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Testing the effects of the Japanese vehicle emission-control law on the international palladium futures market

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Abstract

This paper tested the effects of the 2005 vehicle emission-control law issued in Japan on the market linkages between the U.S. and Japanese palladium futures markets. To determine these effects, we applied a cointegration test both with and without break points in the time series and found that the market linkages between the two countries changed after the break in October 2005. Our results show that the 2005 long-term regulation of vehicle emissions enacted in Japan influenced the international palladium futures market.

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1. Introduction

As global demand for platinum group metals (PGMs) increases, it has become more important for countries to apply effective policy measures for the sustainable management of these minor metals. Because the ore of PGMs is found in a limited number of countries, PGM markets are highly international. Therefore, it is essential to understand how domestic PGM markets are linked internationally and how domestic policies on PGM markets influence the international PGM market. We examine the market linkages between the U.S. and Japanese palladium futures markets and analyze how Japanese domestic policies that influence its domestic palladium market affect the international palladium market. Toward these ends, we examine whether an October 2005 vehicle emission-control law passed in Japan, which is likely to influence the Japanese palladium market, affected the price linkage between the U.S. and Japanese palladium futures markets.

Currently, a significant amount of the world's palladium supply is used to create catalytic converters in automobiles. Catalytic converters are generally found in diesel engines because they reduce hydrocarbon and carbon monoxide emissions. As emissions controls become stricter, diesel vehicles that violate regulation standards are required to be replaced by vehicles that can pass such standards. Hence, the demand for catalytic converters is expected to rise in countries that set a high vehicle emission standard, which would increase the demand for palladium in these countries.

On October 1, 2005, the Japanese government enacted new long-term regulations on NOx and particulate matter (PM). At the time, this was the world's most stringent diesel regulation. Japan is one of the largest automobile-producing countries in the world, and this regulatory policy has the potential to increase the use of palladiums for catalytic converters in Japan, thereby affecting the international palladium market. Shibata (2004) suggests that after Japan issued the new emission standards in October 2005, regulatory controls between Japan, the U.S., and Europe became similar. Thus, Japan's vehicle emission-control law may have precipitated changes in the international palladium market after its enactment in October 2005. We investigate whether the effect of this law was manifested in the price linkage between the U.S. and Japanese palladium futures markets by comparing the linkages both before and after October 2005.

Aruga and Managi (2011) reveal that there has been a sustained linkage between the U.S. and Japanese palladium futures markets.[1] However, this international price linkage may be affected by the long-term regulation of vehicle emissions enacted by Japan in 2005. This regulation may have increased the use of palladium for catalytic converters in Japan, and this increased demand is likely to affect the international palladium market. Therefore, international price linkages may have changed after this law was implemented in October 2005. If our results show that Japanese domestic policy influenced the price linkage between the U.S. and Japanese palladium markets, this finding would imply that the effects of domestic policies on the international palladium market cannot be ignored. Policymakers would need to consider the

[1] Aruga and Managi (2011) took into account of structural breaks and tested the breaks as unknown breaks while in this paper we focus on the effects of the known break that may have occurred in 2005 and we treated the break in a different way from this previous study.

effects of domestic policy on the international palladium market when developing policies to sustainably manage this resource. This paper contributes to the existing studies on the palladium markets to help understand how the international palladium markets respond to a change in a domestic policy that affects its domestic palladium market.

In the next section, we discuss the data used in the study. In the third section, we explain the methods used in our analysis, and in the fourth section, we present the results of the study. Finally, in the last section, we discuss the conclusions of the study.

2. Data

To establish the pricing of U.S. palladium futures, we used the daily continuous futures price from the New York Mercantile Exchange (NYMEX) palladium futures contract. We obtained the data for the NYMEX palladium futures prices from EODData, LLC. We collected the pricing of Japanese palladium futures from the website of the Tokyo Commodity Exchange (TOCOM), Inc. Most deferred contracts were used to determine pricing in the TOCOM palladium futures market because they were the most active contracts. We conducted our analysis from October 1, 2004 to September 29, 2006. We chose this period because it covered one year before and one year after the enactment of Japan's new long-term regulation on vehicle emission-control on October 1, 2005. By observing market behavior before and after the implementation of this law for equal periods, we were able to obtain two comparable sets of data.[2]

