# DETERMINANTS AND EFFECTIVENESS OF FOREIGN EXCHANGE INTERVENTIONS: NEW EVIDENCE FROM GEORGIAN DATA

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# Determinants and Effectiveness of Foreign Exchange Interventions: New Evidence from Georgian Data*

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**Abstract**

This paper uses newly available daily and monthly data for the period 1996-2007 to investigate the determinants and the effectiveness of interventions by the National Bank of Georgia (NBG). An analysis shows that the main structural break occurs before the exchange rate regime shifts to free floating in 1998. The estimation of the central bank daily reaction function indicates that the NBG leans against the wind while targeting and smoothing the exchange rate. When estimating the GARCH-M and IV models, there is evidence that the NBG was successful in moderating the depreciation of the national currency. However, the conditional volatility increased with interventions.

**Abstrakt**

Tato studie využívá nově přístupné denní a měsíční údaje z období 1996-2007 ke zkoumání determinantů a účinnosti intervencí Národní banky Gruzie (NBG). Analýza údajů o směnném kurzu GEL/USD ukazuje, že hlavní strukturální zlom předchází změnu kurzovní politiky k volně plovoucímu kurzu. Odhady reakční funkce centrální banky signalizují, že NBG cíluje a snaží se vyhlazovat směnný kurz. Odhady modelu GARCH a IV ukazují, že NBG byla při zmírňování oslabování národní měny úspěšná, i když podmíněná volatilita kurzu s intervencemi roste.

*Keywords*: foreign exchange intervention; Georgia; structural break, reaction function, effectiveness of intervention
*JEL classification*: C13, E44, E58, F31.

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# I Introduction

Aside from monetary policy, sterilized foreign exchange interventions is the most widely used instrument in exchange rate management in transition economies. Interventions are mainly conducted in order to influence the exchange rate level, and to "calm a disorderly market" by decreasing the exchange rate volatility. However, in the academic literature, there is no consensus on the efficiency of such interventions. In general, the evolving views are disposed towards ineffectiveness (Dominguez, 1998). From one point of view, interventions do not alter the level while, at the same time, either increase the exchange rate volatility or decrease it. The other view suggests that forex interventions affect neither the exchange rate level nor volatility. This paper investigates the validity of these views by presenting new evidence on the determinants and the effectiveness of intervention activity in the context of the Georgian transition economy.

A major difficulty in evaluating the causes and the impact of interventions in emerging market economies has always been the lack of data. As most of the transition countries' central banks do not publish official daily data, the research is usually limited to monthly or even quarterly frequency. Alternatively, various proxies for the intervention variable are used in the literature. This paper uses newly available daily and monthly data sets that include the precise dates and extent of intervention activity from the National Bank of Georgia (NBG) during the period 1996-2007. The analysis of this valuable source of information enables one to take a stand on the issues of the determinants and the effectiveness of interventions in transtion CIS-7[1] economy.

The empirical literature on central bank forex interventions focuses on three main issues: (1) identifying factors that cause a central bank to intervene in the foreign exchange market; (2) estimating the effect of interventions on the exchange rate level and volatility in general, without reference to any particular transmission channel; and (3) testing various channels of the effect of interventions on the exchange rate level and volatility such as

[1] CIS-7 list of countries includes Armenia, Azerbaijan, Georgia, Kyrgyzstan, Moldova, Tajikistan and Uzbekistan.

the portfolio balance channel, the liquidity channel, the signaling channel and the noise-trading channel.[2]

Regarding interventions' determinants (1), a number of researchers have estimated an *ad hoc* central bank reaction function to investigate intervention motives (Edison 1993 surveys the literature on reaction functions). In general, most of these studies find strong evidence for a lean-against-the-wind. That is, central banks prevent the exchange rate from moving in one direction via deliberate operations that result in its movement in the opposite direction. However, as most of the central banks do not publish official intervention high-frequency data (or have started to publish only recently), the results on motives differ across countries depending on the proxies for the intervention variable and the data frequency (Gersl, 2006). In this paper, the actual daily intervention data is used to estimate the NBG reaction function.

Recent studies focusing on (2) investigate an interventions' effectiveness directly regressing the changes in the exchange rate on the intervention variable and other exogenous variables. To account for a possible endogeneity problem, many researchers use the instrumental variables/the two stage least squares (IV/2SLS) approach. For example, Égert and Komárek (2005) use lagged interventions as an instrument for current interventions, while Disyatat and Galati (2005) run variation of 2SLS using reaction function predicted values as instruments. Fatum and Hutchison (2003) employ an event study approach in this context. The impact of forex interventions on volatility is studied using the GARCH framework and high-frequency data (Baillie and Osterberg, 1997, Gersl, 2006, Dominguez, 1998, Ito, 2003, Hillebrand and Schnabl, 2003, and many others).

This paper contributes to the existing literature by presenting new evidence on the related issues of determinants and effectiveness of the sterilized

[2] This literature is inconclusive in testing the relevance of these channels. Humpage and Osterberg (1992), Dominguez and Frankel (1993b), and Baillie and Osterberg (1997) find a significant portfolio balance channel; on the other hand, Dominguez and Frankel (1993a) survey the studies that do not. Dominguez (1992) confirms the signaling effect, but Klein and Rosengren (1991) find evidence to the contrary. Finally, Dominguez (2003) argues that the central bank interventions influence intra-daily foreign exchange returns and volatility through information and noise trading channels.

interventions. The careful empirical analysis of newly available daily and monthly interventions data of the National Bank of Georgia for the period 1996-2007 is performed by exploiting most recent methodological advances. Prior to the estimation, an endogenous search for structural breaks the data is performed to account for ongoing transformation process in Georgia.[3] In order to determine the factors that trigger interventions, the OLS, the IV, and the binary regressions are estimated. Analyzing the effectiveness of the interventions, first, the relevance of the theoretical portfolio balance channel is tested using the IV/2SLS. Second, the impact of interventions on the level and the volatility of the exchange rate without reference to any particular transmission channel is tested using GARCH-M framework. This combination of the most recent methodologies is used to examine two related questions of what causes the central bank to intervene and whether the interventions are, in fact, effective.

The results of the paper suggest that the main structural break in the GEL/USD exchange rate is a preamble for the exchange rate policy change to floating in 1998. As for the interventions determinants, the daily OLS and the IV regressions show that the central bank prevents the exchange rate from moving in one direction via deliberate operations that result in its movement in the opposite direction (leaning-against-the-wind). There is also evidence suggesting that the NBG targets the exchange rate level and aims to decrease volatility. The daily actual decision to intervene in the binary Logit regression is mainly driven by the exchange rate targeting, by the short-run depreciation rate, and by the increased volatility. The interventions are found to be effective with respect to the level of the exchange rate. The daily 2SLS/IV and the GARCH estimation results indicate that the sales of foreign currency lead to the appreciation of the domestic currency. Also, the change in asset suppliers influences the monthly currency risk premium suggesting that sterilized intervention works through the portfolio balance channel. Nevertheless, effectiveness-in-mean has a price, namely,

[3] The timing of country-specific events does not necessarily coincide with structural breaks in the macroeconomic data. Kočenda (2005) finds that a break in the exchange rate occurs before the exchange rate policy shifts in a number of European transition countries.

the daily intervention activity increases the volatility of the exchange rate.

The rest of the paper is organized as follows. Section II briefly describes the employed methodology to search for structural breaks, to estimate central bank reaction function, and to study the effectiveness of interventions on the level and the volatility of the exchange rate. Section III describes the Georgian foreign exchange market and discusses the data used in the estimation. Section IV reports empirical findings for the structural break tests in the data, intervention determinants, the relevance of portfolio balance channel, and the effectiveness with respect to the exchange rate level and volatility. Section V concludes.

# II Methodology

## II.1 Structural break tests

When investigating determinants and effectiveness of interventions, one has to take into account the possibility of structural breaks in a series. If an existing break is neglected, the estimation results will be inconsistent. Also, a break biases stationarity tests towards detecting unit root while series are stationary with break (broken trend stationary). There is a wide variety of structural break and broken trend stationarity tests in the literature. In this paper, the Vogelsang (1997) and the Perron (1989) tests are applied to the exchange rates (GEL/USD, GEL/RUR) and to the forex interventions time series.

The test proposed by Vogelsang (1997) endogenously searches for a single break point in a series. The specification of this test is robust to the unit-root dynamics of the series, does not impose restrictions on the nature of the data and the distribution of errors, and can be applied to a general polynomial function of time. The null hypothesis of no break is tested for a data generating process. To perform the Vogelsang test for a time series $\{y_t\}$, a reparametrisation for the data generating process is used and then the following equation is estimated:

$$\Delta y_t = \beta_0 + \sum_{t=1}^{p} \beta_i t^i + \delta_0 DU_t + \sum_{t=1}^{p} \delta_i (DT_t)^i + \pi y_{t-1} + \sum_{t=1}^{K} \rho_i \Delta y_{t-i} + \varepsilon_t, \quad (1)$$

where the dummy variables for the structural break are: $DU_t = 1$ for $t > T_B^C$ and zero otherwise, $DT_t = t - T_B^C$ for $t > T_B^C$ and zero otherwise with $T_B^C$ being the unknown time of break.

This specification allows for a shift in level and trend at the break point. The serial correlation in errors is addressed by including lags of a dependent variable. The appropriate number of lags is usually determined using the method proposed by Campbell and Perron (1991) by setting the upper bound to eight and reducing it until the estimate of the coefficient at the highest lag is significant at the 10% level.

The OLS estimation of the equation (1) is done for all possible break dates $T_B^C = \lambda T, \lambda \in [\lambda^*, 1 - \lambda]$, where $\lambda^*$ is a trimming parameter that represents the portion of the time span that is not allowed to contain a break, and $T$ is the number of observations. There are two possible values of the parameter $\lambda^*$: 0.01 and 0.15. The parameter's choice depends on the expectations of where the break appears. If the break is likely to appear in the beginning or at the end of the sample, the trimming parameter is set to 0.01. In the case of a middle break, $\lambda^* = 0.15$. For each of the estimated equations that differ in the potential break date, the hypothesis $\delta_i = 0$ is tested computing the usual F-test. Finally, the statistic SupF is calculated as the maximum over all F-statistics. The null hypothesis of no break is rejected if this statistic is greater than the appropriate critical value in asolute value.

