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Policy Factors and Exchange Rate Volatility: Panel Data versus a Specific Country Analysis

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Abstract

We study the daily volatility of the exchange rate between the U.S. Dollar and 43 other currencies in 1990-2001. In the panel we find *positive* correlations between exchange rate volatility, real interest rates and the intensity of central bank intervention. These positive correlations, however, most probably reflect a cross-country difference: countries with relatively high exchange rate volatility maintain higher real interest rates and employ more central bank intervention. Indeed, when we examine a specific country, Israel, where we also have more accurate data, real interest rates and central bank intervention restrain (i.e., are *negatively* correlated with) exchange rate volatility. Statistical and macroeconomic factors also help explain exchange rate volatility.

Keywords: Exchange rate volatility; real interest rates; central bank intervention; panel data; GARCH.
JEL classification: F3

1. Introduction

Exchange rate volatility has real economic costs. It affects price stability, firm profitability and the country's financial stability. During the 20th century most countries attempted to moderate their domestic currency fluctuations by imposing regulatory restrictions on exchange rate movements (crawling bands, for example), by monetary measures (changes in the domestic interest rate), by direct intervention in the foreign exchange currency market, and by imposing restrictions on capital flows in and out of the country.

These central government policy measures were only partly or temporarily successful in controlling exchange rate volatility. In the recent decade of increased globalization, regulation and domestic policy tended to collapse spectacularly. The Asian financial crisis and the subsequent crises in Russia, Brazil and Turkey, all took place under "managed" exchange rate regimes, which illustrates the harmful potential of excessive central bank intervention. Consequently, countries such as Korea, Thailand, Brazil, Chile, and Turkey have announced their intention to allow their currency to free-float.

At the same time, other countries have chosen another "corner" solution, with 25 European countries "pegging" their currency to the Euro.

Empirical studies suggest that even in free-floating countries the central bank intervenes in the foreign exchange market – see Calvo and Reinhart (2002). The intervention is seldom in the form of direct purchases and sells of currencies. The more popular intervention tool is changing the real domestic interest rate – see Rose (1996) and Calvo and Reinhart (2002). In fact, it has become popular to model the monetary policy of the central bank by an interest rate rule. Presumably, the central bank adjusts the short term rate in response to deviations of inflation, output and exchange rate from their targeted levels – see Clarida, Gali and Gertler (1999) and Monacelli (2004).

Our study comprises panel data from 43 countries in the years 1990-2001. The main goal is to examine how policy variables such as real interest rates, the degree of central bank intervention and restrictions on capital flows, affect exchange rate volatility. The key question is: are policy measures such as increasing the interest rate effective in restraining volatility. The analysis attempts to control for other variables which might affect exchange rate volatility. We use several macroeconomic variables, that proxy for the domestic economy uncertainty, wealth, and openness to international markets, as controls in our analysis. The well-known GARCH statistical behavior of exchange-rate volatility is also accounted for.

Our main finding is that exchange rate volatility is positively correlated with the real domestic interest rate and with the degree of central bank intervention. This result is somewhat puzzling because we expect high real interest rates and active bank intervention to moderate the exchange rate volatility.

It is possible that our international panel results are misleading. We suggest that the positive correlation between exchange rate volatility and the levels of real interest rate and bank intervention may reflect the cross-country difference in our panel data: in countries with high exchange rate volatility, real interest rates are higher and central banks intervene more frequently and vigorously. We examine this conjecture by repeating the policy factors' analysis in a specific country, Israel, where we also have access to more accurate data on central bank intervention. Indeed, when this single economy is studied, high real interest rates and central bank intervention are successful in curbing exchange rate volatility. Thus, our single economy evidence revives the more plausible hypothesis that exchange rate volatility is fundamentally *negatively* correlated with real interest rates and with central bank intervention.

The paper is organized as follows. Section 2 proposes several factors that might affect exchange rate volatility. Section 3 describes the sample and empirical variables. Sections 4 and 5 report results of the panel data and single country (Israel) analyses, and Section 6 concludes.

2. Policy Factors and Exchange Rate Volatility

We seek to infer the effect of policy variables such as interest rate changes and direct central bank intervention on exchange rate volatility.

2.1. Policy variables

Government and central bank may attempt to control exchange rate fluctuations by heavily regulating the foreign exchange sector. Typically, there are bounds on the "allowed" fluctuation of the domestic currency exchange rates. IMF, our data source, classifies the country's exchange rate regime, from a pegged exchange rate, through various "managed" floating regimes (such as crawling pegs and crawling bands), to "free floating" exchange rates. We employ the official IMF classification. However, for robustness tests we examine also the more novel Reinhart and Rogoff (2002) exchange rate regime classification.

Another form of regulatory restrictions focuses on (in and out) capital flows. IMF publications indicate whether the country imposes: 1) restrictions on capital flows to other countries, 2) restrictions

on transactions with foreign countries, or 3) surrender requirements (of foreign currency). This information enables us to rate the degree of capital flow regulatory control in each country.

A third common type of policy tools is referred to as central bank intervention. It is of a more dynamic nature than the regulatory restrictions discussed above. The central bank may directly and actively intervene in foreign exchange trading of the domestic currency, or it can change the domestic real interest rate.