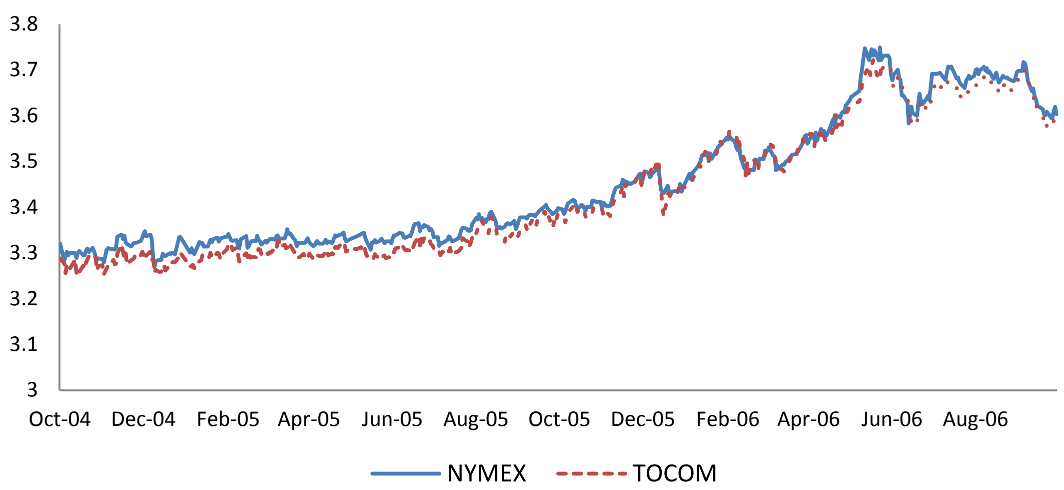

Figure 1. Plots of U.S. and Japanese palladium futures prices

We adjusted the prices of the U.S. and Japanese palladium futures markets to take the variable price units into account. Japanese palladium prices were converted to U.S. dollars by using the daily currency rate between the U.S. dollar and the Japanese yen. We obtained the daily currency rate from the OANDA Corporation. The prices were also adjusted for the weight

[2] We used 490 observations in total, with 244 observations for the period before October 1, 2005 and 246 observations for the period after this date.

of palladium per price unit. The original data for the NYMEX palladium price were provided in one troy ounce (31.1 gram), whereas the TOCOM provided its palladium futures price in grams. Therefore, to match the units between the U.S. and Japanese palladium markets, the prices of the NYMEX palladium were transformed into price per gram. Finally, we converted the NYMEX and TOCOM palladium futures prices into their natural logarithmic forms.

Figure 1 shows plots of the natural logarithm of the palladium futures prices for the NYMEX and TOCOM. We found that the U.S. and Japanese palladium futures markets seemed to be diverging before the implementation of Japan's vehicle emission-control law, whereas after the regulation was enacted, the U.S. and Japanese palladium futures markets appeared to display increased synchronicity. Therefore, the cointegration relationships between the U.S. and Japanese palladium markets may have been altered by the implementation of this regulation.

3. Methods

The methodology consisted of two parts. In the first part, the Carrion-i-Silvestre and Sanso (CS) (2006) cointegration test was used to determine whether the U.S. and Japanese palladium futures markets were cointegrated when the effects of structural breaks were considered endogenous to the cointegration model. We assumed that a structural break occurred after the new vehicle emission-control law was implemented on October 1, 2005, and we created a dummy variable for the period after October 1, 2005. This dummy variable was incorporated into the CS cointegration model (the details are explained later in this section). The Johansen (1991) cointegration test (which does not take into account the effects of structural breaks) was also performed for the entire period, and the results of this test were compared with those of the CS cointegration test. If the results between the two cointegration tests differed, it would imply that the long-run price relationship between the U.S. and Japanese palladium markets was affected by the break on October 1, 2005. In the second part of our methodology, we investigated whether these results indicated the influence of the structural break. We separated the whole price series into periods before and after October 1, 2005 and performed the Johansen cointegration and the Granger Causality tests for each period. If Japan's vehicle emission-control law affected the international palladium market, we expect that the results of these tests would be different for the periods before and after October 1, 2005.

