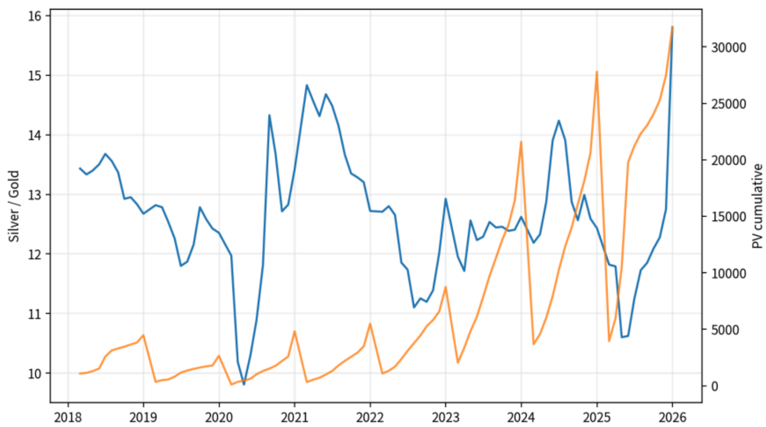

Figure 2. Silver-gold ratio and PV cumulative

4.2. Baseline regressions: price-level relationships

Table 5 reports three regressions based on price levels. Model M1 shows that the coefficient of log(PHO) on log(SILVER) is 0.1870 and significant at the 1% level. This indicates that, if one looks only at price levels, cumulative PV capacity is indeed strongly and positively associated with silver prices, and H1 is supported on the surface.

However, once log(GOLD) is added in Model M2, the coefficient of the PV variable rapidly declines to 0.0109, and the p-value rises to 0.605. By contrast, the coefficient on gold prices is 0.9313 and remains highly significant. This suggests that the earlier significance largely stems from common trends rather than from an independent effect of PV on silver. Furthermore, in Model M3,

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where silver prices relative to gold are used as the dependent variable, the coefficient of log(PHO) is -0.0021 and completely insignificant. H2 is therefore not supported at the relative-price level.

Table 5. Baseline and control regressions

Variable	M1: Level	M2: +Gold control	M3: Relative price
Constant	7.059*** [0.000]	2.8576*** [0.000]	2.5482*** [0.000]
log(PHO)	0.1870*** [0.000]	0.0109 [0.605]	-0.0021 [0.888]
log(GOLD)	—	0.9313*** [0.000]	—
N	88	88	88
R^2	0.514	0.933	0.001

Note: p-values are reported in brackets. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Estimation uses HAC/Newey-West robust standard errors.

4.3. Robustness tests: returns, relative returns, and year-on-year changes

To avoid the influence of trend components in price-level regressions, this paper further conducts robustness tests using monthly additions, relative returns, and year-on-year specifications. The results are shown in Table 6. M4 indicates that, when the monthly return on silver is used as the dependent variable, the coefficient of log(monthly PV add) is 0.0099, but it is not significant. In M5, after adding the return on gold, the PV variable remains insignificant, whereas the gold return is significantly positive. In M6, where the dependent variable is the return on silver relative to gold, the PV variable is still insignificant. M7 likewise finds no significant relationship under the year-on-year specification.

Figure 3 provides a visual display of the scatter distribution between year-on-year PV growth and the year-on-year movement in silver relative to gold. The fitted line is almost flat, which further confirms the lack of a robust linear relationship between the two. Taken together, Table 5, Table 6, and Figure 3 suggest that the available data reveal more of a "co-movement under a common trend" than a situation in which "PV independently determines the relative performance of silver."

Table 6. Robustness regressions

Variable	M4: Silver return	M5: +Gold return	M6: Relative return	M7: Relative YoY
Constant	-0.0478 [0.295]	-0.0279 [0.460]	-0.0334 [0.391]	-0.0195 [0.418]
log(monthly PV add)	0.0099 [0.162]	0.0040 [0.498]	0.0057 [0.359]	—
Gold return	—	1.3841*** [0.000]	—	—
PV YoY	—	—	—	0.0190 [0.581]
N	80	80	80	77
R^2	0.032	0.430	0.017	0.006

Note: p-values are reported in brackets. M4–6 use the 2018–2025 main sample; M7 uses the 2019–2025 year-on-year sample.

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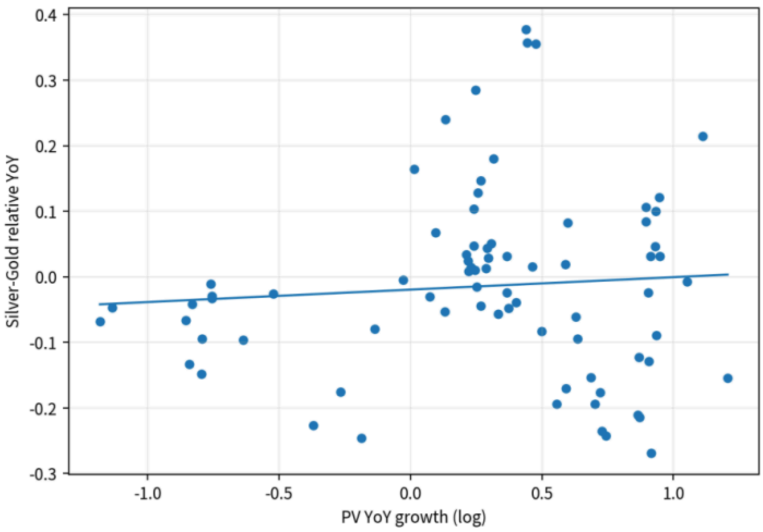

Figure 3. PV YoY growth and silver-gold relative YoY

5. Discussion

The empirical results indicate that the effect of PV expansion on the silver market is more likely to be manifested as price linkage under a background of demand expectations than as an independent reshaping of the pricing logic of silver relative to gold. The significantly positive coefficient in the price-level model suggests that, as PV installations expand, silver prices and the PV variable tend to rise in tandem. Yet this relationship weakens rapidly once gold is controlled for, implying that silver is still deeply constrained by the common movement of the precious-metals market.