Rose (1996) and Calvo and Reinhart (2002) document a positive correlation between the real interest rate variance and the exchange rate variance, which suggests that central banks change domestic interest rates in an attempt to restrain exchange rate fluctuations. For example, in response to rapid devaluation, the central bank raises the domestic interest rates, which slows down the devaluation. In this study we use the expected real interest rate as the relevant policy variable. Central banks can control only the nominal interest rate. However, given an expected inflation, this may be perceived as an attempt to control the expected real interest rate.

The other form of central bank intervention is more direct. The central bank may intervene by acting against any large excess demand or supply for the domestic currency in the foreign exchange market. When there is a large excess demand (supply) for the domestic currency, the central bank sells (buys) the domestic currency in the foreign exchange markets. This "market offsetting" activity is presumed to moderate exchange rate volatility, although recent evidence shows it sometimes instigates volatility – see McKenzie (2002).

Data on the central bank direct intervention is unavailable for most countries. Hence, in the panel we use the absolute value of the change in the country's foreign reserves as a proxy for the intensity of central bank intervention. Calvo and Reinhart (2002) document a positive correlation between the exchange rate volatility and our proxy (the country's foreign reserve volatility), and interpret it as an " … explicit policy choice: international reserves move more from month to month for those countries with the more stable exchange rate (*ibid* page 391). In our analysis of Israel, we have refined measures of central bank intervention, based on the central bank's reports on its purchases/sells of foreign currency on the foreign exchange market.

2.2. Statistical and macroeconomic variables

It is well documented that exchange rates follow GARCH (Generalized Auto-Regressive Conditional Heteroscedasticity) processes – see Domowitz and Hakkio (1985) and Engle and Bollerslev (1986), for example. According to the fitted GARCH models, the exchange rate variance is persistent and serially correlated. In the panel data analysis we take into account these statistical properties of exchange rate volatility, and in the specific country (Israel) analysis we use a specific variant of the GARCH model.

The macroeconomic analysis of exchange rate volatility starts with Mundell (1961)'s Optimal Currency Area hypothesis. Mundell shows that countries with relatively large bilateral trade and countries with correlated economic shocks might benefit from a common currency. Recent literature such as Devereux and Lane (2003) suggests that financial variables such as external debt also affect optimal exchange rate volatility.

Our conclusion from the Optimal Currency Area literature is that the country's real and financial openness may impact exchange rate volatility. The effect of real and financial openness is difficult to predict. Countries with relatively high real openness (i.e., more trade with abroad) may try to decrease their domestic exchange rate volatility. However, since their increased trade with abroad makes them more susceptible to the global economy shocks, countries with relatively high real openness may in fact manifest higher exchange rate volatilities. Similarly, when financial openness is relatively high, foreign investors may easily speculate on or against the domestic currency, which may

increase exchange rate volatility.[1] In our empirical analysis of policy measures' effectiveness, we will use real and financial openness as control variables.

Two other macroeconomic variables also serve as controls. First, we propose that exchange rate volatility is influenced by and correlated with the domestic economy uncertainty. We use the volatility of the domestic stock index return as a proxy for domestic economic uncertainty. This is because the stock market index captures and encapsulates a lot of the country's key real and financial indicators.

Second, the country's economic wealth may stabilize the exchange rate. Financial and currency crises are more common in poor countries. We use the per capita Gross Domestic Product (GDP) as an estimate of the country's wealth and add it as a control variable to our exchange rate volatility equation.

3. Data and Empirical Variables

The sample includes data from 43 countries in the period 1990 – 2001. The 43 countries comprise all countries with daily exchange rate data on Bloomberg for at least 75% of the sample period. We start in 1990 because Bloomberg provides pre-1990 data only for very few countries. Table 1 lists the countries and their exchange rate regime during the sample period.

[1] Cheung and Wang (1996) report that over 90% of the professional traders in Japan, Hong Kong and Singapore believe that foreign investors increase exchange rate volatility. In contrast, Friedman (1953) argues that speculative activity tends to smooth exchange rate fluctuations, and Osler and Carlson (2000) suggest that speculation trims volatility on normal periods and instigates volatility during crisis periods.

Table 1: Exchange rate regimes during 1990-2001[a]

