Accepted Manuscript

Tracking Exchange Rate Management in Latin America

César Carrera

PII: S1058-3300(15)00018-X
DOI: doi: [10.1016/j.rfe.2015.02.004](https://doi.org/10.1016/j.rfe.2015.02.004)
Reference: REVFIN 341

To appear in: *Review of Financial Economics*

Received date: 11 July 2014
Accepted date: 27 February 2015

Please cite this article as: Carrera, C., Tracking Exchange Rate Management in Latin America, *Review of Financial Economics* (2015), doi: [10.1016/j.rfe.2015.02.004](https://doi.org/10.1016/j.rfe.2015.02.004)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Tracking Exchange Rate Management in Latin America

CÉSAR CARRERA[†]

*Banco Central de Reserva del Perú and Universidad Peruana de Ciencias
Aplicadas - UPC*

This version: 15 October 2014

Abstract:

The exchange rate is one of the most important prices in any open economy. Tracking deviations from its long-run value may provide important information for policymakers. One way to track such deviations is to examine numerical patterns in exchange rates to see if the patterns appear to have been subject to some degree of policy management. Following this approach, we use **Benford's Law** as our base case for free-floating exchange rates. **Benford's Law** argues that the frequency of the appearance of numerals finds 1's more frequent, than 2's, than 3's, etc., and this established statistical patterns has been verified and used in research tests in many scientific fields. We apply our forensic approach to exchange rates, computing the distribution of exchange-rate observed values and comparing them with those of **Benford's Law**. We document such cases for 15 Latin American countries. Latin American countries are small open economies that are characterized for having different degrees of dollarization and intervention in the forex market, primary based on US dollar transactions. This is an alternative view of how these characteristics play a role with respect to an implied equilibrium exchange rate.

JEL Classification: C16, F31, F41

Key words: Exchange rate, Forex, Benford's Law, international reserves, FX intervention.

[†] I would like to thank Phillipe Bachetta, Lawrence Christiano, Thomas Wu, Adrian Armas, Diego Winkelried, Sofia and Catherine Carrera, Nelson Ramirez-Rondan, and Hilda Guay for their valuable comments and suggestions. Yrasema Dioses and Maria Robles provided excellent research assistance. The points of view expressed throughout this document are the author's own and are not necessarily shared by the institutions with which he is currently affiliated.

CÉSAR CARRERA is a Senior Economist in the Research Department, Banco Central de Reserva del Perú (BCRP), Jr. Miroquesada 441, Lima, Perú. Email: cesar.carrera@bcrp.gob.pe and Professor in the Economic Department at the Universidad Peruana de Ciencias Aplicadas (UPC). Email: pcefccar@upc.edu.pe

Tracking the Exchange Rate Management in Latin America

1. INTRODUCTION

Understanding the implications of how countries manage their currency is critical to a full appreciation of the challenges for central bankers in Latin America. The exchange rate is a key variable for any open economy because it reflects trading and financial conditions. The value of exports and imports, as well as capital market flows, is subject to the volatility of the exchange rate. The variability of the exchange rate is also intrinsically linked to a country's short-term interest rate and international reserves policies and is important for the determination of interest rate parity conditions. In a financial crisis in which currencies lose value relative to the US dollar, exchange rate management issues can come to the forefront. Moreover, in a few cases, Latin American economies have experienced a phenomenon called dollarization (common use of the dollar rather than domestic currency for transactions), and some smaller economies have fully replaced their domestic currency and now use U.S. dollars instead.

In this research, we are interested in monitoring the relative degree of exchange rate management using numerical pattern analysis. We note that the forex (FX) market is the world's largest and most liquid market, with trillions of dollars being traded on any given day between millions of parties all around the world in many currencies. Latin American central banks, as in the rest of the world, however, conduct most of their reserve activity in US dollars relative to the local currency. And even though currency diversification is slowly increasing in reserve management activities, our research focuses first on US dollar exchange rates, with some later observations relative to the euro.

Our approach is to study the numerical patterns present in actual exchange rates and to look for deviations that are suggestive of exchange rate management activities. This approach is in contrast to many studies, as we will look beyond just the accumulation or depletion of a central bank's international reserves. Specifically, we want to establish a base case of freely-floating exchange rates based on **Benford's Law**. **Benford's Law** (the law of the first digit or the law of the leading digits) refers to the frequency distribution of digits in many sources of data. Under this law, the larger the digit the less frequent this digit is likely to be the first digit. The implied distribution of first digits can be described on a logarithmic weakly monotonic distribution. **Benford's Law** can also be extended for the expected distribution for the second digit and beyond. For this law to hold, data have to be distributed across multiple orders of magnitude (for example, the list of numbers that represents the populations of U.S. cities). This law does not hold if there is any cutoff that excludes a portion of the underlying data above a maximum or below a minimum value (for example, cities defined as a settlement with a population between 30,000 and 99,000).

