The Relationship between Spot Exchange Rate and Implied Exchange Rate Derived from NTD/USD Gold Futures on the TAIFEX

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Abstract

In this study, we investigate the relationship between spot and implied futures exchange rate between U.S. Dollar (USD) and New Taiwan Dollar (NTD). We are the first to discuss such relationship because only the characteristics of NTD Gold Futures (TGF) and USD Gold Futures (GDF) traded on the Taiwan Futures Exchange (TAIFEX) allow us to do so. Thus, we not only contribute on understanding of price discovery in financial markets, but also on market efficiency and market mechanism through the unique futures contracts on the TAIFEX.

The unit root tests confirm that spot exchange rate and implied exchange rate are integrated of order 1, i.e. I(1). Furthermore, Johansen cointegration test, Granger causality test, and Vector Error Correction Model (VECM) shows that spot exchange rate more influences implied exchange rate. We calculate the information shares (Hasbrouck, 1995) for spot exchange rate and implied exchange rate, and the results show the information shares for spot exchange rate are higher than those for implied exchange rate. Moreover, the multivariate regression analysis demonstrates similar results. The implications of our empirical results indicate the importance of market makers in less mature markets.

Keywords: Spot Exchange Rate; Implied Exchange Rate; Price Discovery; Taiwan Futures Exchange; Microstructure.

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I. Introduction

Price discovery refers to the process of information reflected in transactions (Black ,1976; Grossman, 1989). A market is regarded to have better function for price discovery if the market contains more information to pass to another market. On the other hand, price discovery represents the adjustment speed for information (Covrig and Melvin, 2005). For example, when an asset or some relevant assets are traded in more than one market, a market has better price discovery function if the reaction to information in the market is always leading the other markets. Most traditional studies on price discovery focuse on the relationships between the different markets with the same or similar assets (e.g. Stoll and Whaley, 1990; Chan, 1992; Chu et al, 1999; Covrig et al., 2004).

Garbade and Silber (1979) pioneer in the studies of price discovery on stock markets. They find that the New York Stock Exchange (NYSE) is the leading market than other regional stock exchanges in the U.S. Follow-up studies conclude that the market with larger volume (Harris et al., 1995), the market having closer economic relations, language, and geographical location (Su and Chong, 2007) to the listed stocks, and the market having closer time zone to the listed stocks is likely to immediate response in price (Lieberman, et al. 1999; Lim, 2008).

For stock index commodities, most empirical evidence (e.g. Tse, 1999; Roope and Zurbruegg, 2002; Hsieh, 2004; Chan et al., 2004) supports the cost hypothesis (Chu et al., 1999). Although cost is also important in foreign currency markets (Ramadorai, 2008), empirical results are quite different with those for stock indexes. Some findings point out that the spot markets lead futures markets (e.g. Cabrera, et al., 2009; Poskitt, 2009; Chen, and Gau, 2010), and other studies suggest that the different market microstructure factors (e.g. market transparency) affect the functions of spots and futures markets in price discovery (e.g. Tse, et al, 2006; Rosenberg, and Traub, 2007). In particular, Park (2001) explore the interaction between foreign currency spot and futures markets in South Korea by dividing the sample period into *ex ante* and *ex post* the Asian financial crisis. He concludes that the spot market leads the futures market before the Asian financial crisis, but the futures market leads the spot market after the crisis because the Korean government takes a free-floating exchange rate system, and reduces the limitations of the futures market after the Asian financial crisis. In addition, Tse et al (2006) summarize that open outcry on floor lags electronic retail on-line spot market and GLOBEX FX futures markets because traders prefer fast and anonymous electronic transactions.

In this study, we investigate the relationship between spot and implied futures exchange rate between U.S. Dollar (USD) and New Taiwan Dollar (NTD). We are the first to discuss such relationship because only the characteristics of NTD Gold Futures (TGF) and USD Gold Futures (GDF) traded on the Taiwan Futures Exchange (TAIFEX) allow us to do so. Thus, we not only contribute on understanding of price discovery in financial markets, but also on market efficiency and market mechanism through the unique futures contracts on the TAIFEX. Taiwanese foreign currency spot markets are established in 1978. However, many derivatives of foreign currency, including futures, options, and Non-Delivery Forwards (NDF), are not allowed in Taiwan. However, the TAIFEX launched GDF in the March of 2006 and TGF in the January of 2008. The two futures contracts, GDF and TGF, are almost identical except in traded currency. As a result, an investor may buy (sell) TGF and sell (buy) GDF at the same time if she would like to long (short) USD against NTD.