	Country	Changes in Exchange Rate Regime during 1990-2001		
1	Australia	3 (during all the period)		
2	Austin	4 (till Jan 1995)	2 (Jan 1995-Jan1999)	5 (from Jan 1999)
3	Belgium	2 (till Jan 1999)		5 (from Jan 1999)
4	Brazil	3 (till Jan 1994)	2 (Jan 1994 - Jan 1998)	3 (from Jan 1998)
5	Canada	3 (during all the period)		
6	Chile	2 (till Jan 1999)		3 (from Jan 1999)
7	China, Rep.	2 (till Jan 1998)		
8	Colombia	2 (till Sept 1999)		3 (from Sept 1999)
9	Czech. Rep.	4 (till Jun 1997)		2 (from Jun 1997)
10	Denmark	2 (during all the period)		
11	Finland	4 (till Jan 1992)	3 (Jan 1992 - Sept 1996)	2 (from Sept 1996)
12	France	2 (till Jan 1999)		5 (from Jan 1999)
13	Germany	2 (till Jan 1999)		5 (from Jan 1999)
14	Greece	2 (during all the period)		
15	Hungary	4 (till Apr 1995)		2 (from Apr 1995)
16	Ice land	4 (till Jan 1998)	2 (Jan 1998 - Jan 2000)	3 (from Jan 2000)
17	India	2 (till Jan 1992)	3 (Jan 1992 - Jan 2000)	2 (from Jan 2000)
18	Indonesia	2 (till Jul 1997)		3 (from Jul 1997)
19	Ireland	2 (till Jan 1999)		5 (from Jan 1999)
20	Israel	2 (during all the period)		
21	Italy	2 (till oct. 1991)	3 (Oct. 1991-Oct 1996) 2 (Oct. 1996 - Jan 1999) 5 (from Jan 1999)	
22	Japan	3 (during all the period)		
23	Korea	2 (till Jan 1999)		3 (from Jan 1999)
24	Malaysia	4 (till Jan 1992)	2 (Jan 1992 - Oct 1998)	1 (from Oct 1998)
25	Malta	4 (during all the period)		
26	Netherlands	2 (till Jan 1999)		5 (from Jan 1999)
27	New Zealand	3 (during all the period)		
28	Norway	4 (till Jan 1993)	3 (Jan 1993 - Jan 1995)	2 (from Jan 1995)
29	Pakistan	2 (till Jul 1999)	1 (Jul 1999 - Apr 2000)	2 (from Jul 2000)
30	Peru	3 (during all the period)		
31	Philippines	3 (during all the period)		
32	Poland	4 (till Jan 1992)	2 (Jan 1992 - Apr 2000)	3 (from Apr 2000)
33	Portugal	2 (till Jan 1999)		5 (from Jan 1999)
34	Russia	3 (till Jan 1998)	2 (Jan 1998 - Jan 1999)	3 (from Jan 1999)
35	Singapore	2 (during all the period)		
36	South Africa	3 (during all the period)		
37	Spain	2 (till Jan 1999)		5 (from Jan 1999)
38	Sweden	4 (till Oct 1992)		3 (from Oct 1992)
39	Switzerland	3 (during all the period)		
40	Thailand	4 (till Jul 1997)		3 (from Jul 1997)
41	Tunisia	2 (during all the period)		
42	Turkey	2 (during all the period)		
43	United Kingdom	2 (till Oct 1992)		3 (from Oct 1992)

[a] Classification of the domestic exchange rate (against the U.S. Dollar):
1. Pegged exchange rate within horizontal bands.
2. Managed floating regimes: crawling peg, crawling bands and managed floating with no path.
3. Independent floating.
4. A linkage of the currency to a basket of currencies which includes the USD.
5. A participation in the Euro currency block in 1999-2001.

The remainder of this section describes our empirical variables.

3.1. Exchange rate volatility (MVOL and QVOL)

We compute R_{it}, the daily rate of change of the domestic currency i against the U.S. Dollar (USD) as:

$$R_{it} = \frac{S_{it} - S_{it-1}}{S_{it-1}}$$

where S_{it} is the exchange rate of currency i against the USD on day t. Then, the monthly exchange rate volatility $MVOL_T$ is estimated as the standard deviation of R_{it} in month T. Similarly, $QVOL_T$ is the standard deviation of R_{it} in quarter T. We need both monthly and quarterly volatilities because some of our explanatory variables (mainly the macroeconomic variables) are available in quarterly frequency only.

Table 2 presents the mean, median, maximum, and minimum MVOL for each country. The average MVOL (i.e., average standard deviation of the daily devaluation rate) across the sample countries is about 0.56%, indicating that exchange rate volatility is considerable.[2] Notably, in countries with a relatively high maximum standard deviation (Brazil and Russia, for example), the median standard deviation is relatively low. Apparently, these countries managed their exchange rates too tightly, leading to unreasonable exchange rates, which tend to collapse spectacularly once in a while. That is, in these countries, there are months of panic and extreme exchange rate volatility, which illustrate that regulation and governments cannot overcome "market power".

[2] The corresponding average standard deviation of the daily return on stock markets in our sample

Table 2: Exchange rate volatility in the sample countries
The table presents various statistical properties of MVOL, the within month standard deviation of the daily devaluation rate of the domestic currency (against the U.S. Dollar).