Next, the break detected by the Vogelsang test is used as the expected break in the Perron test for an exogenous structural break and the broken trend stationarity. The Perron's null hypothesis is that a series has a unit root with an exogenous structural break that occurs at the given date. The alternative hypothesis is stationarity around deterministic time trend with an exogenous change. A model that allows an exogenous change in both the linear trend coefficient and in the intercept is estimated

$$\Delta y_t = \mu + \beta t + dD(T_B)_t + \theta DU_t + \gamma DT_t + \alpha y_{t-1} + \sum_{t=1}^{K} \rho_i \Delta y_{t-i} + \varepsilon_t.$$

In this specification, $T_B$ is the predetermined break date. The dummies are $D(T_B)_t - 1$ for $t = T_B + 1$ and zero otherwise; and $DU_t - 1$ for $t > T_B$ and zero otherwise; $DT_t = t - T_B$ for $t > T_B$ and zero otherwise.

The test critical values differ with the pre-break fraction $\lambda = T_B/T$. This fraction accounts for the break timing with respect to the whole time span. If the calculated t-statistic is lower than the appropriate critical value, the $H_0$ of UR with a break is rejected in favor of the broken trend stationarity.

## II.2 Determinants of interventions

Ideally, the central bank reaction function is derived from a theoretical model, typically based on a loss function of the central bank (for example, Almekinders, 1995). However, most studies on intervention determinants postulate central bank reaction function without any theoretical background (*ad hoc*). [4]A typical *ad hoc* central bank reaction function looks as follows.

$$I_t = \beta_0 + \beta_1 \Delta e_t + \beta_2 (e_t - e_t^T) + \beta_3 I_{t-1} + \varepsilon_t. \tag{2}$$

In this specification, $I_t$ is the amount of central bank net intervention (sales minus purchases) in period t; $e_t$ is the level of the exchange rate in units of domestic currency per one unit of foreign currency in the period t; $e_t^T$ is the targeted level of exchange rate in period t;[5] $\Delta$ is the absolute change in the exchange rate level between periods t and (t-1). Some studies use percentage change rather than absolute change, i.e. the first difference in the logarithm of the exchange rate level (for example, Dominguez and Frankel 1993a). The lagged intervention variable $I_{t-1}$ is included as a proxy for unobservable factors that may influence interventions and controls for first-order autocorrelation that is usually found in the intervention data.

[4]For example, Edison (1993) and Gersl (2006) survey literature on *ad hoc* reaction functions.

[5]The targeted level of the exchange rate is usually set to the moving average of the spot exchange rate or to the purchasing power parity equilibrium level (Ito, 2003).

Several hypotheses about intervention motives can be tested based on estimated coefficients and t-statistics. First, a central bank may want to prevent the exchange rate from moving in one direction by using interventions that have an opposite effect (leaning against the wind) or to push the exchange rate further in its trend (leaning with the wind). The coefficient $\beta_1$ would be significantly positive or significantly negative respectively. Second, a significantly positive coefficient $\beta_2$ would indicate that a central bank is targeting a level of the exchange rate.

The direct inclusion of the exchange rate volatility[6] into the above reaction function estimated across periods with different directions of interventions is likely to lead to its insignificant coefficient. Moreover, the sign of the volatility coefficient would not be clearly interpretable. The volatility measure is always positive but the same degree of volatility in the depreciation sub-period has the opposite effect on the interventions than in the appreciation sub-period (Gersl, 2006). Thus, the reaction function with an exchange rate volatility is usually estimated over sub-periods.

The main problem of estimating the reaction function (2) by OLS lies in potential simultaneity (and endogeneity) bias. The change in the exchange rate may be to some extent dependent on interventions. This problem is especially severe if the estimation is conducted using low frequency data (weekly, quarterly, or monthly). If interventions are effective, the probability of endogenous determination increases. A usual practice in dealing with this problem is to replace the current values of the exchange rate with lagged values. This method is risky when applying it to low frequency data as lagged values of exchange rates might be correlated with the lagged intervention variable that is included as an explanatory variable (multicollinearity). Another possibility is to use current and lagged values of the exchange rate as IV for current exchange rate or to follow the Arellano-Bond (AB, Arellano and Bond, 1991) approach. In the AB model, first differences of predetermined and endogenous variables are instrumented with suitable lags of their own levels.

Separating the actual decision to intervene from the decision on the

[6] For the volatility variable the squared changes in exchange rate or moving standard deviation/variance are used in the literature (for example, Hillebrand and Schnabl, 2006).

amount to intervene, binary choice models are frequently used to estimate the probability of intervention rather than the precise amount. Define dummy equals one if intervention took place and zero otherwise. The probability to intervene is then estimated via maximum likelihood from the model $P(D_t = 1/x_t) = F(\beta x_t)$ , where F is the standard normal distribution function (the Probit model) or the logistic cumulative distribution function (the Logit model).[7]

The vector of explanatory variables $x_t$ includes the factors that trigger but do not explicitly refer to the direction of interventions, such as the change in the exchange rate, the deviation of exchange rate from targeted level, and the previous day's intervention amount. The exchange rate volatility and the lagged $D_t$ can be included as explanatory variables only in the model to be estimated separately for the sales and purchases of the foreign exchange.

The signs of estimated coefficients give the direction of the effect of the change in the explanatory variable on the probability of intervention. Marginal effects of continuous explanatory variables on the response probability are calculated by rescaling the estimated coefficients. The scale factor is usually evaluated at the sample means of the explanatory variables. One can also use a rule of thumb: 0.25 times a Logit slope parameter is approximately equivalent to a linear probability model's slope parameter.

## II.3 Effectiveness of interventions

### II.3.1 Impact of interventions on the exchange rate level

In testing the effectiveness of interventions on the exchange rate level, the IV approach is widely used to account for potential endogeneity bias (for example, Egert and Komarek, 2005). The following equation is estimated using the lagged interventions as IV for the current interventions $I_t$ :

$$\Delta e_t = \alpha_0 + \alpha_1 I_t + \alpha_1 X_t + \varepsilon_t. \qquad (3)$$

[7]Despite some differences between these two models, both seem equally suitable for discreet choice analysis of interventions (see Gersl, 2006).

The variable $\Delta e_t$ denotes changes in the exchange rate from the period (t-1) to the period t, and $X_t$ represents explanatory variables that might affect changes in the exchange rate (such as foreign interest rate or changes in exchange rates of other currencies that can be treated as substitutes). Note that this general specification does not refer to any particular channel of influence.

Another approach is a procedure similar to the 2SLS estimation (Galati, Melick and Micu, 2005). First, the reaction function of the central bank is estimated using the lagged exchange rate as IV for the current exchange rate, and the predicted values are obtained. Second, the equation (3) is estimated using these predicted values of interventions as IV for the current interventions.

The IV methodology is also used to test the relevance of the portfolio balance channel of sterilized interventions (Dominguez, and Frankel 1993). In the portfolio balance theory, the equilibrium portfolio share $s_t$ that is allocated to domestic assets is a function of risk premium $rp_t$: $s_t = a + brp_t$. In the case of the forex market, the risk premium is defined as $rp_t = ir^d_{t,k} - ir^f_{t,k} + \Delta e^e_{t,k}$, and $s_t$ is the central bank intervention. The variables $ir^d_{t,k}$, $ir^f_{t,k}$ are k-period ahead of the domestic and foreign interest rates respectively, and $\Delta e^e_{t,k}$ is the expected exchange rate change k-periods ahead.

The risk premium is expressed as $rp_t = -ab^{-1} + b^{-1}s_t$. If domestic and foreign assets were perfect substitutes, the coefficient $b^{-1}$ would be zero, which means that the assets supply would not have any impact on the risk premium. In the portfolio balance theory, the assets are imperfect substitutes. Under rational expectations assumption, the expected and *ex post* exchange rate changes differ only in forecast error $\varepsilon_{t,k}$: $\Delta e^e_{t,k} = \Delta e_{t,k} + \varepsilon_{t,k}$. As investors optimize the function of the mean and variance of end-period wealth, the coefficient $b^{-1}$ is inversely proportional to the variance $v_t$ of the exchange rate changes in the case of the non-stochastic prices: $b^{-1} = r/v_t$, where $r$ is a coefficient of relative risk aversion. Thus, the risk premium equation becomes

$ir^d_{t,k} - ir^f_{t,k} + \Delta e_{t,k} = \alpha + \beta_1 v_t + \beta_2 v_t s_t + \varepsilon_{t,k}$, where $\beta_1 = -ar$, $\beta_2 - r$.

The error term reflects investors forecasting errors. This equation is estimated using IV to capture the potential simultaneity bias. In the literature, different IVs that are correlated with spot exchange rate and actual asset suppliers but uncorrelated with error term are used. For example, these are lagged interventions, news about changes in the exchange rate policy, and secret/official interventions dummy (Dominguez and Frankel, 1993). Unfortunately, data on the NBG announcements are not available, and lagged interventions are used as IV for the current interventions.

### II.3.2 Impact of interventions on the exchange rate volatility

The generalized autoregressive conditional heteroskedastic (GARCH) model was proposed by Bollerslev (1986). This model allows for a longer memory and a more flexible lag structure in the basic autoregressive conditional heteroskedastic (ARCH) model. Since then, GARCH methodology has been widely used to analyze the impact of interventions on the exchange rate level and volatility.[8]

Most studies analyze the effectiveness of interventions using a baseline GARCH (1,1) model for the change in the exchange rate $\Delta e_t$ ,estimating both the effect of interventions on levels (in the mean equation) and on conditional volatility (in the variance equation):

$$\begin{aligned}\Delta e_t &= \gamma_0 + \gamma_1 I_t + \sum_{i=2}^{n} \gamma_i X_{it} + \varepsilon_t, \\ v_t &= \alpha_0 + \alpha_1 v_{t-1} + \alpha_2 \varepsilon_{t-1}^2 + \alpha_3 \mid I_t \mid + \sum_{i=4}^{n} \alpha_i X_{it} + u_t.\end{aligned}$$

In the mean equation, change in the exchange rate $\Delta e_t$ is a function of the intervention variable $I_t$, other exogenous variables $X_{it}$ (for example, foreign interest rate, or changes in the exchange rate of some "peer" currencies), and the error term.