To anticipate some of the highlights of our results, we find definite deviations from the freely-floating base case using **Benford's Law** for selected Latin American currencies relative to the US dollar, suggesting varying degrees of currency management. The numerical patterns for Latin American currencies relative to the euro are more like the freely-floating base case, which we interpret as reflecting the fact that Latin American central banks use the US dollar, not the euro, as the primary currency for any FX purchases or sales aimed at currency management. We are encouraged by these results, and feel that the use of **Benford's Law** in this, essentially, forensic manner, is both an appropriate and valuable addition to the statistical toolkit used by currency market analysts.

The paper is organized as follows: Part 2 is a brief review of the literature for using **Benford's Law** in economic studies. Part 3 introduces **Benford's Law** and its relationship

with data in economics. Part 4 presents the main characteristic of the data. Part 5 includes an estimation and comparison of each exchange rate distribution versus the implied Benford's distribution. Part 6 summarizes our conclusion about the usefulness of **Benford's Law** as well as the degree of currency management in selected Latin American currencies.

2. LITERATURE REVIEW

Benford's Law has been found to apply to a wide variety of data sets, including those of the social sciences. For example, **Varian (1972) argues that Benford's Law could be used to detect possible fraud in socio-economic data.** If people who make up figures tend to distribute their digits uniformly, then comparing the frequency of the first-digit distribution with that expected from Benford's distribution would show significant differences. Along the same lines, **Nigrini (1999) showed that Benford's Law could be used in auditing as an indicator of accounting and expenses fraud.**

El Sehity et al. (2005) use **Benford's Law** as a benchmark for price adjustments and for detecting irregularities in prices. El Sehity et al. (2005) use two facts: (i) retail managers use psychological pricing to make the prices of goods appear to be just below a round number, and (ii) the euro was introduced in several cities in 2002. Those facts distorted existing nominal price patterns while at the same time retaining real prices. The authors find that the tendency toward psychological prices results in different inflation rates independent of the price pattern.

Some other works that use **Benford's Law** and the idea of a psychological barrier in financial assets are De Grauwe and Decupere (1992), De Ceuster et al. (1998), Aggarwal and Lucey (2007), and Dorfleitner and Klein (2009). In particular, De Grauwe and Decupere (1992) cluster the USD/DEM and USD/JPY exchange rates and compare them against **Benford's Law**. De Grauwe and Decupere (1992), Ley (1996), and De Ceuster et al. (1998)

argue that **Benford's Law** describes many data series, including financial data, so that widespread clustering simply due to the form of the number itself is possible.

Abrantes-Metz and Bajari (2009) study how statistical methods have started to be used in antitrust and finance to detect a variety of conspiracies and manipulations. Abrantes-Metz et al. (2011) investigate deviations of the LIBOR from equilibrium values by testing different realizations for different samples (around February 2006) and suggest that those deviations have as a source the collusion among big commercial banks.

De Grauwe and Decupere (1992) are the only ones who use **Benford's Law** as a benchmark for realizations of the exchange rate. Donaldson and Kim (1993), Koedijk and Stork (1994), and Ley and Varian (1994) demonstrate the existence of price clustering in the last digit of stock market indices. They also tested for psychological barriers through the observation of unequal passing values of predetermined digits. De Grauwe and Decupere (1992) follow this strategy of clustering in the FX market for the USD/DEM and USD/JPY exchange rates and compare them against the implied distribution in **Benford's Law**. These studies infer that clustering, or unequal observations of various digits, implies that psychological barriers exist.¹

In the case of Latin American countries, the application of exchange rate policies is heterogeneous. In the presence of a crisis, policymakers reacted with measures that range from exchange rate bands to open market operations. In that regard, we depart from De Grauwe and Decupere (1992) and argue that the implied **Benford's Law** distribution can be used as a benchmark of the long-run misalignments that those policies generate.