	Mean	Minimum	Maximum	Median
Australia	0.56%	0.21%	1.34%	0.53%
Austria	0.64%	0.34%	1.50%	0.62%
Belgum	0.64%	0.31%	1.49%	0.60%
Brazil	0.77%	0.03%	11.94%	0.45%
Canada	0.28%	0.07%	0.63%	0.28%
Chile	0.43%	0.08%	1.44%	0.33%
China	0.11%	0.00%	1.3S%	0.01%
Colombia	0.35%	0.06%	1.45%	0.29%
Czech Republic	0.62%	0.22%	1.88%	0.58%
Denmark	0.63%	0.27%	1.32%	0.58%
Finland	0.73%	0.2S%	6.57%	0.62%
France	0.61%	0.27%	1.41%	0.58%
Germany	0.64%	0.31%	1.35%	0.59%
Greece	0.64%	0.28%	2.03%	0 59%
Hungary	0.53%	0.20%	2.02%	0.46%
Iceland	0.52%	0.18%	2.16%	0.45%
India	0.27%	0.02%	3.40%	0.17%
Indonesia	1.00%	0.03%	8.71%	0.19%
Ireland	0.63%	0.22%	1.88%	0.61%
Israel	0.42%	0.01%	3.89%	0 34%
Italy	0.64%	0.20%	2.15%	0.60%
Japan	0.66%	0.30%	1.78%	0.61%
Korea	0.44%	0.05%	8.54%	0.25%
Malaysia	0.24%	0.00%	2.99%	0.12%
Malta	0.69%	0.06%	2.49%	0.61%
Mexico	0.50%	0.05%	6.67%	0.32%
Netherlands	0.64%	0.31%	1.41%	0.60%
New Zealand	0.44%	0.16%	1.29%	0.39%
Norway	0.62%	0.24%	1.75%	0.57%
Pakistan	0.44%	0.01%	5.74%	0.15%
Peru	0.25%	0.05%	1.06%	0.19%
Philippines	0.52%	0.02%	2.19%	0.36%
Poland	0.59%	0.18%	3.78%	0.46%
Portugal	0.66%	0.28%	1.98%	0.60%
Russia	0.84%	0.01%	15.88%	0.19%
South Africa	0.42%	0.08%	3.10%	0.33%
Spain	0.65%	0.28%	2.42%	0.60%
Sweden	0.67%	0.28%	2.17%	0.62%
Switzerland	0.69%	0.35%	1.49%	0.66%
Taiwan	0.26%	0.01%	9.92%	0.14%
Tunisia	0.64%	0.09%	1.56%	0.57%
Turkey	0.85%	0.18%	9.74%	0.43%
United Kingdom	0.55%	0.25%	1.49%	0.51%

3.2. Exchange rate regimes (REG2 through REG5)

Based on the IMF publication "Exchange Arrangements and Exchange Restrictions" we construct several dummy variables to characterize the exchange rate regime – see also Table 1. REG3 equals 1 for a country with a free floating exchange rate regime (and equals zero otherwise). REG2=1 for a country with a managed exchange rate regime or a linkage to a basket of currencies which include the USD (REG2=0 for all other countries). Empirically, countries with managed exchange rates behave similarly to countries whose currency was linked to a basket of currencies. Thus, we unified these "middle way" categories. Finally, because the switch to the Euro could have impacted exchange rate volatility, we set REG5=1 in 1999-2001 for all countries that adopted the Euro at the time (REG5=0

for non-Euro countries and for all countries in the pre-1999 period). The above array of dummy variables does not include a dummy variable for pegged exchange rate countries. The effect of pegged exchange rate is captured by the intercept of our regressions. Hence, the coefficients of the above dummy variables estimate the "extra volatility" of adopting a more flexible exchange rate regime.

We have also examined a more modern classification of exchange rate regimes due to Reinhart and Rogoff (2002). Based on it we construct an alternative set of dummy variables using the same principles employed with the IMF classification. Namely, REG3 equals 1 for a country with a free floating exchange rate (and equals zero otherwise). REG2=1 for a country with a managed exchange rate regime (REG2=0 for all other countries).

3.3. Regulatory restrictions on capital flows (REST)

Data regarding restrictions on capital flows (in and out of the country) are retrieved from the IMF publication "Exchange Arrangements and Exchange Restrictions". Three types of restrictions are indicated: 1) restrictions on capital flows to other countries, 2) restrictions on transactions with foreign countries, and 3) surrender requirements (of foreign currency).

We construct a variable, REST, equal to the number of types of restrictions that the country adopts. For example, REST=3 if the country imposes all three types of restrictions, and REST=0 when the country has no restrictions at all. We have also attempted generating a separate dummy variable for each type of capital flow restriction, but results were unchanged.

3.4. The expected real interest rate (RIR)

The expected real interest rate in each country is calculated based on Fisher's equation as:

$$RIR_{it} = \frac{1 + r_{CB_{it}}}{1 + \pi_{it}} - 1 \qquad (1)$$

where $r_{CB_{it}}$ is country i's one-year nominal interest rate on month t, and π_{it} is country i's annual CPI inflation rate in months t-12 through t-1. The above formulation assumes that the expected annual inflation equals the preceding twelve months inflation. Data on nominal interest rates and inflation rates are from the IMF data base (IFS CD-Rom).

3.5. Central bank intervention in the foreign exchange market (ACRES)

Active intervention of the central bank in its currency trading tends to change the country's foreign reserves. Thus, we approximate the intensity of central bank's intervention by the absolute value of the rate of change in the country's foreign reserves. Admittedly, this is not an ideal estimate, because foreign reserves can change for many other reasons. However, this estimate is readily available, and has served in the past (see Calvo and Reinhart, 2002, for example). Data on foreign reserves (without gold) are from the IMF data base.

