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Empirical Properties of the Indonesian Rupiah: Testing for Structural Breaks, Unit Roots, and White Noise

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This paper shows that the real exchange rate of the Indonesian rupiah (against the US dollar) during the period January 1979-July 1995 did not follow a random walk process. Both the unit-root and the white-noise properties of the random walk are rejected. These findings are consistent with active sterilization measures by the central bank in ensuring gradual depreciations of nominal rupiah. In turn, the designed weakening of nominal rupiah limited the consequences of faster domestic inflations to rupiah real exchange rate.

I. Introduction

This paper discusses the statistical properties of the Indonesian rupiah real exchanges rate from January 1979 to July 1995, roughly two years before the break of financial crisis in Indonesia. The question asked is whether the rupiah can be characterized as a random walk. A random walk is a process with two properties: (i) a unit root; and (ii) white-noise error term. Often, however, the literature has concluded that a series follows a random walk because the null hypothesis of a unit root is not rejected, or because the error term is white-noise. No recent study, however, has tested both properties for the rupiah. The test results of these two properties of the random walk are critical before taking any steps to understand such fundamental issues as the determinant factors for the rupiah's movements, or Indonesia's exchange rate policy. Failure to conduct proper tests of these two properties can lead to wrong conclusions regarding the statistical properties of the rupiah, as well as to the construction of wrong theoretical models and to misleading empirical tests.

This paper followed a sequential testing procedure to test for a random walk. First we tested the Augmented Dickey Fuller unit-root test. The result showed that the rupiah real exchange rate followed a random walk with drift, confirming the findings of Baharumshah and Ariff (1997) and Montiel (1997) found that the nominal rupiah exchange rate (*vis-a-vis* the Us dollar) for the period of 1974: Q1 to 1993:Q4 was nonstationary. By conducting the standard Augmented Dickey-Fuller (ADF) and the Phillips-Perron unit-root tests, their findings showed that the Indonesian rupiah nominal exchanges rate is integrated of order 1 - I(1). Likewise, the same testing procedure for the period of 1960-1994 with annual data led Montiel (1997) to conclude that the

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rupiah real effective exchange rate was nonstationary.[1]

Second we tested whether the error term is white-noise. For this purpose, we applied two tests: the Cochrane Variance Ratio (1988) and the Lo and MacKinlay (1989) heteroscedasticity-consistent variance. Both tests rejected the null hypothesis of White-Noise error term.

The rejection of the white-noise null hypothesis indicates a relatively strong presence of the stationary component in the rupiah real exchange rate series. However given the possibility of a single or multiple structural breaks in the series, the low power of the standard unit-root tests employed earlier may not be sensitive enough to differentiate a stationary series from that of a non-stationary series.[2] To address the issue, the third test conducted in the paper is the Banerjee, Lumsdaine and Stock (1992) recursive and rolling tests. These tests extend the standard Dickey-Fuller t test statistics. The rolling test results rejected the unit-root null hypothesis for the rupiah real exchange rate.

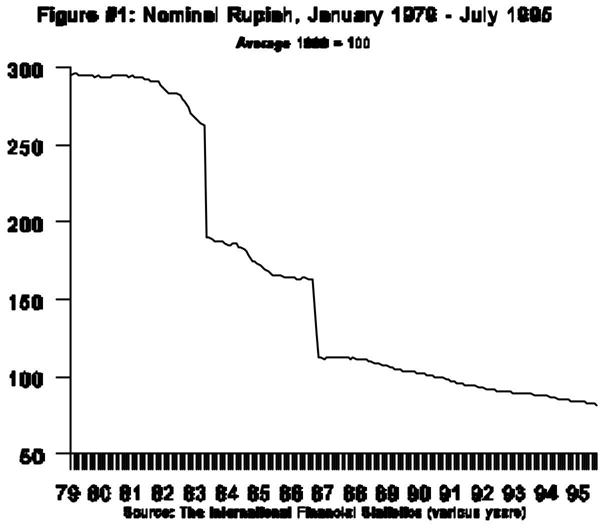
The rejections of both unit-root and white noise null hypothesis lead to the rejection of the random walk process for the rupiah real exchange rate. These results confirm the stylized facts in the economy. An active government role in maintaining the stability of the rupiah real exchange rate through frequent sterilization measures supports the test results. The rest of the paper is as follows. The second section covers briefly the relevant stylized facts. The third section discusses the tests. Brief analysis on the sterilization measures will be presented in Section IV. The paper ends with some concluding remarks (Section V).