The remainder of the paper is organized as follows: section II presents the institutional background and the data from TAIFEX, section III introduces our methodology, section IV presents our empirical findings, and section V summarizes the results and concludes.

II. Institutional background and the data from TAIFEX

In the 11 years since its establishment in 1998, the Taiwan Futures Exchange (TAIFEX) has become a high-volume exchange in the derivatives market. As of the end of 2009, stock index contracts, interest contracts, and gold futures and options contracts are all traded on the TAIFEX. The number of trading accounts has grown from 75,035 in July 1998 to 1,268,199 at the end of 2009. In 2009, the yearly volume is 136,719,777 contracts, making TAIFEX the 18th largest derivatives exchange, according to the Futures Industry Association (FIA). The trading hours for TAIFEX are 8:45 a.m. to 1:45 p.m.

In particular, the TAIFEX launched Gold Futures (ticker symbol: GDF), which is traded in USD in March, 2008. Furthermore, the TAIFEX launched NT Dollar Gold Futures (ticker symbol: TGF), which is traded in New Taiwan Dollar (NTD) in January, 2008. In particular, there are designated market makers in GDF and TGF markets. In addition, GDF and TGF are exactly identical in trading hours, delivery months, daily settlement price, daily price limit, last trading day, final settlement day, final settlement price, and cash settlement. As Table 1 shows, GDF and TGF are only different in traded currency, contract size, and purity of gold.

Table 1 Contract Specifications of NTD Gold Futures (TGF) and USD Gold Futures (GDF)

	NTD Gold Futures	USD Gold Futures
Underlying	Gold with a purity of 0.9999	Gold with a purity of 0.995
Ticker Symbol	TGF	GDF
Trading Hours	・8 : 45 AM - 1 : 45 PM ・Trading days conform to regular exchange trading days	・8 : 45 AM - 1 : 45 PM ・Trading days conform to regular exchange trading days
Contract Size	10 Taiwan taels (100 Taiwan cians or 375 grams)	100 troy ounces
Delivery Months	6 consecutive even months (Feb., Apr., Jun., Aug., Oct., Dec.)	6 consecutive even months (Feb., Apr., Jun., Aug., Oct., Dec.)
Daily Price Limit	+/-15% of previous day's settlement price	+/-15% of previous day's settlement price
Last Trading Day	Third-to-last business day of the delivery month; the following business day is the starting day of trading for new contracts.	Third-to-last business day of the delivery month; the following business day is the starting day of trading for new contracts.
Final Settlement Day	The first business day following the last trading day	The first business day following the last trading day
Final Settlement Price	The final settlement price of the Contracts shall be set on the basis of the London Gold AM Fixing price announced by London Gold Market Fixing Limited on the same calendar day as the last trading day and the interbank closing foreign exchange rate for NT dollars to US dollars announced by Taipei Forex Inc. on the last trading day, after conversion for weight and fineness. The formula for its calculation is as follows: (London Gold AM Fixing ÷ 31.1035 × 3.75 × 0.9999 ÷ 0.995)× NTD/USD closing rate If the London Gold AM Fixing is not available before the settlement operation on the final settlement day, the final settlement price will be determined according to TAIFEX's Guidelines for Determining the NT Dollar Denominated Gold Futures Contract and Gold Options Contract Final Settlement Price.	The final settlement price will be based upon the London Gold AM Fixing as released by The London Gold Market Fixing Limited on the last trading day. In the event that the London Gold AM Fixing is not available, the final settlement price will be determined by the exchange in accordance with the "Guidelines for the Final Settlement Price of Gold Futures"
Settlement	Cash settlement.	Cash settlement.

In this study, we analyze the relationship of the implied NTD/USD futures exchange rate derived from GDF and TGF and the spot exchange rate. The study period is from January 5, 2009 through July 15, 2009, a total of 131 trading days. We divide a trading into 35 5-minute and 11 15-minute intervals, respectively. We calculate the spot exchange rate by taking the midpoint of bid and offer prices at the end of each interval from the Bloomberg database, quoted by Taipei Foreign Exchange Brokerage (TFEB), the largest foreign exchange brokerage in Taiwan. Implied futures exchange rates are calculated by taking the midpoint of bid and offer prices at the end of each interval from GDF and TGF on the TAIFEX. Due to the differences between GDF and TGF in purity of gold and contract size, implied exchange rate (P_t^{IE}) is:

$$P_t^{IE} = \frac{P_t^{NTD}}{P_t^{USD}} \times \frac{31.1035}{3.75} \times \frac{0.995}{0.9999}. \tag{1}$$

where P_t^{NTD} and P_t^{USD} are the midpoint of bid and ask prices for TGF and GDF at the end of interval t.