3.6. The domestic stock market volatility (VINDEX)

In our framework, the domestic stock market volatility reflects the economic uncertainty of the country. Daily data on stock market indices is collected from Bloomberg. Then, for each country, we compute the standard deviation of the daily return on its stock index. The stock market and exchange rate volatilities are contemporaneous, that is are assessed in the same period. When monthly (quarterly) exchange rate volatility is analyzed we use as an explanatory variable the same month (quarter) volatility of the domestic stock index.

3.7. The country's economic wealth (GDPC)

The country's economic wealth is represented by the per capita Gross Domestic Product (GDP) in U.S. Dollars (USD). From the IMF data base we extract the nominal per capita GDP in domestic currency, and divide it by the mean exchange rate of the domestic currency against the USD in the corresponding period.

3.8. The domestic economy real openness (OPENR)

We propose to estimate the country's real economic openness to abroad, OPENR, as the relative importance of foreign trade in its economy. That is:

$$OPENR_t = (export_t + import_t) / GDP_t \quad (2)$$

Quarterly data on each country GDP, Import and Export, is collected from the IMF data base.

3.9. The domestic economy financial openness (OPENF)

The index of financial openness, OPENF, is constructed by dividing the net capital flows (net direct investment, net portfolio investment and net other investments) by the country's GDP. Quarterly data on the variables is collected from the IMF data base.

4. Panel data results

The main objective of the study is to examine how various policy factors affect exchange rate volatility. Table 3 summarizes the results of our monthly panel data regressions. All regressions are pooled time series cross section regressions with fixed effects (separate intercept for each country). That is,

$$\ln(VOL_{jt}) = \alpha_j + \beta_i X_{ijt} + e_{jt} \quad (3)$$

where ln(VOL) is the natural logarithm of our exchange rate volatility estimate, X_i is the i-th explanatory variable, j is the country's index, and t is the period.

Table 3: Factors that affect exchange rate volatility: An international panel analysis

The table presents results of pooled time-series cross-country regressions with fixed effects in 1990-2001. The dependent variable is the natural logarithm of the within-month standard deviation of the daily devaluation rate of the domestic currency against the U.S. Dollar. MVOL(-1) is the previous month exchange rate standard deviation; REG2 is a dummy variable equal to 1 when the country has a "managed" exchange rate (0, otherwise); REG3=1 when the country has a free floating exchange rate (0, otherwise); REG5=1 in 1999-2001 for the Euro-block countries (0, otherwise); REST is a categorical variable, with a range of 0 to 3, that counts the number of types of restrictions that the country imposes on foreign capital flows; RIR is the expected real interest rate in the month; ACRES is the absolute value of the rate of change in the country's foreign reserves; VINDEX is the within-month standard deviation of the daily return on the domestic stock market; and AR(1) is the autocorrelation of the regression residuals (preceded by a minus sign). More details on the variables are provided in Section 3.

Regression No.	Countries No.	Log (mvol(-1))	Reg 2	Reg3	Reg5	Rest	Rir	Log (acres)	Log (vindex)	Ar (1)	Adj. R2
1	43	0.85								-0.27	0.78
		(108.2)								(-19.3)	
2	43	0.82	0.33	0.40	-0.04					-0.26	078
		(96.6)	(7.2)	(7.8)	(-1.3)					(-18.2)	
3	43	0.82	0.38	0.44	-0.02	0.01				-0.26	0.77
		(89.6)	(7.1)	(7.4)	(-0.7)	(0.9)				(-16.8)	
4	28	0.84	0.33	0.40	-0.04					-0.30	0.74
		(84.3)	(6.1)	(6.7)	(-1.4)					(-17.6)	
5	28	0.83	0.34	0.42	-0.06		0.48	0.03		-0.30	0.74
		(80.2)	(6.2)	(6.9)	(-1.2)		(2.9)	(4.7)		(-16.9)	
6	28	0.82	0.37	0.45	-0.10		0.67	0.03	0.12	-0.30	0.76
		(76.0)	(6.8)	(7.4)	(-2.2)		(3.8)	(46)	(8.2)	(-16.1)	
6b*	28	0.76	0.29	0.50	-0.21		0.46	0.09	0.91	-0.27	0.76
		(58.5)	(8.7)	(10.3)	(-3.7)		(3.9)	(58)	(5.1)	(-13.8)	

* The dummy variables REG2, REG3 and REG5 are based on Reinhart and Rogoff (2002) exchange rate regime classification.

In the first regression we examine our statistical "explanatory" variables. The coefficient of the previous month volatility is 0.85 and highly statistically significant, suggesting that the "expected" (or conditional) exchange rate volatility is sticky, that is does not change much from month to month. The negative coefficient of AR(1), -0.27, indicates that some fraction of the previous month unexpected volatility is persistent and repeats in the next month. Both these properties of exchange rate volatility are well known from previous studies that fitted GARCH models to bilateral exchange rates – see Andersen and Bollerslev (1998) and Malik (2003), for example.