II. Brief Stylized Facts

By devaluing the rupiah (with respect to the US$) in November 1978, the government of Indonesia officially abandoned a seven-year period of fixed exchange rate - US$1=Rp 415. The currency was left to float under a managed floating regime against a basket of major world currencies until late 1997. But it is clear that the US dollar has been the major currency in that basket. Frankel and Wei (1993) have indicated that from the late 1970s to 1992, as much as 97% of the rupiah's fluctuations were explained by fluctuations in the U.S. dollar. In fact, only during 1985-1986 the Japanese yen played a more influential role.

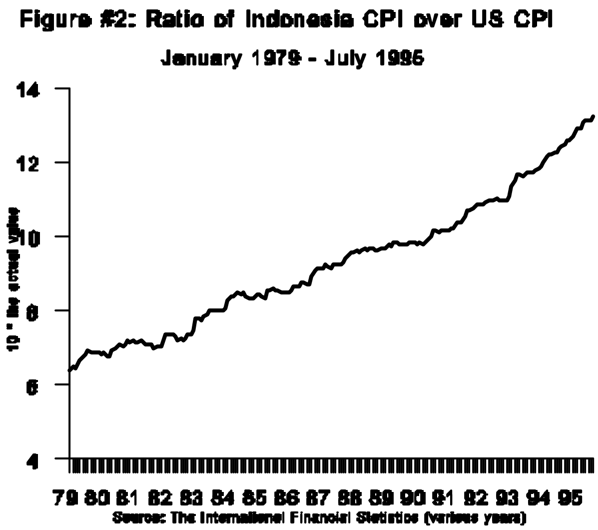
With the exception of the two devaluations in March 1983 and September 1986, the nominal rupiah was very stable during the period of 1979 to mid 1995 (Figure 1). In fact, since 1986, the currency has been gradually depreciating with respect to US$ at an annual average rate of 3-5%. The gradual depreciation of the nominal rupiah offset faster domestic inflation and ensured a relatively stable rupiah real exchange rate, particularly since 1987 (Figures 2 and 3).

1. Montiel acknowledges that given his study's small sample size, the test results may not be robust.
2. The Cochrane Variance ratio test is often considered to be an alternative unit-root test (see Maddala and Kim (1998), Section 3.8).



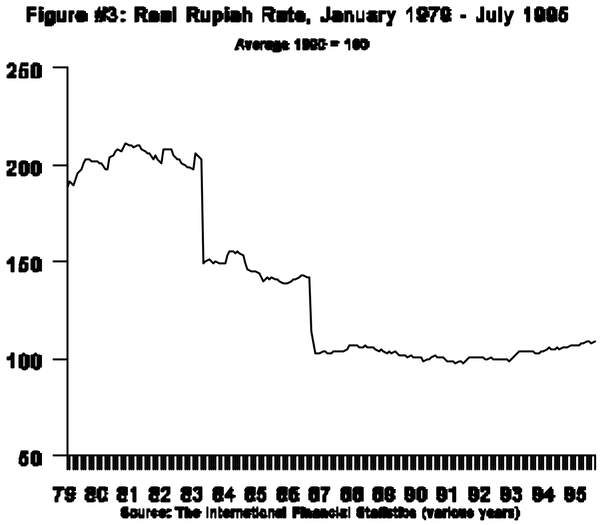
Source: The International Financial Statistics (various years)

Figure 1 Nominal Rupiah, January 1979 - July 1995



Source: The International Financial Statistics (various years)

Figure 2 Ratio of Indonesia CPI over US CPI, January 1979 - July 1995



Source: The International Financial Statistics (various years)

Figure 3 Real Rupiah Rate, January 1979 - July 1995

III. Sequential Testing

The period covered in the analysis is January 1979 to July 1995 (monthly data). The starting point, January 1979, is chosen because prior to it, the nominal rupiah had pegged to the US dollar for seven years. The source is the International Financial Statistics of the International Monetary Fund (various years). The rupiah real exchange rate is constructed as:

$$REX_{\frac{US\$}{Rp}} = NEX_{\frac{US\$}{Rp}} \times \left[\frac{CPI_{Ind}}{CPI_{US}}\right], \tag{1}$$

where:
- REX is the real exchange rate. An increase in REX level implies an appreciation in the real rupiah with respect to the US dollar,
- NEX is the nominal rupiah exchange rate,
- CPI_{Ind} is the consumer price index for Indonesia,
- CPI_{US} is the US consumer price index.