The approach in this paper is to investigate whether deviations in the exchange rate from the implied distribution in **Benford's Law** provides evidence of deviations in the exchange rate from a long-run equilibrium perspective. In that regard, we use samples from at least 10

¹ Mitchell and Izan (2006) argue that this interpretation is misleading and the evidence found in previous literature is not strong enough to argue in favour of psychological barriers in the exchange rate market.

years of domestic versus US dollar exchange rates, as the primary case, for 15 Latin American countries in order to be consistent with a long-run perspective. We find that in economies in which exchange rate policies are more active, deviations from **Benford's Law** are typically stronger. This may suggest that these policies tend to distort longer-term relative prices. We also looked at domestic versus euro exchange rates, and find a much less evidence of FX management, which is consistent with the US dollar being the primary vehicle for currency activities by central banks in Latin America.

3. BENFORD'S LAW

In a given data set, Benford (1938) shows that the probability of occurrence of a certain digit as the first digit decreases logarithmically as the value of the digit increases from 1 to 9. This observation is known as **Benford's Law** and holds for data sets in which the occurrence of numbers is free from any restriction. This result has been probed to hold for a wide variety of variables. This law can be generalized to numbers with a base different than 10, or to posterior positions of a digit in a number.² Originally, in Benford (1938), the data from 20 different domains are tested. The original data set included the surface areas of 335 rivers, the sizes of 3,259 U.S. populations, 104 physical constants, 1,800 molecular weights, 5,000 entries from a mathematical handbook, 308 numbers contained in an issue of Readers' Digest, the street addresses of the first 342 persons listed in American Men of Science, and 418 death rates.

Several studies show that numbers that have been tampered with or are unrelated or fabricated do not usually follow **Benford's Law**. Thus, significant deviations from the

² For details and extensions to Benford's law, see Gottwald and Nicol (2002), Lolbert (2008), and Clippe and Ausloos (2012).

Benford implied distribution may indicate unauthorized intervention or fraudulent or corrupted data.

Specifically, **Benford's Law** implies that the probability of a digit to be the first digit in a numerical variable is given by:

$$Prob(x = d) = \log_{10}(1 + d^{-1}) \text{ for } d = 1, 2, 3, \dots, 9 \quad (1)$$

where d is the value of the digit.

Equation (1) can be generalized for the probability of being the second digit:

$$Prob(x = d) = \sum_{k=1}^9 \log_{10}[1 + (10k + d)^{-1}] \text{ for } d = 0, 1, 2, 3, \dots, 9 \quad (2)$$

Equations (1) and (2) imply distributions for the first and second digit of a numerical variable, respectively (see Table 1 and Figure 1).

TABLE 1 – BENFORD'S LAW

Digit	First digit	Second digit
0		0,12
1	0,30	0,11
2	0,18	0,11
3	0,12	0,10
4	0,10	0,10
5	0,08	0,10
6	0,07	0,09
7	0,06	0,09
8	0,05	0,09
9	0,05	0,08

FIGURE 1 – BENFORD’S LAW

A: FIRST DIGIT

B: SECOND DIGIT

A few comments are relevant to applying Benford’s Law to exchange rates. We note that the real exchange rate equilibrium value has always been a key issue in international economics. Views about its behavior range from the short-run market approach to the long-run power purchasing parity theory. Among all views to derive equilibrium exchange rate values, the Behavioral Equilibrium Exchange Rate (BEER) approach is one of the most accepted and is based on a long-run (cointegrating) relationship between the real exchange rate and economic fundamentals. The BEER value is the predicted exchange rate from the

cointegrating equation. This long-run view is complemented with a vector error correction model (VECM) that identifies how quickly the real exchange rate converges toward its long-run equilibrium value.

Dufrénot et al., (2008) argue that the experience of real exchange rates has been characterized by substantial misalignments, with time lengths much higher than those suggested by theoretical models. According to the standard view, deviations from the equilibrium level are temporal because there are forces that ensure mean-reverting dynamics. Béreau et al. (2010) points out that this relationship can be explained with nonlinear dynamics and, if so, that exchange rates can spend long periods away from their fundamental values.

The goal of this paper is to contribute to this literature by providing evidence of such misalignments process of the exchange rate toward its equilibrium value using an essentially forensic technique rather than depending on judgments based on the accumulation or decrease of international reserves.

4. DATA CHARACTERISTICS

Previous to testing the deviations of the exchange rate from equilibrium values, we describe first the currencies under inspection and then describe the two exchange rates. In the next section, we use these results to test the deviations from the distribution implied by Equation (2).