The TFEB's morning trading hours are from 9:00 a.m. through 12:00 a.m. After breaking hours from 12:00 a.m. through 2:00 p.m., the afternoon's trading hours start, and end at 4:00 p.m. However, the TAIFEX trades from 8:45 a.m. through 1:45 p.m. without any breaking. Due to spot exchange rate market and the gold futures market trading time differences, we select the two markets overlap trading time: 9:05 to 11:55 to avoid the possible opening (closing) time effects. In addition, we rollover to the nearby gold futures contract 5 trading days before expiration to avoid the maturity effects.

III. Methodology and Empirical results

To begin with, we apply the unit root tests to verify whether the spot exchange rate (P_t^E) and implied exchange rate (P_t^{IE}) are stationary, and we analyze the long-term relationship in equilibrium between P_t^E and P_t^{IE} by Johansen cointegration test. We apply the Vector Error Correction Model (VECM) to explore the lead-lag relationship, and we decompose the variance to analyze the source of predicted error for P_t^E and P_t^{IE} . In particular, we apply the Information Share Model (Hasbrouck, 1995) to explore the contribution of price discovery from P_t^E and P_t^{IE} . Finally, we investigate the effects of market variables (i.e. liquidity and volatility) on ratios of information shares.

3.1 Basic statistics

Panel A of Table 2 shows the basic statistics for $\ln(P_t^E)$ and $\ln(P_t^{IE})$, and panel B shows those for $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$. As Table 1 shows, $\ln(P_t^{IE})$ is more volatile than $\ln(P_t^E)$, and they are both right skewed and platykurtic. In addition, the J-B test rejects the hypothesis of normal distribution for both $\ln(P_t^E)$ and $\ln(P_t^{IE})$ at the 1% significance level. For $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$, panel B of Table 2 shows that both $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$ are leptokurtic, and the J-B test also rejects the hypothesis of normal distribution for both $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$. However, $\Delta\ln(P_t^E)$ is left skewed but $\Delta\ln(P_t^{IE})$ is right skewed.

Table 2 Basic statics

Panel A $\ln(P_t^E)$ and $\ln(P_t^{IE})$

	5-minute interval		15-minute interval	
	$\ln(P_t^E)$	$\ln(P_t^{IE})$	$\ln(P_t^E)$	$\ln(P_t^{IE})$
No. of obs.	3480	3480	1320	1320
Mean	3.514	3.507	3.514	3.507
S.D.	0.021	0.213	0.021	0.021
Max.	3.562	3.554	3.561	3.553
Min.	3.475	3.465	3.475	3.465
Coef. of Skewness	0.402	0.100	0.405	0.094
Coef. of Kurtosis	2.209	2.062	2.243	2.078
J-B test	184.331***	133.284***	67.555***	48.713***

Panel B $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$

	5-minute interval		15-minute interval	
	$\Delta\ln(P_t^E)$	$\Delta\ln(P_t^{IE})$	$\Delta\ln(P_t^E)$	$\Delta\ln(P_t^{IE})$
No. of obs.	3479	3479	1319	1319
Mean	-0.017 ^{a}	0.208 ^{a}	-0.064 ^{a}	0.293 ^{a}
S.D.	0.072	0.086	0.120	0.135
Max.	1.055	1.159	1.001	1.189
Min.	-1.303	-0.781	-1.315	-0.801
Coef. of Skewness	-1.346	1.694	-0.410	1.680
Coef. of Kurtosis	91.656	37.992	35.585	20.979
J-B test	1140406***	178591.9***	58391.58***	18385.96***

Notes:

1. The J-B test (Jarque and Bera, 1987) is a goodness-of-fit test of whether sample data have the skewness and kurtosis matching a normal distribution.

2. ^{a} denotes for multiplying by 10^{-3}.

3. *** denotes for significance at the 1% level.

3.2 Unit root tests and cointegration tests

We use the Augmented Dickey and Fuller (ADF) test and Phillips and Perron (PP) test to examine whether the series are stationary to avoid the possibility of spurious regressions. As panel A of Table 3 shows, both ADF and PP tests do not reject the null hypothesis for $\ln(P_t^E)$ and $\ln(P_t^{IE})$ at the 10% significance level. However, $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$ are cointegrated because both ADF and PP tests reject the null hypothesis for them at the 1% significance level. Thus, $\ln(P_t^E)$ and $\ln(P_t^{IE})$ are integrated of order 1, i.e. I(1).

