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Examining the Effect of Crude Oil Shock on the U.S. PPI Through Time Series Analysis

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Abstract: Nowadays, people are becoming more curious about how changes in oil prices affect inflation, particularly how they impact macroeconomic indicators like the PPI (Producer Price Index) and CPI (Consumer Price Index), due to the ongoing pandemic and war's impact on oil prices. The present study examines the relationship between oil price changes and the PPI in selected industries. Using data from the trucking, chemical manufacturing, semiconductor, and electronic device industries PPI from 2020, with WTI (West Texas Intermediate) as the reference of U.S. oil price. The Pearson correlation coefficient and linear regression model were employed to analyze the correlations and evaluate the impact of oil price changes. The results demonstrate that the PPI for the trucking industry had the strongest correlation with oil prices over the same period, while the PPI for the chemical manufacturing industry demonstrated the strongest relationship with oil prices a month earlier. The PPI for the semiconductor industry displayed a strong correlation with oil prices six months ago. Overall, the transportation industry appears to be highly sensitive to changes in contemporaneous oil prices, and oil prices one month ago have a significant concussion on the current PPI of the chemical lines, and the effect of oil prices on the electronic device industry is weaker and more delayed.

Keywords: PPI, WTI, Time Series Analysis, Crude Oil Shock, the United States.

1. Introduction

During the pandemic, price fluctuations were more obvious, prompting people to pay more attention to indicators such as CPI to make more informed decisions. PPI has received less attention than CPI, but existing research shows that changes in PPI can significantly affect CPI. The findings suggest that in some regions, a price shift seen in one PPI component would have a direct impact on that same CPI component [1]. By observing PPI indices, people can gain insight into the price changes of the supplier, allowing them to forecast market price changes, including CPI in advance. To summarize, the PPI serves a dual role: it is used to create price indices that help adjust gross domestic product data, and it also acts as a general measure of inflation [1]. Hence, It is crucial to examine the main factors that cause changes in the Producer Price Index.

Currently, there is evidence that the producer price indices exhibit short-term responses to short-term oil price shocks [2]. Since 2020, the impacts of the epidemic and conflicts on oil supply and demand have led to sharp fluctuations in oil prices, which may have a greater influence on PPI. Existing studies mainly focus on changes in a country's overall PPI, which is called PPI for all commodities. There is a lack of research on PPI specific to certain industries. At present, there are limited models for studying PPI, and the models found by the author in existing research mainly include the ARIMA (Autoregressive Integrated Moving Average model) model and the non-linear error correction model. By adjusting the ARIMA model, these researchers were able to achieve more accurate forecasts of PPI, with the assistance of GA-SVR (Genetic Algorithm-Support Vector Regression) [3]. In non-linear research, researchers proved that there is a significant non-linear error-correction relationship between producer prices and oil prices, which suggests asymmetry and time-variance in error correction [4]. Overall, the current research on the linear correlation between PPI and crude oil prices is scarce.

In this study, the time series connection between the price of crude oil and PPI in particular industries is analyzed, and the linear relationships between changes in the price of oil and PPI in various industries are contrasted. The author also compares the linear relationship between current and near-term (3-6 months) oil prices and PPI in different industries, finding that industries have different responses to current and forward oil prices, and ultimately drawing several conclusions. This research clarifies the direct correlation between PPI and the cost of oil, filling a gap in current research on this topic. Additionally, this study visualizes the different impacts of crude oil prices on the transportation, chemical, and high-end manufacturing industries, which helps the prediction of future trends in PPI for these industries. Finally, this study sheds light on how the volatility of oil prices affects inflation.

2. Methodology

2.1. Data Selection

All research data for this paper are sourced from the official data website of the Federal Reserve, and the codes of each data are the codes assigned to the data by the website [5]. WTI is a crude oil used to price most of the oil produced in the United States. Due to the commoditization of WTI and its use as a hedging tool by buyers and sellers of crude oil, in numerous nations that export crude oil to the U. S., it has evolved into the benchmark crude. market [6]. It is widely considered an important benchmark both in the domestic and global oil market. As a result, the author decided to use WTI data to illustrate the random variables of the cost of oil, which is coded as WTISPLC on the website.