(i) Augmented Dickey-Fuller (ADF) and Recursive Estimation of the ADF regression

The standard ADF regression is as follows

$$\Delta Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 t + \sum_{j=1}^{k} \alpha_j \Delta Y_{t-j} + \varepsilon_t. \quad (2)$$

Note: (i) $Y = \{REX\}$; and the variable is in natural logarithm form (Ln);
(ii) t is the time trend.

The ADF test shows that Ln(REX) series for the period of January 1979-July 1995 follow a random walk with drift (Table 1). This finding is consistent with the findings of Baharumshah and Ariff (1997) and Montiel (1997).

Table 1 Augmented Dickey-Fuller Unit Root Test
(Period: 1979:01 - 1995:07)

ADF t-statistics for Ln(REX):-1.2166*
* Ln(REX) is a Random Walk with Drift. Number of lags = 1, Akaike Info Criterion = -7.1016 and Schwarz Criterion = -7.0516.

(ii) The Cochrane Variance Ratio Test

To complement the ADF test in evaluating the random walk properties of the Ln(REX), the Cochrane Variance Ratio (1988) test is applied to examine whether the error term is white-noise. The test is as follows. For variables that have a standard representation as,

$$x_t = \delta x_{t-1} + \varepsilon_t, \quad \text{where } \varepsilon_t \sim N(0, \sigma_\varepsilon^2). \quad (3)$$

Cochrane (1988) provides a measure of the persistence of shocks to a variable by examining the variance of its long difference. The methodology is outlined below:

a) if $\delta = 1$ (random walk), the variance of its k-difference will be:

$$var(x_t - x_{t-k}) = k\sigma^2. \quad (4)$$

b) If $\delta < 1$ (stationary), then the variance of its k-difference:

$$var(x_t - x_{t-k}) = \frac{\sigma_\varepsilon^2 (1 - \sigma^2 k)}{(1 - \sigma^2)}. \quad (5)$$

c) If x has both permanent (random walk) and temporary (stationary) components, Cochrane (1988) proposes the following ratio as an indicator.

$$R_c = \frac{(\frac{1}{k}) \times var(x_t - x_{t-k})}{var(x_t - x_{t-1})}. \quad (6)$$

This ratio will converge to the ratio of the variance of the permanent shock to the total variance of x. Hence, *the closer that ratio is to unity, the lower is the relative importance of temporary shocks*.

Table 2 summarizes the main results. The value of k ranges between 24 months and 132 months. The ratio indicates that the temporary shocks account for a sizable share of the variance of the real exchange rate, especially when k is equal or greater than 96 months. The temporary shocks - representing the impacts of government interventions in the foreign exchange market - play an important role in explaining the fluctuations of the rupiah real exchange rate. This test, therefore, rejects the null hypothesis of a White-Noise error term. Interestingly, the significance of the temporary component of the rupiah real rate is higher than those reported by Calvo, Reinhart and Vegh (1995) for Brazil, Chile, and Colombia.

Table 2 Cochrane Variance Ratio

(Data: Real Exchange Rate, January 1979 - July 1995)

24 months	60 months	84 months	96 months	108 months	120 months	132 months
0.945	0.919	0.95	0.67	0.415	0.347	0.22

(iii) The Lo and MacKinlay Test[3]

This time-series econometrics tool provides another test for a White-Noise error term by analysing the disturbances component of the series. As mentioned earlier, for any random walk, the disturbances are serially uncorrelated or the innovations are unforecastable from past innovations. The Lo and MacKinlay test will complement the Cochrane procedure by providing test statistics that are robust to heteroscedasticity and to non-normality. This is important, especially due to the increasing evidence that exchange rate series often possess time-varying volatilities and deviations from normality. The test is also more-reliable than the Box-Pierce Q test for detecting serial correlation in the finite sample case.