Table 3 Unit root tests

Panel A $\ln(P_t^E)$ and $\ln(P_t^{IE})$

		5-minute interval		15-minute interval	
		$\ln(P_t^E)$	$\ln(P_t^{IE})$	$\ln(P_t^E)$	$\ln(P_t^{IE})$
Intercept	ADF	-1.267	-1.250	-1.024	-1.437
		(23)	(1)	(0)	(14)
	PP	-1.029	-1.326	-1.117	-1.242
		(8)	(6)	(11)	(3)
Trend and intercept	ADF	-2.213	-2.605	-2.240	-2.428
		(0)	(1)	(0)	(14)
	PP	-2.222	-2.749	-2.270	-2.624
		(7)	(7)	(11)	(0)
None	ADF	-0.019	0.085	-0.026	-0.157
		(0)	(1)	(0)	(14)
	PP	-0.019	0.140	-0.025	0.072
		(8)	(6)	(11)	(2)

Panel B $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$

		5-minute interval		15-minute interval	
		$\Delta\ln(P_t^E)$	$\Delta\ln(P_t^{IE})$	$\Delta\ln(P_t^E)$	$\Delta\ln(P_t^{IE})$
Intercept	ADF	-10.322***	-61.356***	-10.994***	-7.465***
		(22)	(0)	(7)	(13)
	PP	-58.595***	-61.363***	-36.867***	-36.895***
		(8)	(5)	(11)	(3)
Trend and intercept	ADF	-10.388***	-61.395***	-11.058***	-7.518***
		(22)	(0)	(7)	(13)***
	PP	-58.613***	-61.412***	-36.889***	-36.962
		(7)	(6)	(11)	(0)
None	ADF	-10.324***	-61.364***	-10.998***	-7.468***
		(22)	(0)	(7)	(13)
	PP	-58.603***	-61.372***	-36.879***	-36.909***
		(8)	(5)	(11)	(3)

Notes:

1. The models for ADF unit root test are:

(1) Intercept: $\Delta y_t = \alpha_0 + \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t$.

(2) Trend and intercept： $\Delta y_t = \alpha_0 + \gamma y_{t-1} + \alpha_2 t + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t$.

(3) None: $\Delta y_t = \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t$.

where y_t is the time series, t is the trend , and ε_t is the residual.

The null hypothesis for ADF test is $H_0 : \gamma = 0$.

2. The models for PP unit root tests are non-parametric:

(1) Type 1: $y_t = \tilde{\mu} + \tilde{\beta}(t - T/2) + \tilde{\gamma}\, \mathrm{y}_{t-1} + \tilde{\varepsilon}_t$.

(2) Type 2: $y_t = \mu^* + \gamma^* y_{t-1} + \varepsilon_t^*$.

The null hypotheses are $H_0 : \tilde{\gamma} = 1$ and $H_0 : \gamma^* = 1$, respectively. The test statistics are

$Z(t_{\tilde{a}}) = (S_u / S_{T1}) t_{\tilde{a}} - (T^3 / 4\sqrt{3} D_y^{1/2} S_{T1})(S_{T1}^2 - S_u)$, and

$Z(t_a^*) = (S_u / S_{T1}) t_a^* - (1/2 S_{T1})(S_{T1}^2 - S_u^2)\left[T^{-2} \sum (y_{t-1} - \bar{y}_{-1})^2\right]^{(-1/2)}$.

where $t_{\tilde{a}}$ and t_a^* are t statics, and T is the number of observations. S_u^2 is the estimate for δ_u^2, where $\delta_u^2 = \lim_{T\to\infty} T^{-1} \sum_{t=1}^{T} E(u_t^2)$, and S_{T1}^2 is the estimate for δ^2.

$\delta^2 = \lim_{T\to\infty} T^{-1} E(S_T^2)$, $S_T = \sum_{t=1}^{T} u_t$, $D_y = \det(y' y)$.

3. The number in parentheses denotes the lag length, determined via the Akaike's Information Criterion (AIC) for ADF and Newey-West Bandwidth for PP.

4. *** denotes for significance at the 1% level.