The second and the third regression examine our policy regulatory variables. In the second regression we find that regime flexibility has a positive effect on exchange rate volatility. The coefficients of the dummy variables for managed regimes, REG2, and for free-floating regimes, REG3, are positive and statistically significant. This implies that countries that free-float their currency or use only limited control on it, experience higher intra-month exchange rate volatility than countries that peg their exchange rate. (Countries that peg their exchange rate are represented by the intercept of the regression.) This result is well known since Mussa (1986). Moreover, when we run a regression without the pegged exchange rate countries, we find that the coefficient of REG3 is significantly positive, indicating that exchange rate volatility is highest in a free-floating exchange rate regime.

In the third regression we add REST, a categorical variable for the degree of control on capital flows. We find no significant relationship between REST and exchange rate volatility. We also attempted separate dummy variables for each type of capital flow regulatory control, that is separate dummy variables for restrictions on transactions with abroad, capital flows to abroad, and surrender requirements. None of these dummy variables attained statistical significance. Thus, similarly to Rose

(1996), we conclude that restrictions on capital flows are ineffective in reducing exchange rate volatility.

The rest of the regressions in Table 3 extend the analysis to other policy and macroeconomic variables. However, because of missing observations, sample size drops to 28 countries. This decrease in sample size (from 43 to 28 countries) does not appear to change the results. The coefficients of the second and the fourth regressions are almost identical, illustrating the robustness of our empirical evidence.

The fifth regression adds two explanatory variables that are related to the central bank's direct and indirect intervention in the foreign exchange market. The expected real interest rate, RIR, represents central bank's indirect intervention, and the absolute value of the change rate in foreign exchange reserves, ACRES, represents central bank's direct intervention. Both these variables have served in empirical studies before – see Calvo and Reinhart (2002), for example. We find that the coefficients of RIR and ACRES are both significantly positive. Apparently, central bank's intervention increases exchange rate volatility.

The findings of the fifth regression are somewhat surprising because they contradict the common belief that central bank's intervention moderates exchange rate volatility. On reflection, it is possible that these puzzling results emanate from the difference between the sample countries. That is, our findings may just reflect the fact that in countries where exchange rate volatility is relatively high, the central bank intervenes more aggressively. Indeed, in the next section, where we examine a single country, Israel, we show that the coefficients reverse, that is central bank's intervention via monetary policy and via direct intervention in the foreign exchange market tends to mitigate exchange rate volatility.

Finally, we add the variable VINDEX (the local stock index volatility) that reflects the uncertainty of the domestic economy. Similar to Kearney (1998), we find a positive correlation between the stock market and the exchange rate volatilities, suggesting some relation between the domestic economy uncertainty and exchange rate volatility. Admittedly, we do not examine, nor do we argue, for any causality in this relation. It is likely that the domestic economy uncertainty has a feedback relation with exchange rate volatility, i.e., domestic uncertainty is influenced by and influences exchange rate volatility. The main purpose of adding VINDEX to the panel regressions is to elaborate our controls, so that the effect of policy variables would be measured more precisely.

Control for additional macroeconomic variables requires use of quarterly data. Based on economic analysis, such as Mundell (1961), we add three variables: OPENR, estimating the country's real openness to international trade; OPENF, representing the country's financial openness; and GDPC, which proxies the country's economic wealth. (See section 3 for more detail.) Because of missing observations, sample size is reduced to 16 countries only.[3] In this quarterly sample

$$\underset{}{\text{Ln}(QVOL_t) = \alpha_i + \underset{(12.3)}{0.60}\ \text{Ln}(QVOL_{t-1}) + \underset{(1.5)}{0.07}\ REG2 + \underset{(2.5)}{0.03}\ \text{Ln}(ACRES)} \qquad (4)$$

$$+ \underset{(3.9)}{1.53}\ RIR + \underset{(3.6)}{0.12}\ \text{Ln}\,(VINDX)\ \text{Adj. } R^2 = 0.58,$$

where α_i is the country-specific intercept and all other variables are as before. (t-statistics are shown in parentheses.) The coefficients of the quarterly regressions are of the same sign as their counterparts in the monthly regression. Hence, our monthly evidence appears robust.

When OPENR, OPENF and Ln(GDPC) are added to the quarterly regressions, the adjusted R^2 of the regression increases slightly to 0.59, but only the coefficient of Ln(GDPC) is statistically significant. The negative coefficient of Ln(GDPC) (-0.33 with a t-statistic of -2.7) indicates that the currencies of wealthy countries are less volatile. This is expected given that poor and weak countries suffer more often from currency crises.

[3] All of these countries have managed or free-floating exchange rate regimes.

Diagnosis of the monthly and quarterly regressions does not reveal any serious multicolinearity problems. Omitting any explanatory variable from the regressions does not change the sign or statistical significance of any other explanatory variable. We have also attempted adding yearly dummy variables to the set of explanatory variables. These yearly dummies should capture contemporaneous correlation between the unexplained volatility of different countries. The yearly dummies were all statistically insignificant. Finally, we attempted a set of exchange rate regimes dummy variables based on Reinhart and Rogoff (2002). The results, reported in Table 3, support all our previous conclusions.