The conditional variance $v_t$ depends on the constant term $\alpha_0$; on the GARCH term $v_{t-1}$that represents the last period's forecast variance; on the ARCH term $\varepsilon_{t-1}^2$that reflects the news about volatility from the previous period, measured as the lag of the squared residual from the mean equation;

[8]See Baillie and Osterberg (1997); Gersl (2006); Dominguez (1998); Egert and Komarek (2005); Ito (2003); Hillebrand and Schnabl (2003); and many others.

on the absolute value of the intervention variable; and on other exogenous variables. The sum of the ARCH and GARCH coefficients shows the speed of convergence of the forecast of the conditional volatility to a steady state.

Several interventions studies (for example, Dominguez, 1998) extend the baseline GARCH framework for analyzing the effectiveness of interventions by introducing conditional variance (standard deviation, or variance in logarithmic form) into the mean equation (GARCH-M). This class of models initially is well suited to study asset markets as an asset's riskiness can be measured as the variance of its return. In the forex market case, the mean of an asset's return (change in the exchange rate) depends on its (logarithm of) conditional variance:

$$\begin{aligned} \Delta e_t &= \gamma_0 + \gamma_1 I_t + \sum_{i=2}^{n} \gamma_i X_{it} + \gamma_{n+1} \ln v_t + \varepsilon_t, \\ v_t &= \alpha_0 + \alpha_1 v_{t-1} + \alpha_2 \varepsilon_{t-1}^2 + \alpha_3 \mid I_t \mid + \sum_{i=4}^{n} \alpha_i X_{it} + u_t. \end{aligned}$$

To complete the GARCH specification, the conditional distribution of the error term is specified. The commonly used distributions are the Normal (Gaussian) distribution, the Student's t-distribution, and the Generalized Error Distribution (GED, Nelson, 1991). Most of the empirical studies estimating a GARCH-type model simply assume Normal or Student's distribution. The GED distribution captures the fat tails usually observed in the distribution of a financial time series. In particular, this distribution is used to avoid the overestimation of volatility in the case of leptokurtic distribution of conditional volatility derived from data.[9]

Given the distributional assumption, the GARCH model is estimated by the method of maximum likelihood. The estimated key parameters in the variance equation must be significant and must satisfy restrictions of stability and non-negativity of variance:

$$\alpha_0 > 0; \alpha_1, \alpha_2 \geq 0; \alpha_0 + \alpha_1 + \alpha_2 < 1.$$

[9] Rahman and Saadi (2005) show that although the day of the week effect in the mean is independent of imposed error distribution, this result is sensitive to error distribution in the conditional volatility case.

After the GARCH model is estimated, diagnostic tests must be performed. Q-statistics for a model's standardized residuals $\varepsilon_t/v_t$ provide a test for the specification and remaining serial correlation in the mean equation. If the mean equation is correctly specified, all Q-statistics should not be significant. Similarly, a correlogram of squared standardized residuals is used to test the variance equation specification. Another possibility is to perform Ljung-Box test on the standardized residuals.

The next step is to verify that the standardized residuals are independent and identically distributed (iid) as it should be in the case of a correctly specified model. In order to test the residual's iid, in this paper, two tests are applied, namely the BDS (Brock, Dechert, Scheinkman, and LeBaron, 1996) and the Kocenda (Kocenda, 2001; Kocenda and Briatka, 2005) tests.[10]

The BDS test detects the hidden nonlinearities independent of linear dependencies in the data. The null hypothesis is that the series are iid and the alternative is unspecified. The critical values for two-sided BDS statistics differ in the proximity parameter (tolerance distance) $\varepsilon$, embedding dimension $m$, sample size $T$, and critical values. The *ex ante* dependence on $\varepsilon$ and $m$ represents the main weakness of the BDS test as it can make the test results ambiguous. The Kocenda's alternative test eliminates the arbitrariness in the choice of the proximity parameter $\varepsilon$ leaving only the choice of $m$.

# III Data Description

## III.1 Tbilisi Interbank Foreign Exchange Market

Every working day, before the Tbilisi Interbank Foreign Exchange (TIFEX) trade session starts, the NBG computes the demand-supply ratio for foreign currency from the local commercial banks based on their preliminary bids received by the TIFEX electronic system. Based on this demand-supply ratio, current economic conditions, and the trends in monetary and

[10] The technical details of the tests are provided in the appendix.

foreign exchange policy, the NBG decides on the volume of interventions. The NBG claims to intervene mainly in order to stabilize the forex market.

The trade at the TIFEX market is held mostly in US dollars.[11] The market participants are local commercial banks and the NBG. Central bank interventions are sterilized: the NBG sells certificates of deposits to the commercial banks in order not to alter money supply and not to cause inflation. The exchange rate of the national currency (lari) against the US dollar is defined by open fixing: the exchange rate GEL/USD is fixed when the demand for foreign currency becomes equal to the supply level after TIFEX trade session.

## III.2 Data set

The data set used in this paper includes the precise dates and amounts of the NBG daily and monthly foreign exchange interventions (sales and purchases of the US dollar on the TIFEX market); the official daily and monthly exchange rates (GEL/USD, GEL/RUR), and monthly interest rates on deposits of Georgian commercial banks. The data has been provided by the NBG research department. In addition, the US data on the interest rate on certificates of deposit is used for estimation.

The daily data covers the period 01/01/1996 – 19/04/2007. The NBG net interventions are shown in Figure 1.[12] The "peak" interventions are caused by high USD demand or supply by local commercial banks and are not related to any specific shock or event in the economy. The high demand mainly arises from the need for domestic banks to pay loans or credit lines to foreign banks. The excess supply of US dollars usually results from a foreign capital inflow into Georgian commercial banks. The largest intervention at the end of November 2006 is not shown in Figure 1. The NBG made an 89 million USD purchase on the forex market, which is an outlier in the whole sample. The reason for such a big intervention was the very high demand for the lari by one of the biggest local banks (the Bank of Georgia). The

[11] The time series of the EURO and the Russian ruble interventions are much shorter and are not analyzed in this paper.

[12] The net intervention is defined as the amount of the USD sold minus the USD purchased.

shares of this bank were sold on the London Stock Exchange Market for the amount of 120 million USD, and this bank converted this amount into GEL in November 2006. From December 1998 until the second part of 2004, following the IMF recommendations, the NBG only purchases the USD. However, starting from the second half of the year 2004, the central bank significantly increased intervention activity in both directions.

In Figures 2 and 3, the exchange rates of the lari against the US dollar and against the Russian ruble are depicted respectively. Notice that until 1998 the annual lari depreciation rate against the USD was only about 2-3 percent under the managed floating exchange rate regime. However, after the Russian crises in 1998, the rate of depreciation was very high and the central bank implemented a tight monetary policy through foreign exchange interventions. In December 1998, the exchange rate regime was switched to free-floating. Since this switch, the domestic currency gradually depreciated against the US dollar until the year 2002. However, starting from 2002, the lari has continuously appreciated.

Tables 1 and 2 provide the summary statistics and the stationarity tests for the GEL/USD exchange rate (*usd*); differenced GEL/USD exchange rate (*dusd*); the GEL/RUR exchange rate in levels and differences (*rur*, *drur*); net interventions (*net*); and differenced net interventions (*dnet*). The result of a Q-test for high order serial correlation in *dusd* is given in the last row.

The monthly time series cover the period January, 1996 - February, 2007. The graphs of monthly interventions and exchange rates (both GEL/USD and GEL/RUR) are shown in Figures 4, 5 and 6. Table 2 provides summary statistics for monthly interventions (*net*, *dnet*); exchange rates (*usd*, *dusd*, *rur*, *drur*); domestic (*std*) and foreign (*cda*) interest rates on deposits; and the interest rate differential (*ird*) defined as differences between the domestic and the foreign interest rates.

# IV Estimation Results

## IV.1 Structural breaks

An endogenous search for structural breaks and a test for broken trend stationarity are performed in this section. This is done in order to include variables in correct form (levels versus differences) and to split the sample for further investigation. The time series that are most likely to have a break are considered. They are the GEL/USD exchange rate (*usd*), the differenced exchange rate GEL/USD (*dusd*); the GEL/RUR exchange rate (*rur*), the differenced GEL/USD exchange rate (*drur*); and the net interventions (*net*), the differenced net interventions (*dnet*).

First, the Vogelsang and the Perron tests are applied to the series over the period 1996- 2007. Second, focus is on the period after the exchange rate regime change to the floating in December 1998. The results of the Vogelsang and Perron tests are given in Tables 3, 4, 5, and 6.

To summarize the results, the Vogelsang test detected two main structural breaks in the GEL/USD exchange rate series. The first one took place in November 1998. This break happened shortly before the exchange rate regime was revisited and, thus, can be seen as a preamble to the exchange rate policy change from a managed to a free floating regime in December 1998.[13] In the second half of 1998, the Russian crises had a large negative impact on the Georgian economy and, in particular, on the value of the domestic currency. The central bank implemented a tight monetary policy through foreign exchange interventions, and after several months, in December 1998, was the exchange rate regime switched to a free-float. That is, the monetary authority responded with this policy step to accommodate the structural break in the exchange rate. Note, however, that the break in the changes of exchange rate appears only in March 1999, that is, after the exchange rate regime change.

One more break in the GEL/USD exchange rate marks the end of the lari's continuous depreciation and is not associated with any policy step. This break occurred in November 2001 for the exchange rate level, and in

[13] Kocenda (2005) obtains a similar result for a number of Central European countries.

December 2001-January 2002 for the exchange rate differences.

The GEL/RUR exchange rate series has a structural break in August-September 1998. Following the ruble denomination in January 1998 (one new Ruble was set to equal 1000 old rubles), the Russian crises took place in August 1998.

The net interventions series has a structural break on 27 November 2006. This is the exact day the NBG purchased the largest amount of the US dollar, which was caused by a very high demand for the domestic currency by a local commercial bank (see Section III.2). Thus, this break is not connected to any exchange rate or intervention policy changes.

The Perron test indicates that the daily exchange rates and net interventions series are broken trend stationary, while the monthly series are integrated of order one with an exogenous change at the break date indicated by the Vogelsang test. Thus, the series are included in levels in daily analysis, and in first differences in monthly estimation.