In this study, the author selected the PPI data of the transportation, general manufacturing, and high-tech manufacturing industries. These industries have different relationships with oil prices: specifically, the transportation industry consumes gasoline or diesel derived from the primary processing of oil, while the general manufacturing industry sources part of its raw materials from the secondary processing of oil. In terms of the high-tech manufacturing industry, manufacturing does not appear to be directly related to crude oil. Therefore, the author selected three PPI time series data from the official website, including Producer Price Index by Industry: General Freight Trucking, Long-Distance Truckload (PCU484121484121), Producer Price Index by Industry: Chemical Manufacturing (PCU325325), and Producer Price Index by Industry: Semiconductor and Other Electronic Component Manufacturing (PCU33443344).

In terms of time selection, the author first chose WTI and PPI time series data starting in 2020 to examine their correlation. The author also chose data from July and October 2019 to evaluate how prior oil prices affected PPI, corresponding to the PPI data starting from 2020, to investigate the impact of oil prices from six months ago and three months ago on current PPI.

2.2. Pearson's Correlation Coefficient

Pearson's correlation coefficient is a statistical measure used to assess the strength and direction of a linear relationship between two variables. It is often used to judge whether there is a significant

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correlation between the two time series variables. Set a and b are two random variables. The Pearson correlation coefficient is calculated by the formula(1), where E(ab) represents the cross-correlation between a and b, σ_a and σ_b represent the variances of variables a and b respectively [7].

$$\rho(a,b)= \frac{E(ab)}{\sigma_a^2\sigma_b^2} \tag{1}$$

The test result ranges from -1 to 1. When a positive correlation exists between two variables, an increase in one corresponds with an increase in the other, then the correlation coefficient will be between 0 and 1. The stronger the correlation coefficient between two variables, the stronger the linear relationship between them.

2.3. Univariate Linear Regression Model

Figuring the line of greatest fit that best captures the connection between the two variables is the aim of univariate linear regression. The value of the dependent variable is anticipated using the independent variable's value. To be more precise, the line's intercept and slope stand for the line's junction with the y-axis and the strength and direction of the link between the two variables, respectively. In the formula(2), Y_t is a related time series and X_t is an independent time series. α represents the slope of the line, which is the regression coefficient estimated by the model. β represents the intercept of the linear equation [8].

$$Y_t = \alpha \times X_t + \beta \tag{2}$$

In R studio, researchers can directly obtain the best simple linear regression model of two variables. The results of the model include the values for α (regression coefficient) and β, the t-values, and the Multiple R-squared values. The t-value is a result of the correlation test, and the higher t-value, the stronger correlation. A model's quality of fit is gauged by the Multiple R-squared, which has values between 0 and 1. A result closer to 1 indicates a better-fitting model and represents the percentage of the data that conforms to the model. By examining the t-value and R-squared values, researchers can determine the strength of the relationship between the independent and dependent variables in a linear regression model. There are also p-value and residual standard error calculated by R that determine whether the model fits well.

3. Empirical Results

Initially, the author of this study looked into how three PPIs might be affected by fluctuating oil prices starting in 2020, including the PPI of trucking transportation, chemical manufacturing, semiconductor and electronic component. Table 1 are the results of Pearson's correlation test. Table 1 shows the results of Pearson's correlation test between WTI and the PPI for three industries. The data obtained from the t-test are shown in the second row, those of the p-test are displayed in the third row, the 95% confidence interval for the correlation coefficient is presented in the fourth row, and Pearson's correlation coefficient is visible in the fifth row. Upon examination, it is found that in all three correlation tests, the p-values are less than 0.05, indicating a linear correlation between the PPIs of the three industries and crude prices. By comparing the correlation coefficients in the inspection process, the correlation coefficients of truck transportation and chemical manufacturing are relatively close and both greater than 0.9, indicating that there is a high linear correlation between these two industries and crude oil prices in the same period. However, the correlation coefficient between PPI in the semiconductor and electronic component manufacturing industry and crude costs in that time frame is around 0.72, indicating a general linear correlation between the two. Again, observing the

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result of the t-test also verifies that the correlation between truck transportation and chemical manufacturing with crude oil prices over the same period is stronger than that between the high-end manufacturing industry represented by semiconductors and oil prices at the specified timeline.