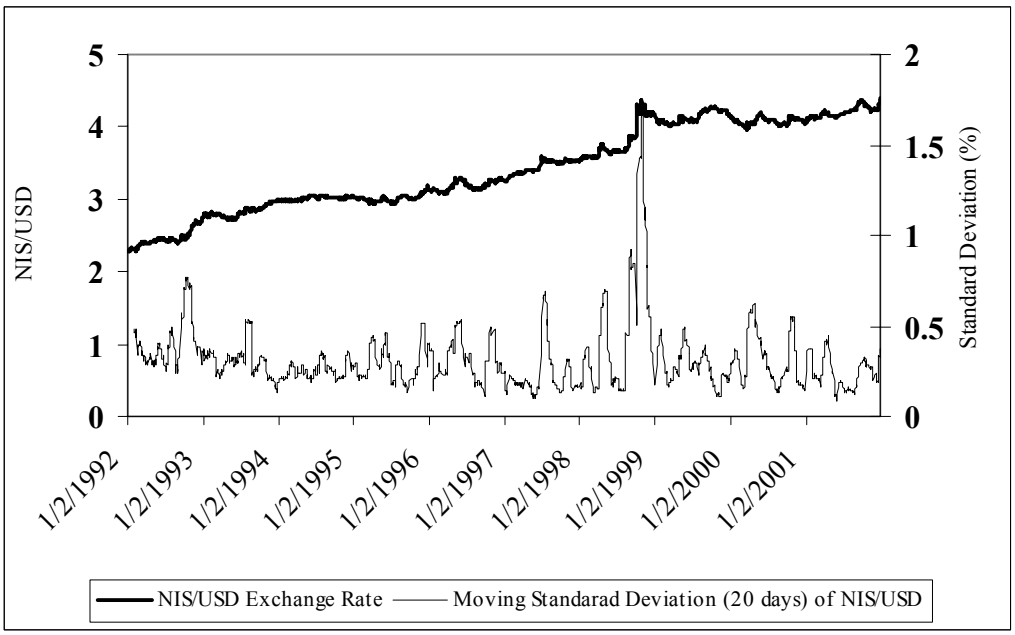
A concluding observation is that the statistical variables contribute the most to the explanatory power of our regressions. In fact, policy and macroeconomic variables increase the adjusted R^2 of the regressions only by a few percents – see Table 3. This suggests that pure statistical exchange rate volatility models are often sufficient for predicting future volatility. The relatively low incremental explanatory power of policy and macroeconomic variables is not surprising because these variables are measured with errors. We have only poor measures of central bank's direct intervention in trade, and our measure of indirect intervention (the expected real interest rate) serves also many other monetary objectives. Further, we probably miss some policy and macroeconomic variables, thus, again underestimating the effect of policy and macroeconomic variables. In fact, our evidence that the coefficients of all policy variables and some of the macro-economic variables are significant despite of all the estimation difficulties is encouraging because it illustrates that the fundamental policy and macroeconomic factors have significant effects on exchange rate volatility.

5. Israel results

This section extends the panel data analysis to a specific country, Israel. Data on all variables was collected from Bank of Israel data bases. Israel appears like an average country in our sample. Its average expected real rate (RIR) of 2.3% is in the 4th decile relative to our sample; its average absolute change rate in foreign reserves (ACRES) of 7.8% is in the 6th decile; its average monthly stock market volatility (VINDX) of 1.4% is in the 6th decile; and its average per capita GDP of $ 15,300 is in the 6th decile. During the entire sample period Israel used a managed exchange rate regime.

More specifically, Israel employed a managed regime with a crawling band. The band's boundaries were determined relative to a central rate that was adjusted every day at a fixed pre-announced rate. This assures some steady devaluation of the New Israeli Shekel (NIS) relative to foreign currencies. In fact, the central rate referred to a basket of currencies, in which the USD had a significant weight. Figure 1 depicts the exchange rate of the NIS relative to the basket, the crawling band boundaries, and a moving 20 days standard deviation of the rate of devaluation of the NIS relative to the USD.

Figure 1: The New Israeli Shekel exchange rate and its daily volatility, 1992-2001.



We have data from Bank of Israel on months when the central bank intervened in foreign exchange trade. Based on it, we construct a dummy variable, INTER, that equals 1 in the months of intervention and equals 0 in months without intervention. This dummy variable is an improvement relative to our panel data central bank intervention variable (ACRES, the absolute changes in foreign exchange reserves) because changes in reserves can occur for many other reasons besides central bank intervention.

We also elaborate our measure of the expected real interest rate by using Bank of Israel estimates of expected inflation instead of the past year inflation in the Fisher equation (equation (1) above).

Our methodology is based on the GARCH model. We assume that the NIS/USD exchange rate follows a random walk, i.e., the daily devaluation rate, R_t, is given by:

$$R_t = \alpha + \varepsilon_t \tag{5}$$

where α is the mean daily devaluation rate, and ε_t is a random deviation term caused, for example, by the arrival of new information. Conditional on day t-1 information, ε_t is distributed $N(0, \sigma^2_t)$, where:

$$\sigma_t^2 = c + \sum_{i=1}^{n} MA_i \varepsilon_{t-i}^2 + \sum_{j=1}^{n} AR_j \sigma_{t-j}^2 \tag{6}$$

MA_i is the coefficient of the day t-i deviation-squared, and AR_j is the coefficient of the conditional variance on day t-j.