## IV.2 Estimating the NBG daily reaction functions

In this subsection, the determinants of the NBG interventions are examined. Daily continuous reaction functions are estimated over the sample 1996-2007, and over two sub-samples characterized by interventions of the same sign (only the USD purchases) and by the lari appreciation. In order to account for simultaneity bias, first, the current values of the GEL/USD exchange rate are replaced with the lagged, and equations are estimated via OLS. Second, current values are instrumented with lags.[14] Next, binary reaction functions are estimated.

The general specification of the continuous reaction function is

$$I_t = \beta_0 + \beta_1(e_t - e_{t-1}) + \beta_2(e_t - e_{t-20}) + \beta_3(e_t - e_t^T) + \\ + \beta_4(\Delta e_t)^2 + \beta_5 I_{t-1} + \beta_6 d1 + \beta_7 d2 + \beta_8 d3 + \varepsilon_t. \quad (4)$$

The dependent variable $I_t$ is the NBG net intervention (amount of

[14]The reaction function in first differences with lags in levels as instruments (AB approach) does not give significant results.

the USD sold minus purchased) at the day t. First, the NBG may decide on the amount of intervention based on exchange rate movements in the short and the medium run (leaning with/against the wind). That is, the (absolute) change[15] in the exchange rate from the previous day $(e_t - e_{t-1})$ and the change from previous 20 business days[16] $(e_t - e_{t-20})$ are introduced as explanatory variables.

Second, the NBG may intervene if the lagged spot exchange rate deviates from its target $e_t^T$, which is allowed to be time-dependent and is set as a 10-day backward moving average. The volatility that can trigger the decision on the intervention's amount is measured as squared changes in the exchange rate as in Hillebrand and Schnabl (2006). The variable $I_{t-1}$ is the previous day's intervention that is expected to influence the current intervention amount. Finally, three dummies are included to capture the detected structural breaks in the interventions and differenced exchange rate series. Precisely,

$$d1 = \left\{ \begin{array}{c} 1, t < 27/11/06 \\ 0, t \geq 27/11/06 \end{array} \right\}, d2 = \left\{ \begin{array}{c} 1, t < 16/03/99 \\ 0, t \geq 16/03/99 \end{array} \right\},$$
$$d3 = \left\{ \begin{array}{c} 1, t < 27/12/01 \\ 0, t \geq 27/12/01 \end{array} \right\}. \tag{5}$$

The specifications of reaction functions estimated over three periods are imbedded in (4). They differ in the inclusion of the exchange rate volatility and dummies. Namely, the volatility measure is not included into the regression ( $\beta_4 = 0$) for the whole sample because its sign would not be clearly interpretable (see Section II.2).[17] The second reaction function is estimated over the sub-period with the same direction of interventions. The NBG was only purchasing the US dollar during the period 07/12/1998 - 14/09/2004. The exchange rate volatility is introduced, and $\beta_6 = 0$. Finally, the third reaction function is estimated over the lari appreciation sub-period 26/02/2002 - 19/04/2007, where $\beta_7 = \beta_8 = 0$ and $\beta_4 \neq 0$.

[15] The percentage measure of the change in the exchange rate leads to similar results.
[16] The approximate amount of one month's working days.
[17] In fact, the volatility coefficient turns out to be insignificant in regression estimated over the whole sample.

First, these reaction functions are estimated over three periods with current values of the exchange rate replaced with lagged. Second, the lagged and current values are used as instruments for the first three variables in period t. As to volatility, it is not assumed to be exogenous, but is believed to be to some extent dependent on the intervention activity. Thus, the lagged volatility is included.[18]

The estimation results of OLS and IV techniques and specification tests are given in Tables 7 and 8. The results give clear evidence that the NBG is expected to intervene if the spot exchange rate deviates from the target exchange rate in the full sample and in the appreciation sub-samples. However, the instrumented targeting motive is not significant in the first sub-period.

Looking at the whole sample (Table 7), there is evidence of a medium-run leaning against the wind. That is, the lari depreciation in the preceding 20 business days prompts an intervention of buying the lari and thus selling the USD. The short-run effect is, however, insignificant in the OLS regression over the whole sample.

Next, the NBG leans against the wind both in the short- and medium-run in the first sub-period of USD purchases. In the second sub-period, the short-run leaning-against-the-wind motive is significant, but results are unambiguous for the medium-term effect. The exchange rate volatility in the sub-sample of USD purchases is significant determinant of intervention. Note that its sign is not clearly interpretable as the lari first depreciated and then appreciated. In the lari appreciation (second) sub-period, the NBG attempts to decrease volatility.

Table 9 presents estimation results of the binary reaction function. First, the Logit model[19] is estimated over the whole sample with dependent variable $D_t$ that equals to one if intervention took place and zero otherwise. The probability to intervene is estimated via maximum likelihood from the model $P(D_t = 1 \mid x_t) = F(\beta x_t)$, where F is a logistic cumulative distribution function. The vector of explanatory variables $x_t$ includes the (lagged) short-term and medium-term change in the exchange rate, the deviation of

[18] The instrumented current volatility with its lags leads to roughly similar results.

[19] The Probit estimation gives similar results.

exchange rate from the targeted level, and the previous day's intervention amount. Second, the model is estimated separately for the period of the lari appreciation, adding the lagged and the exchange rate volatility to the list of explanatory variables.

In the regression estimated over the whole sample, first, the results give evidence that the NBG intervenes when the exchange rate deviates from a targeted value (scale factor 0.247). Second, the negative value of the lagged intervention coefficient implies that an increase in the previous day's amount of the USD sold decreases the probability of the response. The probability to intervene increases with the short- and medium-run depreciation rate. In the sample of the lari appreciation (scale factor is 0.243), the previous period's deviation from the target, the short-run exchange rate change increase the response probability. The volatility is also a significant determinant of decision to intervene.

## IV.3 Testing the effectiveness of interventions

### IV.3.1 Impact on the level of the exchange rate

Immediate (one day) and short-run (two-four days) impacts of the interventions on the changes in the exchange rate level over one-, two-, and three-day periods are estimated. The estimation procedure is as follows. First, the reaction function over the period 1996-2007 is re-estimated by IV with only significant variables left and predicted values are obtained. Second, the following exchange rate equation is estimated using the predicted values from the reaction function as instruments for the interventions:

$$\Delta e_t = \beta_1 + \sum_{i=0}^{4} \alpha_i I_{t-i} + \beta_2 dffr_{t-1} + \beta_3 drur_{t-1} + \beta_4 d1 + \beta_5 d2 + \beta_6 d3 + \beta_7 d4 + \varepsilon_t.$$

The dummies are defined as in (5) and

$$d4 = \left\{ \begin{array}{l} 1, t < 26/08/98 \\ 0, t \geq 26/08/98 \end{array} \right\} \qquad (6)$$

The change in the exchange rate at the end of the day t is expected to be dependent on the volume of the current (t) and lagged NBG interventions. For other exogenous variables the (lagged) change in the US Federal Fund Rate (*dffr*) and in the GEL/RUR exchange rate (*drur*) are included. The GEL/EURO exchange rate is not included as the series start only from 2003. Intuitively, if the foreign interest rate goes up, domestic bonds are substituted with foreign bonds, and thus, the domestic money supply increases and the local currency depreciates. From balanced portfolio perspective, the investor can treat other foreign currency (RUR)[20] as a substitute for the US dollar in his currency portfolio.

Table 10 shows the estimation results of three regressions.[21] The first regression (regression I in Table 10) estimates the impact of the current and lagged interventions on the one-day change in the exchange rate. The immediate impact of the interventions on the changes in the exchange rate level is significant and positive. This means that the increase in the NBG net (foreign currency sales minus purchases) intervention leads to the lari depreciating in the same day. However, if the intervention is effective the negative coefficient is expected, i.e. the sales of the foreign currency are associated with the appreciation of the domestic currency. This is true for the third and fourth day's interventions but only at 10% significance level.

The impact of the interventions on the two and three day's change in the level of the exchange rate are given by regressions II and III respectively in Table 10. Again, only lagged interventions have an expected negative marginally significant impact on the change in the exchange rate level.

The coefficient of the (lagged) change in the Federal Fund Rate is insignificant. The changes in the GEL/RUR exchange rate have a positive impact on the change in the GEL/USD exchange rate indicating that not a substitution but a wealth effect is present in the investor's behavior.

Next, the IV methodology is used to test the relevance of the portfolio balance channel of sterilized interventions. Due to a lack of the daily data on the domestic interest rates the monthly frequency data over the period January, 1996- February, 2007 are used.

[20] Russia is the main trade partner of Georgia (76% of Georgian foreign trade).
[21] Surprisingly, the structural break dummies are insignificant and are not reported.

The following model is estimated using the lagged interventions as IV for the current interventions:

$$\begin{aligned} drp_t &= \alpha + \beta_1 v_t + \beta_2 v_t DI_t + \beta_3 d1 + \beta_4 d2 + \beta_5 d3 + \varepsilon_{t,k}, \\ \varepsilon_{t,k} &= u_{t,k} - \theta u_{t-1,k}. \end{aligned}$$

The risk premium variable is found to be the integrated of order one and thus, is included in first differences $drp_t$ into the regression. The variable $DI_t$ denotes the first differenced net interventions, $v_t$ is the variance of the exchange rate changes. The forecast error follows the MA(1) process to account for serial correlation as in Humpage and Osterberg (1992). Three different volatility measures are employed: the changes in squared exchange rate, moving variance, and the conditional volatility from a simple monthly GARCH model[22]

$$\begin{aligned} \Delta e_t &= \gamma_0 + \gamma_1 DI_{t-1} + \gamma_2 d1 + \gamma_3 d2 + \gamma_4 d3 + \varepsilon_t, \\ \varepsilon_t &\mid \Omega_{t-1} \sim GED, \\ v_t &= \delta_0 + \delta_1 \varepsilon_{t-1}^2 + \delta_2 v_{t-1} + \delta_3 |DI_t| + \delta_4 d1 + \delta_5 d2 + \delta_6 d3 + u_t. \end{aligned}$$

All volatility measures lead to similar results. Three dummies as in (5) account for structural breaks.

The estimation results of the portfolio balance effect for the risk premium are given in Table 11. The coefficient of the main interest is $\beta_2$. It is significant at the 10% level in the one-month-ahead and three-month equations. In ten-months ahead risk premium equation it is significant at the 5% level. This implies that the instrumented interventions have at least a marginal impact on the risk premium defined as the interest rates differential minus *ex post* depreciation. Thus, the change in asset suppliers has an effect on risk premium.[23]

[22] As this monthly GARCH model is not of the main focus itself, the results are not provided for the sake of brevity. The model passes necessary specification and diagnostic tests.