In order to determine whether there is a cointegration relationship between $\ln(P_t^E)$ and $\ln(P_t^{IE})$, we perform the Johansen (1988) cointegration test, and the results are reported in Table 4. Both the maximum eigenvalue and the trace statistics indicate that there is one cointegration vector because we reject the null hypothesis for r≦0 in λ_{trace}, and we also the null hypothesis for r＝0 in $\lambda_{\max}$, at the 5% significance level. Moreover, we can not reject the null hypothesis for r≦1 in λ_{trace} and r＝1 in $\lambda_{\max}$, at the 10% significance level. Hence, $\ln(P_t^E)$ and $\ln(P_t^{IE})$ are cointegrated.

Table 4 Johansen test for cointegration

			$\ln(P_t^E)-\ln(P_t^{IE})$			
Panel A 5-minute interval						
		λ_{trace}			$\lambda_{\max}$	
Eigenvalue	Null hypothesis	Trace Statistic	Critical value at the 5% level	Null hypothesis	Trace Statistic	Critical value at the 5% level
0.006	r≦0	19.448**	12.321	r=0	19.448**	11.225
0.133 [a]	r≦1	0.461 [b]	4.130	r=1	0.461 [b]	4.130
Panel B 15-minute interval						
		λ_{trace}			$\lambda_{\max}$	
Eigenvalue	Null hypothesis	Trace Statistic	Critical value at the 5% level	Null hypothesis	Trace Statistic	Critical value at the 5% level
0.014	r≦0	18.838**	12.321	r=0	18.838**	11.225
0.209 [a]	r≦1	0.275 [b]	4.130	r=1	0.275 [b]	4.130

Notes:

1. We perform the Johansen (1988) cointegration test:

$$\Delta y_t = \mu_t + \Pi y_{t-1} + D_1 \Delta y_{t-1} + \cdots + D_{p-1} \Delta y_{t-p+1} + \varepsilon_t .$$

where $D_j = -\sum_{s=j+1}^{p} \Phi_s ,\ j = 1,2,\cdots p-1$

$$\Pi = -\Phi(1) = -(I - \Phi_1 - \Phi_2 - \cdots - \Phi_p)$$

where Πy_{t-1} is the error correction term. rank(Π) is to determine the number of cointegration vector in y_t .

(1) There is no cointegration vector in y_t if rank(Π)=0.

(2) y_t is stationary if rank(Π)=k.

(3) There are r cointegration vectors in y_t if rank(Π)=r and $0 < r < k$.

(4) Trace test:

$$H_0 : rank(\Pi) \le r$$

$$H_1 : rank(\Pi) > r$$

Trace static: $\lambda_{trace}(r) = -T \sum_{j=r+1}^{k} \ln(1 - \widehat{\lambda}_j).$

(5) Maximum eigenvalue test:

$$H_0 : rank(\Pi) = r$$

$$H_1 : rank(\Pi) = r + 1$$

Maximum eigenvalue statistic: $\lambda_{\max}(r, r+1) = -T \ln(1 - \widehat{\lambda}_{r+1}).$

λ_i is the estimate of eigenvalue, r is the cointegration vector, T is the number of observations.

2. ** denotes for significance at the 5% level.

3. λ_{trace} and $\lambda_{\max}$ are the statistics for trace test and maximum eigenvalue test, respectively.

4. Critical values are calculated according to MacKinnon-Haug-Michelis(1999).

5. ^{a} denotes for multiplying by 10^{-6}, and ^{b} denotes for multiplying by 10^{-3}.

3.3 Granger causality and Vector Error Correction Model

We conduct Granger causality test to identify the direction of the relationships between $\ln(P_t^E)$ and $\ln(P_t^{IE})$. Different with Roope and Zurbruegg (2002) and Covrig et al. (2004), the results of Table 6 show that there is only a uni-directional Granger causality between $\ln(P_t^E)$ and $\ln(P_t^{IE})$. For both 5-minute and 15-minute intervals, we reject the hypothesis that $\ln(P_t^E)$ does not Granger cause $\ln(P_t^{IE})$ at the 1% significance level, but we do not reject the hypothesis that $\ln(P_t^{IE})$ does not Granger cause $\ln(P_t^E)$ at the 10% significance level.

Table 5 Granger causality test

	5-minute interval		15-minute interval	
Hypothesis	F static	p value	F static	p value
H_0 ： $\ln(P_t^E)$ does not Granger cause $\ln(P_t^{IE})$	14.588***	0.000	12.639***	0.000
H_0 ： $\ln(P_t^{IE})$ does not Granger cause $\ln(P_t^E)$	0.601	0.549	0.113	0.736

Note: *** denotes for significance at the 1% level.