3.1 Carrion-i-Silvestre and Sanso test

The following four CS models are tested in this study:

$$\text{Model 1:}\quad Y_{it} = \alpha_i + \beta_i X_{it} + \theta_i DU_{it} + \varepsilon_{it}, \tag{1}$$

$$\text{Model 2:}\quad Y_{it} = \alpha_i + \beta_i X_{it} + \xi_i t + \theta_i DU_{it} + \varepsilon_{it}, \tag{2}$$

$$\text{Model 3:}\quad Y_{it} = \alpha_i + \beta_i X_{it} + \xi_i t + \gamma_i DT_{it} + \varepsilon_{it}, \tag{3}$$

$$\text{Model 4:}\quad Y_{it} = \alpha_i + \beta_i X_{it} + \xi_i t + \theta_i DU_{it} + \gamma_i DT_{it} + \varepsilon_{it}, \tag{4}$$

where $X_{it} = X_{it-1} + u_{it}$, $DU_{it} = \begin{cases} 1, & \text{for } t > T_b \\ 0, & \text{otherwise} \end{cases}$, $DT_{it} = \begin{cases} (t - T_b), & \text{for } t > T_b \\ 0, & \text{otherwise} \end{cases}$.

Here, T is the number of observations, $T_b = \lambda T,\ 0 < \lambda < 1$ indicates the date of the break, Y_{it} is the price series that is used as the dependent variable in our model, α_i is the intercept, X_{it} is the price series that is used as the independent variable where β_i is its coefficient, and $u_{it} \sim \text{i.i.d.}(0, \sigma^2_{u,i})$. Because the break is related to the introduction of a new vehicle emission-control law in Japan, we set the Japanese palladium price series as Y_{it} and the U.S. palladium price series as X_{it}. The null hypothesis proposes a cointegrating relationship among the variables of interest. In the CS cointegration test, the null is represented as $\sigma^2_{u,i} = 0$. As seen in equation (1), Model 1 accounts for the structural break with a level shift but without a time trend. Model 2 incorporates the break by containing a time trend and a level shift. Model 3 takes the change in the slope of the time trend into account, and Model 4 contains both the change in the slope of the time trend as well as the level shifts.

In the CS test, these models are estimated by the dynamic ordinary least squares (DOLS) method developed by Stock and Watson (1993). Compared to other cointegration methods, the CS test has the advantage of being applicable even if the variables of interest are integrated in different orders. Furthermore, the CSS test can account for simultaneity among the regressors and can be used for a small data sample.

The null hypothesis of cointegration against the alternative of non-cointegration is tested with the Lagrange-Multiplier (LM-type) test statistic:

$$LM_j(\lambda) = \frac{\sum_{t=1}^{T} S_{j,t}^2}{T^2 \hat{\omega}^2}, \tag{5}$$

where $S_{j,t} = \sum_{k=1}^{t} \hat{\varepsilon}_{j,k}$ is the partial sum of residuals in Models 1 through 4, $\hat{\omega}^2$ is an estimator of the long-run variance of ε_{it}, and $\{j = \text{Model 1, Model 2, Model 3, Model 4}\}$.[3] The critical values to test the null hypothesis are provided in Table 1 of Carrion-i-Silvestre and Sanso (2006).

Because we are analyzing the effect of Japan's vehicle emission-control law on international linkages in the palladium futures market, we set the break date at October 1, 2005, the date of this law's implementation. We then tested whether a cointegrating relationship persisted between the U.S. and Japanese palladium futures markets when this break was considered endogenous to the CS cointegration model.

3.2 Johansen cointegration and Granger causality tests

Setting P_t as the $n \times 1$ vector of prices used in the analysis, the Johansen cointegration test was conducted under the following vector error correction (VEC) form of the vector autoregressive (VAR) model:

$$\Delta P_t = \Pi P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \mu + \varepsilon_{t,}, \tag{6}$$

[3] Models 1 through 4 represent models An, A, B, and C in Carrion-i-Silvestre and Sanso (2006).

where k is the order of the vector autoregressive process, $\Pi = -\mathrm{I} + \sum_{\mathrm{i}=1}^{\mathrm{k}} \Pi_{\mathrm{i}}$, $\Gamma_{\mathrm{i}} = -\sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{k}} \Pi_{\mathrm{j}}$, μ is a constant, and ε_t is an n-dimensional white noise process.[4] Whether equation (6) shows a cointegrating relationship between the U.S. and Japanese palladium futures prices depends on the rank of the Π matrix.[5] We used the trace and maximum eigenvalue test statistics in the Johansen test. The trace and eigenvalue test statistics have the following form:

$$\lambda_{trace}(l) = -T \sum_{i=r+1}^{n} ln\left(1 - \hat{\lambda}_i\right), \tag{7}$$

$$\lambda_{Max}(l, l+1) = -T ln\left(1 - \hat{\lambda}_{r+1},\right), \tag{8}$$

where $\hat{\lambda}_i$ is the estimated value of the eigenvalues, T is the number of usable observations, and l denotes the number of possible cointegrating vectors. We used the Akaike information criteria (AIC) to determine the appropriate lag length for the VAR model.