The policy and macro-economic variables can be added as explanatory variables to the GARCH model, yielding:

$$\sigma_t^2 = c + \sum_{i=1}^{n} MA_i \varepsilon_{t-i}^2 + \sum_{j=1}^{n} AR_j \sigma_{t-j}^2 + \underline{\beta}\underline{X}_t + e_t \tag{7}$$

It is noteworthy that our policy and macroeconomic variables data are monthly or even quarterly. Because GRACH is estimated on daily data, we duplicate the quarterly and monthly data to daily data. For example, in all the days of a calendar month we use the same RIR that is the RIR that was calculated at the beginning of that month.

Table 4 summarizes the GARCH analysis of the NIS/USD exchange rate. The GARCH (1,1) model fits the NIS/USD exchange rate best. The coefficient MA(1) and AR(1) are both positive and

statistically significant. The MA(1) coefficient of 0.18 indicates that the unexpected volatility on day t-1 affects positively the expected volatility on day t. The AR(1) coefficient of 0.74 shows that the conditional volatility of the exchange rate is highly auto-correlated. Exchange rate volatility appears extremely sticky and persistent.

Table 4: Policy factors impact on a single country: Israel 1992-2001
The table reports results of a GARCH model analysis of the variance of the daily change rate in the NIS/USD exchange rate.

Aech(1)	Garch(1)	Rir	Inter	V1ndex	Akaike info criterion	Schwarz criterion
0.18	0.74				-8.631	-8.622
(17.0)	(54.0)					
0.21	0.66	-3E-05	-7E-07		-8.640	-8.626
(16.3)	(36.3)	(-7.2)	(-6.1)			
0.22	0.66	-3E-05	-6E-07	5E-05	-8.642	-8.626
(16.3)	(36.2)	(-5.6)	(-5.5)	(3.8)		

Our GARCH findings are not surprising. GARCH(1,1) fits most exchange rates best, and in most cases the coefficients of MA(1) and AR(1) are positive. Malik (2003), uses weekly data for five exchange rates in a sample period similar to ours (1990-2000), and finds a mean MA(1) coefficient of 0.08 and a mean AR(1) coefficient of 0.87. Similarly, our panel analysis also suggested that exchange rate volatility is sticky.

When we add our policy variables, RIR and INTER, both of them have negative and statistically significant coefficients. It appears that high real interest rates can stop panic devaluations and tend to calm the foreign exchange market. Similarly, the negative coefficient of INTER illustrates that central bank intervention tends to offset and restrain exchange rate volatility.

The AIC (Akaike Information Criterion) and SC (Schwarz Criterion) of the policy-variables augmented GARCH model are lower than those of the pure GARCH model, indicating that there is a statistical justification for adding the policy variables. (More negative criterions imply a better fit.)

Adding our four macroeconomic variables, OPENF, OPENR, GDPC and VINDEX does not reduce further the Akaike and Schwartz criterions. In fact, the best model we can fit adds VINDEX, the stock market intra-monthly volatility, to the policy-variables augmented GARCH model – see Table 4. As in the panel analysis, the coefficient of VINDEX is positive, suggesting that the domestic (Israeli) economic uncertainty affects positively the exchange rate volatility.[4]

6. Summary and Conclusions

We examine how policy and macro-economic variables affect the daily volatility of the exchange rate against the U.S. Dollar. Analyzing an international panel of 43 currencies in 1990-2001 we find that the flexibility of the exchange rate regime, central bank's intervention and the uncertainty of the domestic economy increase exchange rate volatility, while the country's economic wealth decreases volatility. Restrictions on capital flows do not affect exchange rate volatility.

The positive correlations of real interest rate and central bank's intervention with the exchange rate volatility that we found in the panel data may be due to a cross-country difference. Countries with higher exchange rate volatility routinely employ higher real interest rates and more central bank intervention in order to control exchange rate volatility. Indeed, when we examine a single country, Israel, we find that the real interest rate is negatively correlated with exchange rate volatility. Thus, we conclude that increasing the real interest rate can be efficient in restraining exchange rate volatility. Similarly, in our single country analysis exchange rate volatility and central bank's intervention are

[4] GDPC, the per capita Gross Domestic Product, has a negative coefficient when added to the GARCH model, similar to our panel results. However, it does not improve the explanatory power of the model.

negatively correlated, which implies that central banks intervention can moderate exchange rate fluctuations.

One may question our conclusion that the central bank's interest rate and direct intervention policies can be effective in controlling exchange rate volatility. In our regressions, policy variables have only a relatively low incremental explanatory power. Hence, it could be argued that policy has little effect on volatility. We do not agree with this interpretation. The low incremental explanatory power of policy variables may be due to the fact that these variables are measured inaccurately and to the fact that we probably miss some potentially important policy and macroeconomic variables. Anyway, it becomes clear that we can infer from our analysis only the direction of the policy variables effect, not their magnitude. Future research should inquire more about the magnitude of policy influence.

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