In the previous analysis, we find that $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$ are cointegrated. Thus, we apply Vector Error Correction Model (VECM) to investigate the adjustment relationships between $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$. Table 6 shows the analysis for VECM. We find that $\Delta\ln(P_t^E)$ dominates over $\Delta\ln(P_t^{IE})$ as evidenced by the estimated coefficient of z_{t-1} being significant (insignificant) at the 1% level for $\Delta\ln(P_t^{IE})$ ($\Delta\ln(P_t^E)$), both in 5-minute and 15-minute intervals, and the results are consistent with Cabrera et al. (2009) and Wahab and Lashgari (1993). Furthermore, we find that $\Delta\ln(P_t^E)$ influences $\Delta\ln(P_t^{IE})$ more as evidenced by the estimated coefficients of $\Delta\ln(P_{t-1}^E)$ and $\Delta\ln(P_{t-2}^E)$ being significant at the 5% level for $\Delta\ln(P_t^{IE})$, but the estimated coefficients of $\Delta\ln(P_{t-1}^{IE})$ and $\Delta\ln(P_{t-2}^{IE})$ being insignificant at the 10% level for $\Delta\ln(P_t^E)$. Interestingly, the results for 15-minute interval are quite different, only the estimated coefficient of z_{t-1} (i.e. α_2) is significant at the 1% level because 15-minute is too long for the model.

Table 6 Vector Error Correction Model

Vector Error Correction Model (VECM):

$$\begin{bmatrix}\Delta\ln(P_t^E)\\ \Delta\ln(P_t^{IE})\end{bmatrix}=\begin{bmatrix}\mu_1+\alpha_1 z_{t-1}+\Sigma\beta_{1,i}\Delta\ln(P_{t-i}^E)+\Sigma\gamma_{1,i}\Delta\ln(P_{t-i}^{IE})+\varepsilon_{1t}\\ \mu_2+\alpha_2 z_{t-1}+\Sigma\beta_{2,i}\Delta\ln(P_{t-i}^E)+\Sigma\gamma_{2,i}\Delta\ln(P_{t-i}^{IE})+\varepsilon_{2t}\end{bmatrix}$$

5-minute interval

$z_t=\ln(P_t^E)-1.016\ln(P_t^{IE})+0.155$

	$\Delta\ln(P_t^E)$		$\Delta\ln(P_t^{IE})$	
z_{t-1}	-0.001	(-0.213)	0.030	(4.101) ***
$\Delta\ln(P_{t-1}^E)$	-0.003	(-0.150)	0.084	(3.939) ***
$\Delta\ln(P_{t-2}^E)$	0.018	(0.996)	0.043	(1.989) **
$\Delta\ln(P_{t-1}^{IE})$	0.017	(1.169)	-0.072	(-4.021) ***
$\Delta\ln(P_{t-2}^{IE})$	0.008	(0.560)	-0.028	(-1.545)
Q(10)	8.073		3.332	
Q(20)	13.421		12.650	

15-minute interval

$z_t=\ln(P_t^E)-1.016\ln(P_t^{IE})+0.174$

	$\Delta\ln(P_t^E)$		$\Delta\ln(P_t^{IE})$	
z_{t-1}	-0.005	(-0.326)	0.073	(4.510) ***
$\Delta\ln(P_{t-1}^E)$	-0.026	(-0.816)	0.043	(1.245)
$\Delta\ln(P_{t-2}^E)$	0.017	(0.519)	0.009	(0.248)
$\Delta\ln(P_{t-1}^{IE})$	0.023	(0.848)	-0.033	(-1.080)

$\Delta\ln(P_{t-2}^{IE})$	0.010	(0.339)	0.004	(0.133)
Q(5)	1.594		0.306	
Q(10)	14.516		8.726	

Notes:

1. The value in parentheses denotes for t value.

2. *, **, and *** denote for significance at the 10%, 5%, and 1% level, respectively.

3. Q (n) denotes for Ljung-Box Q static with lag length n.

3.4 Hasbrouck's Information share

The price in the dominant market is the base for adjustment in the lag markets. We follow Hasbrouck (1995) to calculate the information shares for $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$. In particular, we follow Hasbrouck (1995) to decompose the variance of co-factor disturbance of $\Delta\ln(P_t^E)$ and $\Delta\ln(P_t^{IE})$ to calculate the information shares, including the upper bound, the lower bound, and the median because the orders of variables in the matrix influence the results of information shares (Hasbrouck, 1995; Baillie et al., 2002).