This result is consistent with the findings of the literature on gold-silver linkages. Gold not only exerts a strong guiding role for silver in the long-run relationship, but in periods of macroeconomic shocks, shifts in risk appetite, and contractions in liquidity, silver also tends to move together with gold and other macro-financial variables. Therefore, even if a single industry variable can raise demand expectations for silver, it may not directly rewrite silver's price performance relative to gold within a short sample period.

At the same time, the results also point to several possible reasons why the PV variable fails to maintain robust significance. First, the PV variable is measured on a cumulative basis; although it captures the direction of industrial expansion, it is less informative about marginal monthly changes. Second, silver prices are simultaneously affected by the U.S. dollar, interest rates, risk appetite, and linkages within the precious-metals market, so the independent role of the industry variable is easily absorbed by common trends. Third, the main sample period is relatively short and some months are missing, both of which weaken statistical identification. Future research may identify the transmission mechanism from PV expansion to silver prices more clearly if monthly new installations, inventories, interest rates, or uncertainty indicators can be incorporated.

6. Conclusion

This paper conducts an empirical examination of the linkage between PV expansion and silver prices. The results show that, at the price-level dimension, the PV variable is significantly and positively correlated with silver prices. However, after controlling for gold prices, the PV variable is

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no longer significant, indicating that silver prices are still mainly driven by gold and by the common movement of precious metals.

Furthermore, whether one uses silver prices relative to gold, returns on silver relative to gold, or year-on-year PV growth together with year-on-year silver performance relative to gold, no robust and significant estimates are obtained. This means that the available evidence provides greater support for the view that PV expansion offers background support and co-movement effects for silver prices, rather than demonstrating that it has already generated an independent and stable relative pricing effect on silver.

Overall, against the backdrop of the energy transition, PV expansion has indeed strengthened the industrial-demand logic of silver. Yet under the current sample and variable specifications, the financial attribute of silver and its linkage with gold still occupy the dominant position. This conclusion suggests that, when discussing the impact of PV on the silver market, attention should be paid simultaneously to the industrial-demand channel and the financial pricing mechanism of precious metals, and that richer data and more comprehensive control variables will be needed in future research for further testing.

References

[1] Apergis, I., Apergis, N.: Silver prices and solar energy production. Environmental Science and Pollution Research 26(9), 8525-8532 (2019)
[2] Apergis, N., Carmona-González, N., Gil-Alana, L.A.: Persistence in silver prices and the influence of solar energy. Resources Policy 69, 101857 (2020)
[3] Dutta, A.: Impact of silver price uncertainty on solar energy firms. Journal of Cleaner Production 225, 1044-1051 (2019)
[4] Gervais, E., Kleijn, R., Nold, S., van der Voet, E.: Risk-based due diligence in supply chains: the case of silver for photovoltaics. Resources, Conservation and Recycling 198, 107148 (2023)
[5] Xu, C., Isabella, O., Vogt, M.R.: Future material demand for global silicon-based PV modules under net-zero emissions target until 2050. Resources, Conservation and Recycling 210, 107824 (2024)
[6] Cattaneo, V., Mast, J., Hackenhaar, I., Nardone, S., Scheerlinck, S., Mertens, J., Dewulf, J.: Forecasting silver demand and supply by 2030: impact of silver-intensive photovoltaic cells and sectoral competition. Resources, Conservation and Recycling 224, 108562 (2026)
[7] Baur, D.G., Tran, D.T.: The long-run relationship of gold and silver and the influence of bubbles and financial crises. Empirical Economics 47(4), 1525-1541 (2014)
[8] Yaya, O.S., Vo, X.V., Olayinka, H.A.: Gold and silver prices, their stocks and market fear gauges: testing fractional cointegration using a robust approach. Resources Policy 72, 102045 (2021)
[9] Zhu, H., Peng, C., You, W.: Quantile behaviour of cointegration between silver and gold prices. Finance Research Letters 19, 119-125 (2016)
[10] Koulis, A., Kyriakopoulos, C.: On volatility transmission between gold and silver markets: evidence from a long-term historical period. Computation 11(2), 25 (2023)
[11] Robinson, Z.: A macroeconomic viewpoint using a structural VAR analysis of silver price behaviour. Mineral Economics 37, 15-23 (2024)
[12] Parrey, Z.A., Dar, A.B., Paul, M.: Revisiting precious metal mining stocks and precious metals as hedge, diversifiers and safe-havens: a multidimensional scaling and wavelet quantile correlation perspective. Empirical Economics 68(2), 511-533 (2025)
[13] Feder-Sempach, E., Szczepocki, P., Bogołębska, J.: Can precious metals act as safe-haven or hedge assets in capital markets of China? The Chinese Economy 59(2), 141-159 (2026)