To summarize the test conducted in this paper, we define a variable X that has a standard representation as:

$$X_t = \mu + X_{t-1} + \varepsilon_t,\ E[\varepsilon_t] = 0,\ \textit{for all}\ \ t. \tag{7}$$

$$\Delta X_t = X_t - X_{t-1} = \mu + \varepsilon_t. \tag{8}$$

For any random walk series: - the disturbances, ε_t, are serially uncorrelated, or;

- the innovations are unforecastable from past innovations.

3. For further elaborations of the test, refer to Andrew W. Low and A. Craig MacKinlay, "The Size and Power of the Variance Ratio Test in Finite Samples," *Journal of Econometrics*, 40, 1989, 203-238.

$$\varepsilon_t \sim \textit{i.i.d. with } N(0,\sigma^2). \textit{ The i.i.d Gaussian Null Hypothesis} \tag{9}$$

$$\hat{\mu} \cong \frac{1}{nq}\sum_{k=1}^{k=nq}[X_k - X_{k-1}] \cong \frac{1}{nq}[X_{nq} - X_0]. \tag{10}$$

For the finite sample case,[4] the unbiased estimators of the variance are given by Equation (11) and Equation (12). Lo and MacKinlay (1989) show that by using these unbiased estimators, the finite sample behaviour of the test-statistics can be further improved.

$$\overline{\sigma_a}^2 \cong \frac{1}{nq-1}\sum_{k=1}^{nq}[X_k - X_{k-1} - \hat{\mu}]^2. \tag{11}$$

$$\overline{\sigma_b}^2 \cong \frac{1}{m}\sum_{k=q}^{nq}[X_k - X_{k-q} - q\hat{\mu}]^2. \tag{12}$$

Note: $m = q(nq - q + 1)(1 - (q/nq))$.

Under the null hypothesis of a Gaussian Random Walk, the sizes of the two estimators should be “close” to each other; therefore a test of the Random Walk maybe constructed by either computing the difference,

$$M_d(q) \cong \overline{\sigma_b}^2(q) - \overline{\sigma_a}^2, \tag{13}$$

and checking its proximity to zero, or alternatively (Equation (14)):

$$M_r(q) \cong \left[\frac{\overline{\sigma_b}^2(q)}{\overline{\sigma_a}^2}\right] - 1, \tag{14}$$

which should converge in probability to zero as well.

In the final step, the test statistics (Z-test statistics) are calculated for various *q's*. The variance ratio, $M_r(q)$, for each q, and the variance of each variance-ratio (Equation (15a)) is calculated to generate the corresponding Z-statistics, $Z^*(q)$ (Equation (16)). The Z-statistics is heteroscedasticity-consistent variance-ratio test-statistics. It was derived to allow for quite general forms of heteroscedasticity, including deterministic changes in the variance (due for example, to seasonal components) as well as Engle’s, 1982, ARCH processes (in which the conditional variance depends upon past information). The applicability of this statistic is, therefore, consistent with a growing consensus that many economic time series possess time-varying volatilities.

4. The Lo and MacKinlay test also provides the general estimators for variance of a large sample. But given the size of our observations, we employed the unbiased estimator for the case of finite samples.

$$V(q) = \sum_{j=1}^{q-1} \left[\frac{2(q-j)}{q} \right]^2 \cdot \delta(j) \tag{15a}$$

where,

$$\delta(j) = \frac{\sum_{k=j+1}^{nq} (X_k - X_{k-1} - \mu)^2 \cdot (X_{k-j} - X_{k-j-1} - \mu)^2}{\left[\sum_{k=1}^{nq} (X_k - X_{k-1} - \mu)^2 \right]^2}, \tag{15b}$$

$$Z^*(q) \cong \frac{\sqrt{nq} \times M_r(q)}{V^{1/2}(q)} \xrightarrow{a} N(0,1). \tag{16}$$

The Z-statistic is asymptotic standard normal, hence, the conventional critical values apply when it is adopted to test the random walk hypothesis. For example, if the Z-statistic is greater than 1.96, it would indicate a deviation of the variance ratio $(M_r(q)+1)$, from one at the 5% significance level. Thus, the random walk hypothesis would then be rejected.