Table 1: Results of Pearson's correlation test between WTI and the PPI for three industries.

Time Series	PPI-Truck Transportation	PPI-Chemical Manufacturing	PPI-Semiconductor & Electronic Component
t-value	16.447	15.355	6.0583
p-value	<2.2e-16	< 2.2e-16	8.13E-07
95% confidence intervals	0.891, 0.972	0.877, 0.968	0.518, 0.853
correlation coefficient	0.944	0.937	0.726

To further explore the correlation between the PPI of these three industries and WTI, the author utilized the simple linear regression model. Take the time series of oil price and industry PPI as independent variables and dependent variables, respectively, and entered R studio to obtain the best simple linear regression model. Table 2 manifests that the computing result of α represents the slope of the fitted linear equation, indicating the degree to which oil price determines the PPI index. The value of β represents the intercept of the linear equation, and its meaning is not discussed for now. The most important values in the table are the R-squared and adjusted R-squared, which represent the percentage of entire data that fit the model of linear regression. By comparing the α values and R-squared values of the linear regression models between the PPI of different industries and the contemporaneous oil price, the correlation between the PPI and oil price in different industries can be compared more clearly. For the truck transportation and chemical manufacturing industries, the α values are relatively high, indicating a strong linear relationship between PPI and oil prices, with more than 85% of the data fitting the model for both industries. However, the α value of the semiconductor industry is close to 0.01, which casts uncertainty on how oil prices would affect the PPI of the electronics sector. Furthermore, only 51% of the data fit the linear regression model for the semiconductor industry, suggesting a weak relationship between PPI and oil price in this industry.

Table 2: Results of linear regression.

Time Series	PPI-Truck Transportation	PPI-Chemical Manufacturing	PPI-Semiconductor & Electronic Component
α	1.060	1.129	0.030
α Std. Error	0.064	0.074	0.005
β	96.116	247.294	53.299
β Std. Error	4.619	5.268	0.361
t-value	16.45	15.36	6.058
p-value	<2e-16	<2e-16	8.13E-07
Multiple R squared	0.891	0.878	0.527
Adjusted R squared	0.888	0.874	0.512

The association between oil prices and the PPI for the electronic component business was further investigated by the author, focusing on the correlations with oil prices three months ago and six months. The researcher paired the WTI data from three months ago (started at 2019.10) prior with the current PPI and conducted a Pearson test, and then paired the WTI data from six months ago (started at 2019.07) with the current PPI and conducted the same test. Table 3 displays the outcomes of these examinations.

Table 3: Results of Pearson's correlation test with the paired WTI.

Time Series	Crude Oil	Crude Oil 3 months ago	Crude Oil 6 months ago
t-value	6.058	6.058	6.058
p-value	8.13E-07	1.20E-10	5.81E-14
95% confidence intervals	0.518, 0.853	0.719, 0.921	0.823, 0.953
correlation coefficient	0.726	0.849	0.907

Both the t-value and the correlation coefficient increase as the months advances. Specifically, the correlation coefficient between the PPI in the semiconductor industry and oil prices six months ago is greater than 0.9, which is close to the correlation between the PPI in the truck transportation industry and the same-period oil prices. In Table 4, the linear regression model fits better with oil price data from three months ago and six months ago than with the current data. This is reflected in the higher R-squared values, with approximately 70% and 80% of the data fitting the latter two models, respectively. It is also worth noting that although the correlation between oil prices and PPI in the semiconductor industry has increased over time, the magnitude of the coefficient remains around the order of 0.01 in the linear regression model. According to previous studies, changes in oil price result in smaller price fluctuations in raw materials used in the electronics industry such as gold, silver, and tin, compared to the magnitude of undulation of crude price. However, it cannot be denied that variations in oil prices have an effect on the PPI of the electronics sector.