[23] Intervention matters for the change in the risk premium if it is assumed that the interest rate differential does not fully absorb the impact of intervention (Dominguez, 1993).

The marginal significance might be caused by a small monthly sample size (134 for levels). Alternatively, it can be the problem of measurement of the expected exchange rate changes in the risk premium. In this paper, the *ex post* changes are used as a measure for expected changes in the exchange rate. The forecasts of the exchange rate changes from an independent data set (for example, from surveys) would be more appropriate. Unfortunately, to our knowledge, Georgian survey data on the expected exchange rate changes do not exist for the period 1996-2007.

### IV.3.2 Impact on the volatility of the exchange rate

In this sub-section the effects of interventions on the level of the GEL/USD exchange rate and on the conditional volatility are analyzed within the GARCH-M framework. The GARCH-M model is specified as follows:

$$\begin{gathered}\Delta e_t = \beta_0 + \beta_1 I_{t-1} + \beta_2 \ln v_t + \beta_3 dffr_t + \beta_3 drur_t + \\ +\beta_5 d1 + \beta_6 d2 + \beta_7 d3 + \beta_8 d4 + \varepsilon_t, \\ \varepsilon_t \mid \Omega_{t-1} \sim GED, \\ v_t = \delta_0 + \delta_1 \varepsilon_{t-1}^2 + \delta_2 v_{t-1} + \delta_3 |I_{t-1}| + \delta_4 dffr_t + \\ +\delta_5 drur_t + \delta_6 d1 + \delta_7 d2 + \delta_8 d3 + \delta_9 d4 + u_t.\end{gathered}$$

In this specification, the level change in the GEL/USD exchange rate level ($\Delta e_t$ ) and the conditional volatility ($v_t$ ) depend on the lagged values of interventions ($I_{t-1}$) to control for potential simultaneity bias. The second explanatory variable in the mean equation ($\ln v_t$ ) allows for the possibility that changes in the logarithm of variance influence the conditional mean. Two explanatory variables are included: $dffr_t$ denotes the changes in the US Federal Fund Rate, and the variable $drur_t$ is first differences in the GEL/RUR exchange rate that accounts for a currency substitution effect in the investor's portfolio. The dummies are defined as in (5) and (6). In the conditional variance equation, the intervention variable is included in the absolute value form as in Dominguez (1998).

Table 12 shows the estimation and the diagnostic tests results. The conditional distribution of errors is GED. The regression's diagnostics indicate that there is no remaining GARCH in errors. Standardized residuals are iid according to the BDS test but are not iid by Kocenda's test providing additional support for using the GED in the model.

The impact of (lagged) interventions on the exchange rate level has the expected negative sign (sales of the foreign currency lead to the lari appreciation). This result is in line with the preceding section's marginal evidence. Holding other factors fixed, if conditional variance is 10% higher, the change in the exchange rate level is 0.000095 points lower. That is, the increased riskiness measured by the conditional variance acts to decrease the pace of depreciation, and thus, increases the return on currency "asset".

The change in the GEL/RUR exchange rate is significantly positive related to the change in the GEL/USD exchange rate indicating that there is no substitution effect for 'peer' currency. The coefficient of the changes in the Federal Fund Rate is positive: the increase in FFR is associated with the depreciation of the lari. Intuitively, if the foreign interest rate goes up, the domestic bonds are substituted with foreign bonds, and thus, the domestic money supply increases, and the local currency depreciates.

In the variance equation, the ARCH term, which reflects the impact of surprises from previous periods on the volatility, is significant and positive. The magnitude of the significantly positive GARCH term indicates that the variance effect is highly persistent. The restrictions for the stability and non-negativity of variance are satisfied. Next, the results suggest that the NBG intervention activity increases the conditional volatility.[24] An increase in the FFR leads to a decrease in the conditional volatility. Volatility increases with increase in the change in "peer" currency's exchange rate.

# V Conclusion

Studies on determinants and effectiveness of foreign exchange interventions in emerging-market countries are complicated by severe data limitations and neglected structural breaks in the used data series. This paper presents new evidence on the determinants and the effectiveness of the USD

[24] This is a common finding in the intervention literature (for example, Dominguez, 1998).

foreign exchange interventions conducted by the NBG during the period 1996-2007 exploiting the most recent methodological advances.

The Vogelsang and the Perron tests for daily and monthly GEL/USD and GEL/RUR exchange rates and interventions series are performed in order to include variables in the correct form and to correctly divide the sample. The Vogelsang test suggests that the first break in the GEL/USD exchange rate occurred shortly before the change in the exchange rate regime from the managed to the free floating. Thus, the regime change can be seen as the NBG responding to this structural break caused mainly by the negative impact of the Russian crises. This crisis also leads to a break in the GEL/RUR exchange rate. The second GEL/USD exchange rate break is not connected to any policy step but indicates the start of the lari's continuous appreciation. The structural break in the intervention series was caused by an increased demand for the lari by the Bank of Georgia.

Concerning daily interventions determinants, the central bank intervened when the spot exchange rate deviated from the target. There is evidence of a medium-run leaning-against-the-wind motive over the whole period. In the sub-period of USD purchases (07/12/1998 - 14/09/2004), the NBG leans against the wind both in the short- and medium-run. The exchange rate volatility is also a significant determinant of NBG intervention activity. The actual decision to intervene is mainly triggered by the short-run leaning-against-the-wind, targeting, and the exchange rate smoothing motives.

Finally, as regards to the effectiveness of the NBG interventions, the evidence shows that there exists the high-frequency connection between the sterilized intervention and both the level and volatility of exchange rates. The central bank was successful in its daily leaning-against-the-wind operations during the period 1996-2007. In particular, the sales of USD were associated with an appreciation of the domestic currency in the short-run. In monthly specification, intervention operations have an impact on the risk premium, defined as the interest rates differential minus *ex post* depreciation. However, the NBG daily intervention activity increased the conditional volatility.

# Appendix
# Tests for iid data

In order to decide if a GARCH model is the correct one or not, the model's standardized residuals are tested for being iid. In this paper, two alternative tests are applied, namely BDS and Kocenda tests.

The BDS's null hypothesis states that the time series of GARCH standardized residuals, $r_t = \frac{\varepsilon_t}{\sqrt{v_t}}$, are iid, and the alternative is not specified. To perform the test, the correlation integral for the series must be computed. The correlation integral $C_{m,T}(\varepsilon)$ measures the fraction of the series's pairs for the embedding dimension $m$ that are within tolerance distance $\varepsilon$. For the sample size $T$, define $r_t^m = (r_t, r_{t+1}, ...r_{t+m-1})$ to be the series's $m-$histories, $T_m = T - m + 1$ and the indicator function $I_\varepsilon(r_t^m, r_s^m) = \left\{ \begin{array}{c} 1, \ if\|r_t^m - r_s^m\| = \max\limits_{i=0,1,...,m-1} |r_{t+i} - r_{s+i}| < \varepsilon \\ 0, \quad otherwise \end{array} \right\}$.

Then the correlation integral is

$C_{m,T}(\varepsilon) = 2 \sum\limits_{t=1}^{T_{m-1}} \sum\limits_{s=t+1}^{T_m} I_\varepsilon(r_t^m, r_s^m)/(T_m(T_m - 1))$.

The BDS statistic is computed as

$$BDS_{m,T}(\varepsilon) = T^{1/2}[C_{m,T}(\varepsilon) - C_{1,T}(\varepsilon)^m]/\sigma_{m,T}(\varepsilon). \tag{7}$$

The variable $\sigma_{m,T}(\varepsilon)$ is the standard sample deviation of the numerator that can be consistently estimated by $4[m(m-2)C(\varepsilon)^{2m-2}(K(\varepsilon) - C(\varepsilon)^2) + K(\varepsilon)^m - C(\varepsilon)^{2m} + 2\sum\limits_{i=1}^{m-1}(C(\varepsilon)^{2i}(K(\varepsilon)^{m-i} - C(\varepsilon)^{2m-2i}) - mC(\varepsilon)^{2m-2}(K(\varepsilon) - C(\varepsilon)^2)]^{1/2}$, with $K(\varepsilon)$ and $C(\varepsilon)$ being constants: $K(\varepsilon) = (1/T^2)\sum\limits_{t=1}^{T}\sum\limits_{s=1}^{T}\sum\limits_{k=1}^{T} I_\varepsilon(r_t, r_s)$ $I_\varepsilon(r_k, r_s)$ , $C(\varepsilon) = (1/T^2)\sum\limits_{t=1}^{T}\sum\limits_{s=1}^{T} I_\varepsilon(r_t, r_s)$, and $I_\varepsilon(r_t, r_s)$ being the indicator of the event $|r_t - r_s| < \varepsilon$.

Under the null of iid, the BDS statistic (7) is asymptotically normally distributed with zero mean and unit variance. However in finite samples, simulated distributions are used. The critical values for two-sided BDS statistics differ in significance levels, proximity parameter $\varepsilon$, embedding dimension $m$, and in sample size $T$. The test is usually performed for $\varepsilon = \sigma, \sigma/2$ and $m = \overline{2, 10}$ with $\sigma$ being the standard deviation of $r_t$. Clearly, the *ex ante* dependence on $\varepsilon$ and $m$ represents the main weakness of the BDS test as it can make the test results ambiguous.

The alternative Kocenda test eliminates the arbitrariness in the choice of the proximity parameter $\varepsilon$ leaving only the choice of $m$. Define the correlation integral at embedding dimension $m$ as $C_m(\varepsilon) = \lim_{T\to\infty} C_{m,T}(\varepsilon)$ and the correlation dimension as $D = \lim_{\varepsilon\to 0} \lim_{T\to\infty} \frac{\ln C_{m,T}(\varepsilon)}{\ln \varepsilon}$. The test considers the OLS estimate of the correlation dimension over a range of proximity parameter values for each embedding dimension that equals to the slope coefficient calculated from the regression $lnC_{m,T}(\varepsilon_i) = \alpha_m + \beta_m \ln \varepsilon_i + u_i$, $i = \overline{1,n}$.