As Table 7 shows, the median of information share for $\Delta\ln(P_t^E)$ is 87.131% in 5-minute interval. However, it is only 12.869% for $\Delta\ln(P_t^{IE})$. Thus, $\Delta\ln(P_t^E)$ contributes much more than $\Delta\ln(P_t^{IE})$ in price discovery (Chen and Gau, 2010). Interestingly, the median of information share for $\Delta\ln(P_t^E)$ falls to 83.075% in 15-minute interval, and it rises to 16.925% for $\Delta\ln(P_t^{IE})$. Although it is consistent with Hasbrouck (1995), i.e. the measure of comovement is more related in longer interval, $\Delta\ln(P_t^E)$ still dominates over $\Delta\ln(P_t^{IE})$ in 15-minute interval.

Table 7 Hasbrouck's information share

	$\Delta\ln(P_t^E)$		$\Delta\ln(P_t^{IE})$	
	5-minute	15-minute	5-minute	15-minute
Upper	99.762%	99.549%	25.500%	33.400%
Lower	74.500%	66.600%	0.238%	0.451%
Median	87.131%	83.075%	12.869%	16.925%

3.5 What enhances/weakens price discovery in a market?

In this study, we investigate the price discovery in exchange rate between NTD and USD, and implied exchange rate derived from TGF and GDF, which are both gold futures but in NTD and USD, respectively. To discuss what affects price discovery, we divide the whole sample into two groups according to daily accumulated spread, volatility, and volume[2] (Chen and Gau, 2010), respectively. We then calculate t-stat between the two groups (i.e. high versus low) to

[2] Daily accumulated spreads are the sum of 5-minute interval percentage spreads during the sample period. In addition, we apply GARCH (1,1) to calculate daily volatility. The results are available from the authors upon request.

find whether they are significantly different.

To this end, we calculate the daily ratio of information shares between implied exchange rate and spot exchange rate, and take the natural logarithm of the ratio. That is, $\ln\left(IS_{im,i}/IS_{s,i}\right)$, and $IS_{im,j}$ and $IS_{s,j}$ are the daily information share of implied exchange rate and spot exchange rate, respectively. Table 8 shows the results of the univariate analysis. We find that the mean of $IS_{im,j}$ of the high group in accumulated spread of GDF market is significantly lower than that of low group at the 10% level, and it indicates the price discovery is stronger when spreads are narrower, i.e. the market is more liquid. The phenomenon for high/low groups in accumulated spread of TGF market, however, is insignificant. We conjecture it is due to the difference between TGF and GDF in volume[3]. Thus, we conclude the importance of market makers on price discovery in small volume market because narrower accumulated spread in GDF market implies more active quote for market makers. Consistent with Chen and Gau (2010), the results show more information share in implied exchange rate for high spot volatility as evidenced by the mean of high group in spot volatility being significantly larger than that of low group at the 1% level.

Table 8 Univariate analysis for Hasbrouck's information share between high/low groups in accumulated spread, volatility, and volume

	Accumulated spread				Volatility				Volume			
	TGF		GDF		P_t^E		P_t^{IE}		TGF		GDF	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Mean	-1.111	-1.196	-0.536	-1.770	-2.097	-0.209	-1.069	-1.238	-1.289	-1.017	-1.392	-0.682
S.D.	3.088	4.230	3.465	3.828	3.084	4.013	3.164	4.172	4.126	3.220	3.398	4.208
t-stat	0.123		1.820*		2.841***		0.246		0.396		0.980	

Notes: *, **, and *** denote for significance at the 10%, 5%, and 1% level, respectively.

After the univariate analysis, we perform the multivariate regression analysis between information share, accumulated spread, volume, and volatility. The linear regression is,

$$\ln(IS_{im}/IS_s) = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 \ln(Volatility_s) + \varepsilon. \quad (1)$$

where $IS_{im,i}$ and $IS_{s,i}$ are the daily medians of information shares for implied exchange rate and spot exchange rate, respectively. β_0 is the constant term, and D_1, D_2, D_3, D_4, and D_5 are dummy variables. $D_1 = 0$ if the daily accumulated spread of TGF is lower the median of the whole sample period, and $D_1 = 1$ otherwise. $D_2 = 0$ if the daily accumulated spread of GDF is lower the median of the whole sample period, and $D_2 = 1$ otherwise. $D_3 = 0$ if the daily volume of TGF is lower the median of the whole sample period, and $D_3 = 1$ otherwise. $D_4 = 0$ if the daily volume of GDF is lower the median of the whole sample period, and

[3] In 2009, the volume of TGF (GDF) is 3,342,838 (205) contracts.