To perform the Johansen test, all of the price series used for the analysis must be integrated in the same order. Hence, before conducting the Johansen test, we conducted the Phillips-Perron (PP) (Phillips and Perron, 1988) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) (Kwiatkowski et al., 1992) unit root tests on every price series used in the analysis.

We also tested the short-run price relationships between the U.S. and Japanese palladium futures markets using the Toda and Yamamoto (1995) modified Granger causality test. Sims et al. (1990) suggest that the results of causality tests become spurious when the variables used in the causality test are non-stationary but the Toda and Yamamoto method overcomes this problem. Toda and Yamamoto (1995) suggest that differencing the price series in order to make the series stationary is not necessary for the estimation of the vector autoregressive (VAR) model in their test. Their Granger causality test is tested using $k + d$ lags in the VAR model where k is the statistically optimal lag order in the VAR model and d is the maximal order of integration of the price series in the model. In our study we used the Akaike Information Criteria (AIC) for identifying the order of k in the VAR model.

Table 1. Carrion-i-Silvestre-Sanso test

	LM-type test statistic	95% Critical values
Model 1	0.438*	0.155
Model 2	0.252*	0.106
Model 3	0.098*	0.073
Model 4	0.099*	0.056

Note: * represents significance at 5% level. The critical value for each model is taken from Table 1 of Carrion-i-Silvestre and Sanso (2006) when λ=0.5, and k=1.

[4] n is the number of non-stationary variables used in the model.

[5] Other parts of equation (6) are stationary because (by assumption) the variables in the P matrix are integrated in the same order.

4. Results

The results of the CS test are presented in Table 1. The results suggest that the null hypothesis of cointegration was rejected at the 5% significance level in all four models. Because the previous study suggests that there is a long-run price linkage between the U.S. and Japanese palladium futures markets when an effect of a break is not considered (Aruga and Managi, 2011), these results might be implying that the break caused both level and slope shifts in the Japanese palladium futures price and that the break affected the cointegration relationship between the U.S. and Japanese palladium markets. Hence, we performed the Johansen test where no break is endogenized in the cointegration test on the U.S. and Japanese palladium price series to determine whether the result of this test is different from the CS test.

Table 2. Unit root tests

Variable	For whole period (October 2004 to September 2006)			
	Log Level		First differences	
	PP	KPSS	PP	KPSS
NYMEX Palladium	-2.368	0.416*	-22.251*	0.114
TOCOM Palladium	-2.375	0.405*	-22.249*	0.113
	Period before October 2005			
	Log Level		First differences	
	PP	KPSS	PP	KPSS
NYMEX Palladium	-2.431	0.182*	-13.455*	0.034
TOCOM Palladium	-2.499	0.221*	-17.596*	0.029
	Period after October 2005			
	Log Level		First differences	
	PP	KPSS	PP	KPSS
NYMEX Palladium	-2.122	0.399*	-16.729*	0.026
TOCOM Palladium	-2.398	0.396*	-15.258*	0.024

Notes: * denotes significance at 5%. All the unit root tests for the level and first differences include constant and trend. The bandwidth for the PP and KPSS tests are identified by Newey-West method (Newey et al., 1994).

The Johansen test requires all the price series analyzed to be integrated in the same order and therefore is preceded by the PP and KPSS unit root tests. Table 2 shows the results of these tests. The null hypothesis of the PP test is that the variable of interest has a unit root whereas the null of the KPSS test is that the variable does not have a unit root. The results for the whole period (shown in Table 2) suggest that these price series were nonstationary in the log level of the U.S. and Japanese palladium futures prices. However, after differencing the price series once, the results indicate that they became stationary. Therefore, both the U.S. and Japanese palladium price series are integrated in the first order and satisfy the necessary conditions for the Johansen test.