Thus, the slope coefficient estimate is

$$\beta_m = [\sum_{\varepsilon}(\ln\varepsilon - \overline{\ln\varepsilon}) \cdot (\ln C_{m,T}(\varepsilon) - \overline{\ln C_{m,T}(\varepsilon)}]/[(\sum_{\varepsilon}(\ln\varepsilon - \overline{\ln\varepsilon})^2].$$

This coefficient does not depend on an arbitrary $\varepsilon$ choice because a range of its different values is used.

In order to eliminate the erratic portion of the trajectories (leaving only a linear part) at the highest embedding dimensions ($m = 7$ to 10), the cut-off point is set. This point is a number of matches that maximizes the power of the test (or minimizes type-II error) and usually is between 40 and 50. The cut-off point does not affect the analysis for lower embedding dimensions $m$, but reduces the increasing variance as embedding dimension $m$ grows larger and the tolerance distance $\varepsilon$ becomes smaller. Moreover, the proximity parameters $\varepsilon$ are in the range where $C_m(\varepsilon) \to \varepsilon^\alpha$(scaling property) for some $\alpha$.

Under the null hypothesis that the data are iid, the slopes are equal to the respective embedding dimension $m: \ \beta_m = m$. The critical values differ in significance levels, sample sizes, embedding dimensions, and ranges of tolerance distance. The range $(0.60\sigma, 1.90\sigma)$ is showed to be optimal and is set as a default option in the test's software. Also, three other intervals can be used.

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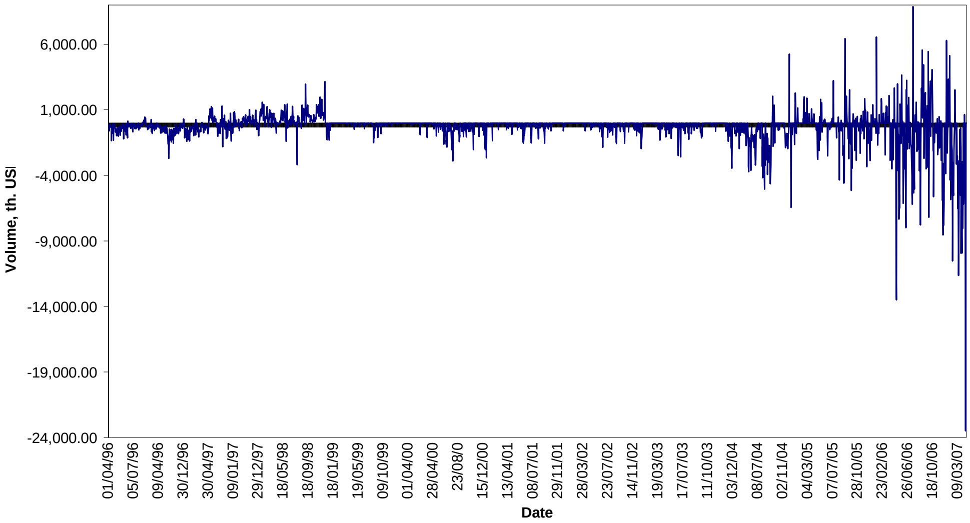