$D_4 = 1$ otherwise. $D_5 = 0$ if the daily volume of spot is lower the median of the whole sample period, and $D_5 = 1$ otherwise. *Volatility* [4] is the daily realized volatility of spot exchange rate, which is obtained by summing square of 5-minute return.

Table 9 demonstrates the results of the regression analysis. Like the univariate analysis, we find negative relationship between $\ln(IS_{im} / IS_s)$ and D_2 as evidenced by $\hat{\beta}_2$ being negative at the 10% significance level. In addition, we find positive relationship between $\ln(IS_{im} / IS_s)$ and *Volatility* as evidenced by $\hat{\beta}_6$ being positive at the 1% significance level. Interestingly, we find no significant evidence for the relationship between $\ln(IS_{im} / IS_s)$ and volume because $\hat{\beta}_3$, $\hat{\beta}_4$, and $\hat{\beta}_5$ are all insignificant at the 10% level. Inconsistent with Chakravarty et al. (2004), it is not surprising because both GDF and TGF are traded in new markets. On the other hand, the spot exchange market has a long history. Furthermore, we find insignificant positive relationships between $\ln(IS_{im} / IS_s)$ and D_3 (D_4). The relationship between $\ln(IS_{im} / IS_s)$ and D_5, however, is insignificantly negative. We thus conjecture the relationships will be more significant when the TGF and GDF markets are more mature.

Table 9 Regression analysis for Hasbrouck's information share

$$\ln(IS_{im} / IS_s) = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 \ln(Volatility_s) + \varepsilon.$$

	Estimate	S.D.	t-stat
$\hat{\beta}_0$	9.119**	3.579	2.548
$\hat{\beta}_1$	-0.083	0.695	-0.119
$\hat{\beta}_2$	-1.428*	0.732	-1.950
$\hat{\beta}_3$	0.477	0.710	0.671
$\hat{\beta}_4$	0.597	0.712	0.839
$\hat{\beta}_5$	-1.156	0.716	-1.615
$\hat{\beta}_6$	1.575***	0.564	2.793
Adjusted R^2			0.064087

Notes: *, * and *** denote for significance at the 10%, 5%, and 1% level, respectively.

IV. Conclusions

In this study, we investigate the relationship between spot and implied futures exchange rate between USD and NTD. We are the first to discuss such relationship because only the characteristics TGF and GDF traded on the TAIFEX allow us to do so. Thus, we not only

[4] We also estimate the range-based volatility and volatility by GARCH (1,1). However, the results show these volatilities are highly linear correlated to realized volatility. The results are available from the authors upon request.

contribute on understanding of price discovery in financial markets, but also on market efficiency and market mechanism through the unique futures contracts on the TAIFEX.

To begin with, the unit root tests confirm that spot exchange rate and implied exchange rate are integrated of order 1, i.e. I(1). Furthermore, Johansen cointegration test verifies long-term relationship in equilibrium between spot exchange rate and implied exchange rate. Granger causality test identifies there is only a uni-directional Granger causality between spot exchange rate and implied exchange rate, i.e. spot exchange rate Granger causes implied exchange rate. VECM shows that spot exchange rate more influences implied exchange rate. We follow Hasbrouck (1995) to calculate the information shares for spot exchange rate and implied exchange rate, and the results show the information shares for spot exchange rate are higher than those for implied exchange rate.

We find that the mean of information share of the high group in accumulated spread of GDF market is significantly lower than that of low group, and it indicates the price discovery is stronger when spreads are narrower, i.e. the market is more liquid. The phenomenon for high/low groups in accumulated spread of TGF market, however, is insignificant. We conjecture it is due to the difference between TGF and GDF in volume. Thus, we conclude the importance of market makers on price discovery in small volume market because narrower accumulated spread in GDF market implies more active quote for market makers. Consistent with Chen and Gau (2010), the results show more information share in implied exchange rate for high spot volatility.

After the univariate analysis, we perform the multivariate regression analysis between information share, accumulated spread, volume, and volatility. In regression analysis, we also find negative relationship between information share of implied exchange rate and accumulated spread of GDF. In addition, we find positive relationship between information share of implied exchange rate and volatility. The implications of our empirical results indicate the importance of market makers in less mature markets.

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