Table 4: Results of linear regression with the paired WTI.

Time Series	Crude Oil	Crude Oil 3 months ago	Crude Oil 6 months ago
α	0.030	0.037	0.045
β	53.299	52.991	52.639
Multiple R squared	0.527	0.720	0.823
Adjusted R squared	0.512	0.712	0.818

In Table 5, the results of Pearson's tests of the correlations between the PPIs of the trucking and chemical manufacturing industries and long-run oil prices are presented. The researcher can deduce the effect of the long-term price of oil on the PPIs of these two industries based on the size of the t-values and the correlation coefficients. Judging from the data, the correlation between the PPI of the transportation industry and oil prices 3 months prior has dropped significantly, and the correlation with oil prices 6 months prior is even lower. The correlation between PPI in the chemical manufacturing industry and oil prices 3 months ago is 0.9, while the correlation with oil prices 6 months prior has greatly decreased.

Table 5: Results of Pearson's correlation test with the PPI of two industries.

Time Series	Crude Oil	Crude Oil 3 months ago	Crude Oil 6 months ago
PPI-Truck Transportation			
t-value	16.447	9.225	5.988
correlation coefficient	0.944	0.849	0.722
PPI-Chemical Manufacturing			
t-value	15.355	13.21	7.358
correlation coefficient	0.937	0.917	0.788

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The investigation into the lagged impact of oil price movements on PPI was motivated by prior research that revealed that rising crude prices have a delayed stock return impact.[9]. Furthermore, the high cost of raw material storage in the chemical industry limits the duration of this lag effect [10]. According to previous research results, the researcher chose to set the lag time to one month in order to evaluate the connection between PPI for the chemical industry and oil prices from one month ago. In addition, in Table 6, by comparing the correlation coefficients of the transport industry and oil prices one month ago with that for the chemical manufacturing industry, the impact of oil price changes on the PPI of the two industries is different. For oil prices one month ago, the correlation coefficient for the transportation industry decreased, while the correlation coefficient for the chemical manufacturing industry increased slightly. This suggests that the link between crude price and PPI in the chemical manufacturing industry is more complicated and may involve a lag effect for one month to three months.

Table 6: Correlation between PPI and oil prices (one month before).

With Crude Oil 1 month ago	PPI-Truck Transportation	PPI-Chemical Manufacturing
t-value	13.797	16.61
correlation coefficient	0.923	0.945
a	1.043	1.146
b	98.002	246.950
Multiple R squared	0.852	0.893
Adjusted R squared	0.848	0.890

4. Conclusion

The paper examines oil price fluctuation and the PPIs' correlation in the fields of trucking, chemical manufacturing, semiconductor, and electronic device industries in the United States. Based on the Pearson correlation coefficient and linear regression model, the results demonstrate that the PPI for the trucking industry had the strongest correlation with oil prices over the same period, while the PPI for the chemical manufacturing industry demonstrated the strongest relationship with oil prices a month earlier. The PPI for the semiconductor industry displayed a strong correlation with oil prices six months ago. To sum up, this study reveals how sensitive the transportation sector is to variations in oil prices in the same time section, while the PPI changes in the chemical industry may be related to oil price changes from 1-2 months ago. Changes in PPI in the high-end manufacturing industry may be related to changes in oil prices further out, although this effect is minimal. Therefore, this study confirms that oil price fluctuations have diverse influences on different PPIs, and provides a reference for predicting PPI and other macroeconomic data based on crude prices. Future studies can concentrate on the PPI of more industries or go deeper into the process underlying how oil prices affect the PPI of a certain industry.

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