Figure 1. Daily Net Interventions

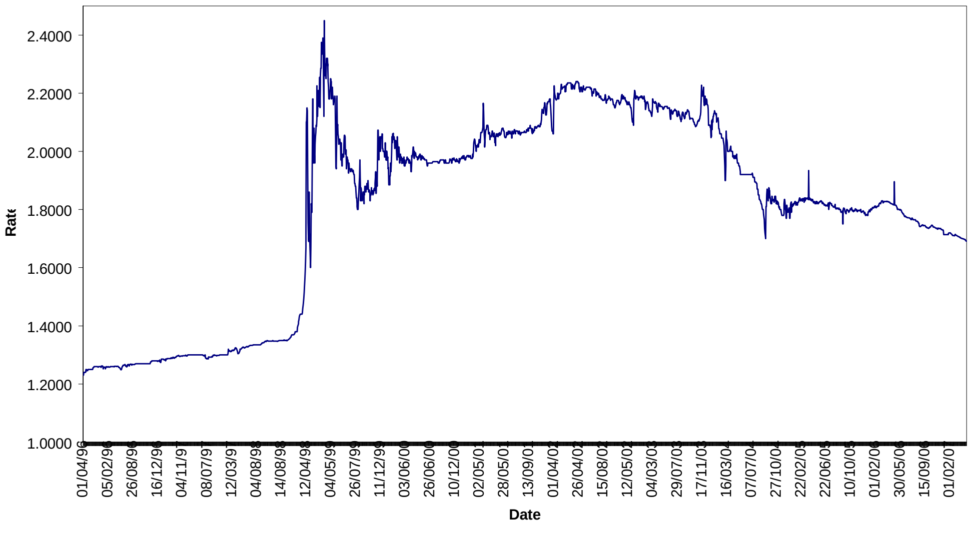


Figure 2. Daily GEL/USD Exchange Rate

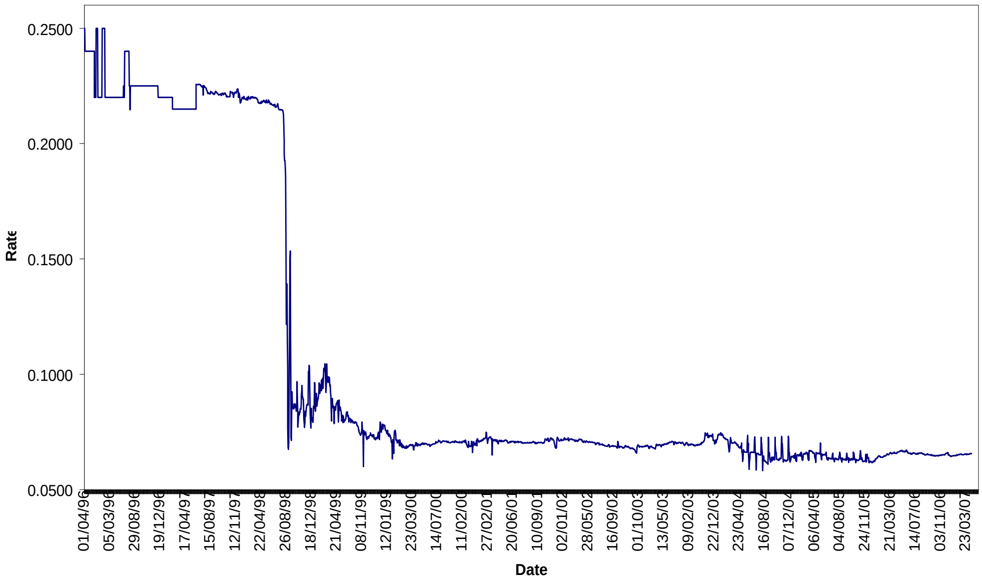


Figure 3. Daily GEL/RUR Exchange Rate

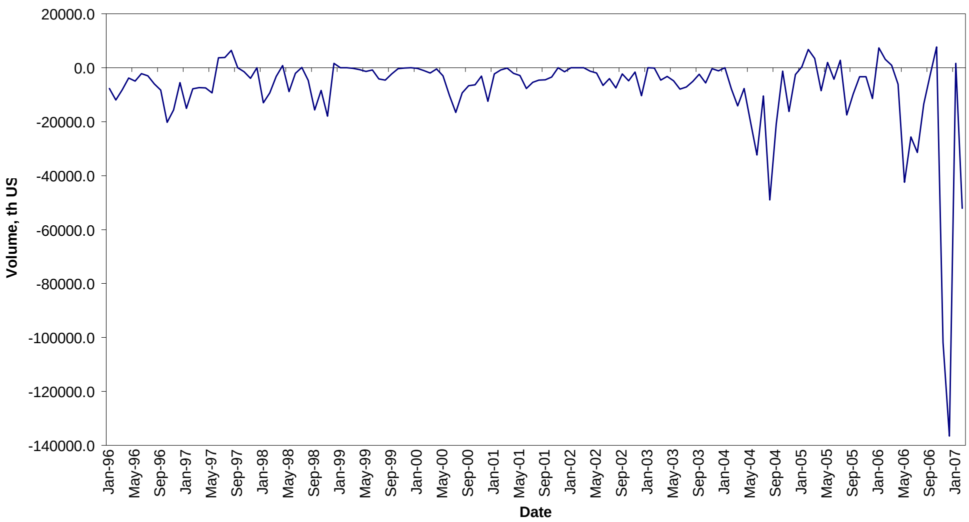


Figure 4. Net Monthly Interventions

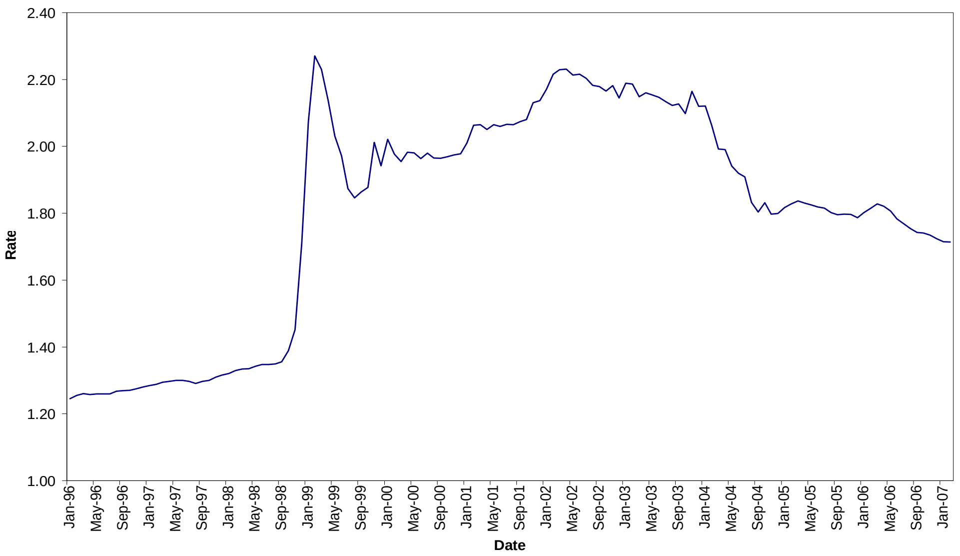


Figure 5. Monthly GEL/USD Exchange Rate

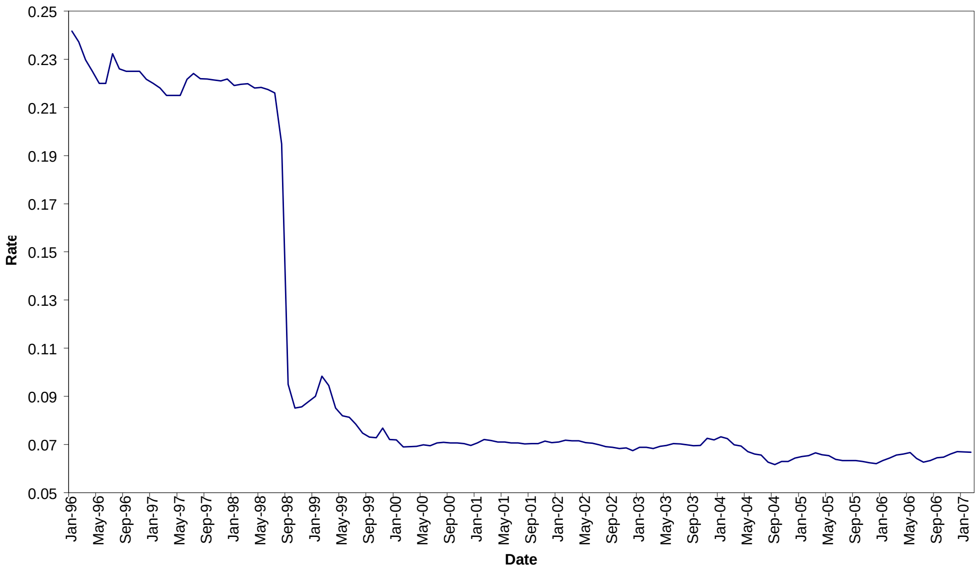


Figure 6. Monthly GEL/RUR Exchange Rate

*Table 1. Daily data summary statistics*

| | usd | dusd | rur | drur | net | dnet |
|---|---|---|---|---|---|---|
| Observations | 2748 | 2747 | 2748 | 2747 | 2748 | 2747 |
| Mean | 1.81 | 1.68E-04 | 0.10 | -6.71E-05 | -334.36 | 0.06 |
| Median | 1.86 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 |
| Maximum | 2.45 | 0.37 | 0.25 | 0.03 | 8870.00 | 87600.00 |
| Minimum | 1.23 | -0.21 | 0.05 | -0.03 | -89230 | -86375.00 |
| Std. Dev. | 0.33 | 0.02 | 0.06 | 2.62E-03 | 2137.13 | 2702.77 |
| Skewness | -0.57 | 3.04 | 1.28 | -2.43 | -27.23 | 0.71 |
| Kurtosis | 1.96 | 83.60 | 2.71 | 93.01 | 1098.27 | 785.57 |
| UR tests result | non-stationary | stationary | non-stationary | stationary | mixed evidence | stationary |
| Q(20) | | 288.51*** | | | | |

The UR decision is based on the results of ADF, PP, and KPSS tests at 5% significance level; the Box-Pierce Q-statistic tests for high-order serial correlation in drate (20 correlations are tested).

*Table 2. Monthly data summary statistics*

| | usd | dusd | rur | drur | net | dnet | std | cda |
|---|---|---|---|---|---|---|---|---|
| Obs | 134 | 133 | 134 | 133 | 134 | 133 | 134 | 134 |
| Mean | 1.80 | 3.53E-03 | 0.11 | -1.31E-03 | -7752.49 | -333.33 | 9.95 | 4.12 |
| Median | 1.84 | 9.00E-04 | 0.07 | -2.00E-04 | -3830.53 | 0.00 | 7.50 | 5.08 |
| Maximum | 2.27 | 0.36 | 0.24 | 0.01 | 7638.00 | 138216.50 | 25.06 | 6.75 |
| Minimum | 1.25 | -0.11 | 0.06 | -0.10 | -136591.50 | -109418.00 | 4.85 | 1.05 |
| Std. Dev. | 0.33 | 0.05 | 0.07 | 9.14E-03 | 16749.55 | 18524.64 | 5.27 | 1.84 |
| Skewness | -0.55 | 3.67 | 1.21 | 9.55 | -6.10 | 1.34 | 1.28 | -0.51 |
| Kurtosis | 1.90 | 24.20 | 2.51 | 103.04 | 34.96 | 34.07 | 3.32 | 1.70 |
| UR tests result | non-stationary | stationary | non-stationary | stationary | mixed evidence | stationary | non-stationary | non-stationary |
| Q(20) | | 77.05*** | | | | | | |

The UR decision is based on the results of ADF, PP, and KPSS tests at 5% significance level; the Box-Pierce Q-statistic tests for high-order serial correlation in drate (20 correlations are tested).

*Table 3. Vogelsang test for daily data*

| Variable | $\lambda^*$ | Test statistic | 5%CV | $T_B^C$ | Sample |
|---|---|---|---|---|---|
| usd | 0.01 | 31.17 | 10.85 (18.20) | 19/11/98 | 01/01/96-19/04/07 |
| dusd | 0.01 | 27.51 | 10.85 (18.20) | 16/03/99 | 01/01/96-19/04/07 |
| rur | 0.01 | 333.50 | 10.85 (18.20) | 26/08/98 | 01/01/96-19/04/07 |
| drur | 0.01 | 19.63 | 10.85 (18.20) | 09/09/98 | 01/01/96-19/04/07 |
| net | 0.01 | 119.26 | 10.85 (18.20) | 27/11/06 | 01/01/96-19/04/07 |
| dnet | 0.01 | 72.47 | 10.85 (18.20) | 29/11/06 | 01/01/96-19/04/07 |
| usd | 0.15 | 40.68 | 9.00(17.88) | 21/11/01 | 01/12/98-19/04/07 |
| dusd | 0.15 | 22.08 | 9.00(17.88) | 27/12/01 | 01/12/98-19/04/07 |

$H_0$: no break; $H_A$: break in intercept and trend; order of trend polynomial p=0; $K$ is determined by the Campbell-Perron method; $\lambda^*$ is a trimming parameter; $T_B^C$ is the estimated break time; 5% critical values are given for stationary and unit root cases in parentheses (source: Vogelsang, 1997).

*Table 4. Perron test for daily data*

| Variable | $T_B$ | Test statistic | 5%CV | $\lambda$ | Sample |
|---|---|---|---|---|---|
| usd | 19/11/98 | -4.59 | -3.99 | 0.25 | 01/01/96-19/04/07 |
| dusd | 16/03/99 | -21.10 | -3.99 | 0.25 | 01/01/96-19/04/07 |
| rur | 26/08/98 | -10.49 | -3.99 | 0.23 | 01/01/96-19/04/07 |
| drur | 09/09/98 | -19.39 | -3.99 | 0.23 | 01/01/96-19/04/07 |
| net | 27/11/06 | -22.26 | -3.80 | 0.97 | 01/01/96-19/04/07 |
| dnet | 29/11/06 | -23.52 | -3.80 | 0.97 | 01/01/96-19/04/07 |
| usd | 21/11/01 | -2.30 | -4.17 | 0.34 | 01/12/98-19/04/07 |
| dusd | 27/12/01 | -18.28 | -4.17 | 0.34 | 01/12/98-19/04/07 |

$H_0$: unit root with exogenous break in trend and intercept, $H_A$: broken trend stationarity; $K$ is determined by the Campbell-Perron method;$T_B$ is a predetermined break date; $\lambda$ is the pre-break fraction; critical values source: Perron (1989).

*Table 5. Vogelsang test for monthly data*

| Variable | $\lambda^*$ | Test statistic | 5%CV | $T_B^C$ | Sample |
|---|---|---|---|---|---|
| usd | 0.01 | 32.27 | 10.85 (18.20) | 11/1998 | 01/01/96-19/04/07 |
| dusd | 0.01 | 20.79 | 10.85 (18.20) | 03/1999 | 01/01/96-19/04/07 |
| rur | 0.01 | 1009.36 | 10.85 (18.20) | 09/1998 | 01/01/96-19/04/07 |
| drur | 0.01 | 20.29 | 10.85 (18.20) | 09/1998 | 01/01/96-19/04/07 |
| net | 0.01 | 147.24 | 10.85 (18.20) | 11/2006 | 01/01/96-19/04/07 |
| dnet | 0.01 | 116.53 | 10.85 (18.20) | 11/2006 | 01/01/96-19/04/07 |
| usd | 0.15 | 78.13 | 9.00(17.88) | 11/2001 | 01/12/98-19/04/07 |
| dusd | 0.15 | 15.78 | 9.00(17.88) | 01/2002 | 01/12/98-19/04/07 |

$H_0$: no break; $H_A$: break in intercept and trend; order of trend polynomial p=0; $K$ is determined by the Campbell-Perron method; $\lambda^*$ is a trimming parameter; $T_B^C$ is the estimated break time; 5% critical values are given for stationary and unit root cases in parentheses (source: Vogelsang, 1997).

*Table 6. Perron test for monthly data*

| Variable | $T_B$ | Test statistic | 5%CV | $\lambda$ | Sample |
|---|---|---|---|---|---|
| usd | 11/1998 | -0.77 | -3.99 | 0.26 | 01/01/96-19/04/07 |
| dusd | 03/1999 | -8.29 | -3.99 | 0.26 | 01/01/96-19/04/07 |
| rur | 09/1998 | 2.86 | -3.99 | 0.24 | 01/01/96-19/04/07 |
| drur | 09/1998 | -4.46 | -3.99 | 0.24 | 01/01/96-19/04/07 |
| net | 11/2006 | -2.22 | -3.80 | 0.98 | 01/01/96-19/04/07 |
| dnet | 11/2006 | -7.97 | -3.80 | 0.98 | 01/01/96-19/04/07 |
| usd | 11/2001 | -0.10 | -4.17 | 0.36 | 01/12/98-19/04/07 |
| dusd | 01/2002 | -7.36 | -4.17 | 0.36 | 01/12/98-19/04/07 |

$H_0$: unit root with exogenous break in trend and intercept, $H_A$: broken trend stationarity; $K$ is determined by the Campbell-Perron method; $T_B$ is the predetermined break date; $\lambda$ is the pre-break fraction; critical values source: Perron (1989).