The results in Table 3 confirm the rejection of the random walk hypothesis reported by the previous Cochrane test. The value of q here ranges from 2 months to 24 months. All the $(M_r(q)+1)$ statistics for both cases of the actual real exchange rate series and its log value passed the 5% level of significance for statistically different from one - implying that $M_r(q)$ is statistically larger than zero. This heteroscedasticity robust autocorrelation statistics indicate that the rupiah real exchanges rate is not a random walk series by rejecting the White-Noise null hypothesis.

Table 3 Test of the Random Walk

(Rupiah Real Exchange Rate: January 1979 - July 1995)

Note: The Variance Ratio = $M_r(q)+1$

No of Observations	q = 2	q = 6	q = 12	q = 24
For X = REX				
199	1.1209 (21.30)*	1.1224 (10.13)*	1.0523 (3.33)*	1.0953 (4.75)*
FOR X = Ln (REX)				
199	1.1795 (18.07)*	1.2418 (13.93)*	1.1705 (8.39)*	1.1667 (7.10)*

The numbers in parentheses indicate the heteroscedasticity - robust test statistics, $Z^*(q)$. Under the random walk null hypothesis, the value of the variance ratio is 1 and the test statistics have a standard normal distribution (asymptotically). Test statistics marked with asterisk indicate that the corresponding variance ratios are statistically different from 1 at the 5 percent level of significance.

(iv) Recursive and Rolling Test Statistic

Based on the two last tests, the strong presence of stationarity component in the Indonesian real exchange rate seems to be significant enough. But the test results are not providing sufficient evidences to reject the unit-root null hypothesis, like the earlier standard ADF test result (Table 1). However, one needs to recognize that these three tests do not take into account the possibility of structural breaks in the series. Looking at Figure 3, the two devaluations of the nominal rupiah may certainly have caused the structural breaks in the real exchange rate series.

To evaluate the unit-root property of Ln(REX) more structurally, we apply the next set of tests introduced by Banerjee, Lumsdaine and Stock (1992). Their work investigates further the possibility that aggregate economic time series can be characterized as being stationary around "a single or multiple structural breaks".[5] Banerjee, Lumsdaine and Stock (BLS) extend the Dickey-Fuller t test to both the recursive and rolling case. They construct the time-series of recursively and rollingly computed estimators and t statistics. When the rolling test is applied, the rupiah real exchange rate series is found to be stationary.

Brief discussions on the tests are as follows. The observations on y_t are assumed to be generated by:

$$y_t = \mu_0 + \mu_1 t + \alpha(y)_{t-1} + \beta(L)\Delta(y)_{t-1} + \varepsilon_t, \qquad \forall\, t = 1, \cdots, T. \tag{17}$$

One of the first steps taken is to transform Equation (17) into Equation (18) by adopting the method discussed by Sim, Stock and Watson (1990). Because of the unit-root null hypothesis, Sim Stock and Watson show that it is convenient to introduce transformed regressors Z_t and a transformed parameter vector θ, and rewrite Equation (17) as:

$$y_t = \theta' Z_{t-1} + \varepsilon_t, \quad \text{where} \tag{18}$$

$$Z_t = [Z_t^1, Z_t^2, Z_t^3, Z_t^4]\,; \tag{18b}$$

$$Z_t^1 = ((\Delta y_t - \overline{\mu}_0), \cdots, (\Delta y_{t-p+1} - \overline{\mu}_0))\ ;'$$

$$Z_t^2 = 1\,; \quad Z_t^3 = (y_t - \overline{\mu}_0 t)\,; \quad Z_t^4 = t+1\,; \tag{18c}$$

$$\theta = (\theta_1\, \theta_2\, \theta_3\, \theta_4)\ ;' \tag{18d}$$

$$\theta_1 = (\beta_1 \cdots \beta_p)\ ;' \quad \theta_2 = \mu_0 + (\beta(1) - \alpha)\,\overline{\mu}_0\,; \quad \theta_3 = \alpha\,; \quad \theta_4 = \mu_1 + \alpha\,\overline{\mu}_0. \tag{18e}$$