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Table 3. Johansen cointegration tests

Period	Dates	H_0: rank=r	Trace test	Max test	Variables
Whole	Oct. 1, 04 - Sept. 29, 06	r=0	62.26*	61.34*	NYMEX
		r<=1	0.93	0.93	TOCOM
Before	Oct. 1, 04 - Sept. 30. 05	r=0	49.19*	39.84*	NYMEX
		r<=1	9.35*	9.35*	TOCOM
After	Oct. 3, 05 - Sept. 29, 06	r=0	20.26*	15.89*	NYMEX
		r<=1	9.16	9.16	TOCOM

Note: * represents significance at 5% level.

The results of the Johansen test conducted for the whole period are illustrated in Table 3. Both the trace and maximum eigenvalue tests indicated only one cointegrating vector between the U.S. and Japanese palladium futures markets. Therefore, the U.S. and Japanese palladium futures markets are cointegrated. However, as seen in Table 1, the U.S. and Japanese palladium prices were not cointegrated when the break dummy was endogenized in the test model. Therefore, by comparing the results of the CS and Johansen cointegration tests, we find that the break on October 1, 2005 changed the cointegration relationship between the U.S. and Japanese palladium futures markets. To verify that the price relationship between the U.S. and Japanese palladium markets changed after the new vehicle emission-control law took effect, we further tested the cointegration relationships for the periods before and after October 1, 2005.

Before performing the Johansen test for the periods before and after October 1, 2005, we conducted the PP and KPSS unit root tests on the U.S. and Japanese palladium futures prices for both periods. As Table 2 illustrates, the unit root tests suggested that the U.S. and Japanese palladium price series were integrated in the same order for both time periods. Given this finding, we further tested the cointegration relationships between the U.S. and Japanese palladium futures markets for each period. These results, provided in Table 3, indicate that the U.S. and Japanese palladium futures markets were not cointegrated during the period before October 2005 but were cointegrated after October 2005. However, the result of Table 3 for the period before October 2005 indicates that the VAR matrix is full rank, which might be implying that all variables are stationary. This contradicts with the results of the unit root tests presented in Table 2. This could be due to the price series being near stationary but we can argue that this contradicting result is indicating the effects of the break on the cointegration relationships.

Table 4. Granger causality test

	Granger Causality test	Chi-sq test	Lag Order (k+d)
Whole	NYMEX $\not\rightarrow$ TOCOM	143.87*	4
	TOCOM $\not\rightarrow$ NYMEX	3.24*	
Before	NYMEX $\not\rightarrow$ TOCOM	73.63*	5
	TOCOM $\not\rightarrow$ NYMEX	1.61	
After	NYMEX $\not\rightarrow$ TOCOM	67.51*	4
	TOCOM $\not\rightarrow$ NYMEX	2.42*	

Note: * represents significance at 5% level. $\not\rightarrow$ denotes the variable does not Granger cause the other.

We also performed the Granger causality test to see if the short-run price relationships between the U.S. and Japanese palladium futures markets changed after October 2005. As seen in Table 4, we find that the direction of the price information flow has changed after October 2005. For the period before October 2005, the short-run information flow was a one-way direction from the U.S. to Japanese market but for the period after October 2005, the short-run causality became both way directions. This result might be implying that the demand on palladium increased in Japan due to the issue of the new Japanese vehicle emission-control law and we expect that this increase in demand made the Japanese palladium futures market to become more active causing the price information flow also from Japan to the U.S.

The results in Tables 3 and 4 imply that the long-run and short-run price linkages between the U.S. and Japanese palladium futures markets changed after the new vehicle emission-control law was enacted in Japan. This suggests that Japan's domestic policy on vehicle emission-control, enacted in October 2005, had an effect on the market linkage between the U.S. and Japanese palladium futures markets. We believe that this is related to the increase in the price information flow in the Japanese palladium futures market after the issue of the new law and this change in the Japanese market affected the international palladium futures market.

5. Conclusion

In this paper, we examined whether a domestic vehicle emission-control law enacted in Japan in October 2005 affected the international palladium futures market. We tested the law's effects on the long-run and short-run price linkages between the U.S. and Japanese palladium futures markets. Our results showed that the market linkage for the U.S. and Japanese palladium markets was affected by the break in October 2005, and the long-run price linkage and causality of the short-run price information flow were different for the periods before and after October 2005. This result indicates that Japan's 2005 long-term regulation of vehicle emission levels had an influence on the international palladium futures market.

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