*Table 7. Continuous reaction functions for whole period 01/01/1996-19/04/2007*

| Estimation method:OLS | | Estimation method:IV IVs:$\Delta e_{t-1}, \Delta_{20} e_{t-1}, \Delta_T e_{t-1}$ | |
|---|---|---|---|
| $Const$ | - | $Const$ | -3311.68*** |
| $\Delta e_{t-1}$ | -1777.66 | $\Delta e_t$ | 3336.05** |
| $\Delta_{20} e_{t-1}$ | 2028.04*** | $\Delta_{20} e_t$ | 572.14*** |
| $\Delta_T e_{t-1}$ | 1447.15*** | $\Delta_T e_t$ | 1596.24** |
| $I_{t-1}$ | 0.16* | $I_{t-1}$ | 0.12 |
| $d1$ | 2015.75*** | $d1$ | 3225.65*** |
| $d2$ | 758.83** | $d2$ | -60.81*** |
| $d3$ | -285.72*** | $d3$ | -153.84*** |
| $R^2 = 0.07$ | $DW = 2$ | $R^2 = 0.1$ | $DW = 1.99$ |
| $BGLM$ | 0.49 | $BGLM$ | 0.67 |
| $ARCHLM$ | 0.15 | $ARCHLM$ | 0.27 |

$\Delta$, $\Delta_{20}, \Delta_T$ are one-period, twenty-period changes, and a one-period change from the target respectively.*=significance at 10%; **=significance at 5%;***=significance at 1%; $BGLM$ is the Breusch-Godfrey serial correlation LM test; $ARCHLM$ is the ARCH LM test.

*Table 8. Continuous reaction functions for sub-samples*

| Sample: 07/12/98-14/09/04 | | | | Sample: 26/02/02-19/04/07 | | | |
|---|---|---|---|---|---|---|---|
| Estimation method:OLS | | Estimation method:IV | | Estimation method:OLS | | Estimation method:IV | |
| | | IVs:$\Delta e_{t-1}, \Delta_{20} e_{t-1}, \Delta_T e_{t-1}$ | | | | IVs:$\Delta e_{t-1}, \Delta_{20} e_{t-1}, \Delta_T e_{t-1}$ | |
| $Const$ | -2304.97*** | $Const$ | - | $Const$ | -4519.03*** | $Const$ | -315.42*** |
| $\Delta e_{t-1}$ | 1083.74*** | $\Delta e_t$ | 2687.43*** | $\Delta e_{t-1}$ | 4778.02* | $\Delta e_t$ | 5358.73*** |
| $\Delta_{20} e_{t-1}$ | 271.06** | $\Delta_{20} e_t$ | 5183.80** | $\Delta_{20} e_{t-1}$ | 4273.76 | $\Delta_{20} e_t$ | 870.82*** |
| $\Delta_T e_{t-1}$ | -1029.24*** | $\Delta_T e_t$ | 344.669 | $\Delta_T e_{t-1}$ | 515.23** | $\Delta_T e_t$ | 174.40*** |
| $I_{t-1}$ | 0.55*** | $I_{t-1}$ | 0.61*** | $I_{t-1}$ | 0.10 | $I_{t-1}$ | 0.25*** |
| $d2$ | 156.12** | $d2$ | 108.278 | $d1$ | 3168.91*** | $d1$ | -37.15 |
| $d3$ | -191.71*** | $d3$ | -69.46*** | $(\Delta e_{t-1})^2$ | -75033.50*** | $(\Delta e_{t-1})^2$ | -24628.55** |
| $(\Delta e_{t-1})^2$ | 5062.99* | $(\Delta e_{t-1})^2$ | 7113.63* | | | | |
| $R^2 = 0.44$ | $DW = 2.12$ | $R^2 = 0.43$ | $DW = 2.18$ | $R^2 = 0.09$ | $DW = 1.99$ | $R^2 = 0.14$ | $DW = 1.99$ |
| $BGLM$ | 0 | $BGLM$ | 0 | $BGLM$ | 0.99 | $BGLM$ | 0.37 |
| $ARCHLM$ | 0 | $ARCHLM$ | 0 | $ARCHLM$ | 0.56 | $ARCHLM$ | 0.63 |

$\Delta, \Delta_{20}, \Delta_T$ are one-period, twenty-period changes, and a one-period change from the target respectively.*=significance at 10%;**=significance at 5%;***=significance at 1%; in the case of detected autocorrelation and/or heteroskedastisity, the robust White or Newey-West standard errors are calculated.

*Table 9. Binary reaction functions*

| Sample: 01/01/1996-19/04/2007 | | Sample: 07/12/98-14/09/04 | |
|---|---|---|---|
| $Const$ | 8.53*** | $Const$ | -3.37*** |
| $\Delta e_{t-1}$ | 5.80** | $\Delta e_{t-1}$ | 31.20*** |
| $\Delta_{20} e_{t-1}$ | 5.95*** | $\Delta_{20} e_{t-1}$ | 1.19 |
| $\Delta_T e_{t-1}$ | 4.00*** | $\Delta_T e_{t-1}$ | 41.96*** |
| $I_{t-1}$ | $-2.42\times10^{-4***}$ | $D_{t-1}$ | -1.69*** |
| $d1$ | 0.62** | $d2$ | 1.16*** |
| $d2$ | -1.63*** | $d3$ | -0.01 |
| $d3$ | 0.21** | $(\Delta e_{t-1})^2$ | 519.02*** |
| $McFR^2 = 0.27$ | $\%CP = 71.29$ | $McFR^2 = 0.31$ | $\%CP = 73.37$ |

$\Delta$, $\Delta_{20}, \Delta_T$ are one-period, twenty-period changes, and a one-period change from the target respectively. Estimation method: ML - Binary Logit (Newton-Raphson);

*=significance at 10%;**=significance at 5%;***=significance at 1%.

*Table 10. Daily impact of interventions on the GEL/USD exchange rate level*

| Variable | Regression I: $\Delta e_t$ | Regression II: $e_t - e_{t-2}$ | Regression III: $e_t - e_{t-3}$ |
|---|---|---|---|
| IVs: $\widehat{I_{t-1}}, \widehat{I_{t-2}}, \widehat{I_{t-3}}, \widehat{I_{t-4}}, \widehat{I_{t-5}}$ | | | |
| $Const$ | 0.02*** | 2.22E-03*** | 3.81E-03*** |
| $I_t$ | 8.13E-06** | 0.01** | 1.23E-03*** |
| $I_{t-1}$ | -1.00E-06 | -4.36E-07 | -1.29E-06 |
| $I_{t-2}$ | -9.75E-09 | -2.73E-08 | 2.30E-07 |
| $I_{t-3}$ | -7.34E-07* | -6.29E-07* | -8.19E-07* |
| $I_{t-4}$ | -6.09E-07* | -5.87E-07* | -1.06E-06* |
| $dffr_{t-1}$ | 1.82E-03 | -3.87E-04 | 8.50E-04 |
| $drur_{t-1}$ | 2.11*** | 2.19*** | 2.63*** |
| $R^2$ | 0.28 | 0.14 | 0.11 |

$\widehat{I_i}$ are predicted values from reaction function with only significant variables; sample: 01/01/1996-19/04/2007; estimation method: IV; *=significance at 10%; **=significance at 1%;***=significance at 1%; In the regressions I, II and IV, the F-test indicates that all intervention variables are significant at 1% level.

*Table 11. Monthly portfolio balance risk premium equations*

| Variable | One-month-ahead risk premium | Three-months-ahead risk premium | Ten-months-ahead risk premium |
|---|---|---|---|
| IVs: $v_{t-1}, v_{t-1}I_{t-1}$ | | | |
| $Const$ | -0.35 | -0.43* | -0.34* |
| $v_t$ | -2.50* | -3.87* | -10.94** |
| $v_tI_t$ | $1.18\times10^{-3}$* | $-5.08\times10^{-4}$* | $-1.33\times10^{-3}$** |
| $d1$ | -0.37*** | -0.40*** | -0.47*** |
| $d2$ | 0.15*** | 0.10*** | 0.31*** |
| $d3$ | 0.14*** | 0.11*** | 0.09*** |
| $ma(1)$ | 0.61*** | 0.84*** | 0.87*** |
| $R^2$ | 0.74 | 0.82 | 0.83 |
| $DW$ | 2.1 | 1.8 | 2.04 |

Sample: 01/01/1996-19/04/2007; estimation method: IV; *=significance at 10%;**=significance at 5%;***=significance at 1%.

*Table 12. Impact of interventions on the GEL/USD exchange rate level and volatility*

| | |
|---|---|
| Mean equation | |
| $Const$ | -0.01*** |
| $\ln v_t$ | -9.05E-04*** |
| $I_{t-1}$ | -6.72E-08*** |
| $drur_t$ | 1.97*** |
| $dffr_t$ | 1.08E-03** |
| $d1$ | 2.88E-03*** |
| $d2$ | -0.01*** |
| $d3$ | -8.53E-04** |
| $d4$ | 0.01*** |
| Variance equation | |
| $Const$ | 1.38E-05*** |
| $Arch(1)$ | 0.18*** |
| $Garch(1)$ | 0.61*** |
| $\|I_{t-1}\|$ | 3.76E-10*** |
| $drur_t$ | 2.71E-04*** |
| $dffr_t$ | -5.78E-06*** |
| $d1$ | 2.15E-05*** |
| $d2$ | -8.23E-05*** |
| $d3$ | 8.94E-06*** |
| $d4$ | 1.05E-04*** |
| $R^2 = 0.07$ | $DW$ =1.90 |
| *Arch LM test* | Not reject $H_0$ |
| *BDS independence test* | Not reject $H_0$ |
| *Kocenda test* | Reject $H_0$ |

BDS test is performed for m=2,3,4,5, and different values of $\epsilon$; the critical values for 2500 observations are used (source: Kanzler, 1999). The Kocenda test is performed for m=2,3,4,5, and the optimal range of $\varepsilon$; the critical values for 2500 observations are used (source: Kocenda and Briatka, 2005). Sample: 01/01/1996-19/04/2007; estimation method: ML - ARCH (Marquardt) – Generalized error distribution; Q-tests indicate no remaining serial autocorrelation in residuals; *=significance at 10%;**=significance at 1%;***=significance at 1%.

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