5. See Perron (1989) and Maddala and In-Moo Kim (1998), chapter 13.

The ordinary least squares (OLS) estimator of the coefficient vectors:

The recursive estimator:

$$\hat{\theta}(\delta) = \left(\sum_{t=1}^{T\delta} (Z_{t-1})(Z_{t-1})' \right)^{-1} \left(\sum_{t=1}^{T\delta} (Z_{t-1})(y_t) \right), \quad 0 < \delta_0 \leq \delta \leq 1; \tag{19}$$

The Rolling estimator:

$$\bar{\theta}(\delta; \delta_0) = \left(\sum_{t=[T(\delta-\delta_0)]+1}^{T\delta} (Z_{t-1})(Z_{t-1})' \right)^{-1} \left(\sum_{t=[T(\delta-\delta_0)]+1}^{T\delta} (Z_{t-1})(y_t) \right). \tag{20}$$

For each of the coefficient vectors, BLS (1992) present the extension of the standard Dickey-Fuller t test statistics. The smallest (minimal) and the largest (maximal) Dickey-Fuller t test statistics from both the rolling and recursive test will be selected and compared against the critical values (presented at BLS (1992)).

Our recursive test results failed to reject the unit-root null hypothesis. The relatively low power of this test suggests that the nonrejections might be uninformative (BLS (1992, p.279)). Since the test results do not add any additional information about the unit-root property of the Ln{REX}, they are not reported in the paper.

In contrast, the rolling test results rejected the unit-root null hypothesis at 5% level. Both the minimal and maximal Dickey-Fuller t test statistics are significantly lower than each critical value, respectively (Table 4). These findings conclude that the Ln(REX) series is stationary.

Table 4 The Rolling Test Results

$\hat{t}_{DF}^{max}$	Critical Value for the Maximal DF Statistic (at 5% level)*	$\hat{t}_{DF}^{min}$	Critical Value for the Minimal DF Statistic (at 5% level)*
-1.98	-1.48	-5.96	-4.85

* Both of these critical values are taken from T=250.
Our observation sample (T)=199.

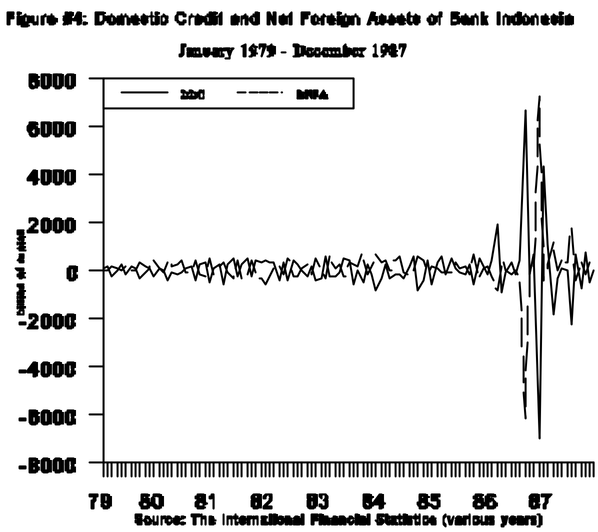
IV. Active Sterilization Policy

The rejections on both the unit-root and white-noise properties of the Indonesian real exchange rate are consistent with the managed floating exchange rate policy adopted by the country's central bank. A recent study by Siregar (1999) has shown that from 1987 to 1995, the monetary authority designed the gradual depreciation in the nominal exchange rate to partly offset faster domestic inflation rates (Figure 2). Evidence of the Indonesian government's effort to stabilize real exchange rate fluctuations, especially in the presence of high inflows of foreign capital, is provided by the composition and the fluctuations of the central bank's reserve money. The change in central bank reserve money (ΔH) is equal to changes in domestic credit (ΔDC) plus changes in net foreign assets (ΔNFA), that is;

$$\Delta H = \Delta DC + \Delta NFA$$

With pressures from capital inflows to appreciate the nominal rupiah, the Bank of Indonesia has followed a sterilization policy by actively purchasing the incoming foreign assets. The changes in the central bank's holdings of NFA were offset by changes in DC (Figures 4 and 5).[6] The high offset correlations (the correlation coefficients) of over 70% and the regression coefficients in Table 5 confirm very active sterilization measures since 1987. In terms of the absolute value, ΔDC (Rp 1.2 trillion) and ΔNFA (Rp 1 trillion) in 1990-1995 were more than doubled their values in 1987-1989 respectively.

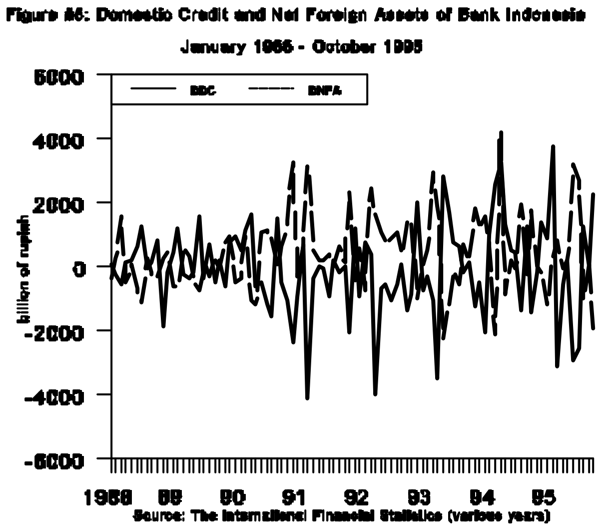
These stylized facts provide strong evidence of government intervention in the foreign exchange market. Given the various structural changes in the local economy throughout those years, in addition to the volatility of foreign exchange markets, it is rational to argue that the remarkably stable rupiah *vis-a-vis* the US dollar has to be largely attributed to the Bank of Indonesia's intervention.



Source: The International Financial Statistics (various years)

Figure 4 Domestic Credit and Net Foreign Assets of Bank Indonesia, January 1979 - December 1987

6. Note: DDC = ΔDC and DNFA = ΔNFA



Source: The International Financial Statistics (various years)

Figure 5 Domestic Credit and Net Foreign Assets of Bank Indonesia, January 1988 - October 1995

Table 5 Domestic Credit and Net Foreign Assets

(a) Period: 1987:01 - 1989:12

OLS Regression Result: $\Delta DC_t = 63.52 - 0.9235 \Delta NFA_t$ + error term

Standard Error of the coefficient: (100.16) (0.158)

R-squared = 0.501

R (Correlation Coefficient) = -0.7078

Durbin-Watson statistics = 2.55 (No autocorrelation at 5% significance level)

F-statistics = 34.13

Mean (average monthly volume (absolute) in Rp billion):

(i) ΔDC = 595.34

(ii) ΔNFA = 498.75

(b) Period: 1990:01 - 1995:07

OLS Regression Result: $\Delta DC_t = 168.26 - 0.924 \Delta NFA_t$

Standard Error of the coefficient: (131.66) (0.095)

R-squared = 0.5952

R (Correlation Coefficient) = -0.7715

Durbin-Watson statistics = 2.7812 (No autocorrelation at 5% significance level)

F-statistics = 95.57

Mean (average monthly volume (absolute) in Rp billion):

(i) ΔDC = 1220.71

(ii) ΔNFA = 1038.38

IV. Conclusions

This paper has applied a sequential procedure to test for the statistical properties of the rupiah real exchange rate. Consistent with the "managed floating regime" adopted during the period observed, this study has illustrated that the commonly accepted random walk hypothesis to describe the real exchange rate of the rupiah series is rejected. This finding also reflects the stylized fact of heavy government intervention in the forex market to ensure the stability of the rupiah real exchange rate.

In addition, the paper has highlighted the weakness of the standard ADF test in capturing the impact of two rupiah devaluations. The standard ADF unit-root test is proven to be not very sensitive to the presence of structural breaks or any other temporary shocks. Failure to address these limitations is likely to create critical flaws on the development of the theoretical model and the empirical testing - as argued against several papers mentioned in the introduction. Obviously, those inconsistencies have broad implications for our understanding about the nature of economic phenomena in explaining the movements of the rupiah.

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