In this paper, “exchange rate” refers to the spot exchange rate.³ For most countries in this sample, this variable is also known as the interbank exchange rate. The data are taken from the Bloomberg Professional and at daily frequency. For most countries, the data for the U.S. dollar exchange rate became available beginning in 1993. Some other countries have data available starting in 1994. Data for the euro exchange rate began in 1999.

4.1 Latin American currencies

In Latin American countries, exchange rate policies refer to the U.S. dollar. For most Latin American countries during the 1990s, the exchange rate policy was characterized by an exchange rate target zone that takes the form of a band, i.e., the exchange rate was flexible as long as it was inside the limits of the band. During the 2000s, a float-managed exchange rate was used. Interventions in the exchange rate market to either influence the exchange rate inside the band or reduce its volatility have been the common factor in the region.

The northern countries of South America, such as Colombia and Venezuela, followed fairly different approaches with respect to the exchange rate. In Colombia, during the 1990s, the exchange rate policy was characterized for exchange-rate bands (in some periods with even a crawling peg in the limit of the band). During the 2000s, the mechanism was direct intervention. In Venezuela, the exchange rate policy can be characterized as exchange rate bands (90s) and a fixed exchange rate, which is under review every year (2000s).

Some other countries, such as Brazil and Argentina, experienced major changes in their domestic currencies in the 1990s. These countries were looking for pegged exchange rates at equal parity to the U.S. dollar. By the 2000s, they both follow managed float exchange rate

³ This is the rate of a foreign exchange contract for immediate delivery. Spot exchange rates are also known as “benchmark rates” because spot rates represent the price that a buyer expects to pay for a foreign currency in another currency.

policies.⁴ Neighboring countries such as Uruguay and Paraguay followed different exchange rate policies. Uruguay was directly affected by the exchange rate policy in Argentina, and during the 90s, this country used an exchange rate band, turning to a managed float exchange rate in the 2000s.

In the Pacific, there were also mixed policies. While Chile used a band during the 1990s and then switched to a managed float exchange rate, Peru primarily used a managed float exchange rate in which interventions were aimed at the reduction in the volatility of the exchange rate. On the other hand, Ecuador used direct interventions, with a central bank fixing the exchange rate. In 1994, the country had a managed float exchange rate; in 1995, it used exchange rate bands; and it began using a full dollarization program in 2000.⁵

In Central America, there were also mixed exchange rate policies. In Guatemala and the Dominican Republic, the exchange rate was fixed (crawling peg) by the government (in the 90s) and a managed float policy was instituted thereafter (2000s). Costa Rica adopted the crawling-peg policy (in the 90s and the mid-2000s) and then crawling bands. El Salvador used a fixed exchange rate (during the 90s) and, since January 2001, the U.S. dollar has become that country's legal tender.⁶

At the beginning of the 1990s, Mexico used a band policy, with a fixed lower bound and a crawling peg in the upper bound. Later on (in 1994) the band scheme was abandoned, and Mexico entered into a scheme of a managed float exchange rate.

⁴ In the case of Argentina, from January 1992 to January 2002 (this period is known as Plan de Convertibilidad), 1 peso equaled 1 U.S. dollar. Since then it has been allowed to float freely. The official Brazilian rate, from October 1993 to January 1999 (plan Real), was 1 real equals 1 U.S. dollar. Since January 1999, the official rate has been the managed float exchange rate.

⁵ On March 13, 2000, the Ecuadorian National Congress approved a new exchange system whereby the U.S. dollar was adopted as the main legal tender in Ecuador for all purposes; on March 20, 2000, the Central Bank of Ecuador started to exchange sucres for U.S. dollars at a fixed rate of 25,000 sucres per U.S. dollar; and since April 30, 2000, all transactions have been denominated in U.S. dollars.

⁶ The exchange rate was then fixed at 8.75 colones per U.S. dollar. Since 1993, the rate has been fixed at 8.755.

4.2 The U.S. dollar and the euro

The first and foremost traded currency in the world is the U.S. dollar. This currency can be found in a pair with any currency and often acts as the intermediary in triangular currency transactions. In addition, the U.S. dollar is used by some countries as the official currency (dollarization) and is widely accepted in other nations, acting as an alternative form of payment (partial dollarization). The U.S. dollar is also a benchmark or target rate for countries that choose to fix or peg their currencies in order to stabilize their exchange rates.

The euro was introduced into world markets on January 1, 1999, and it is the official currency of the majority of nations within the eurozone. Despite being a new currency, the euro has quickly become the second most traded currency and the world's second largest reserve currency. As a matter of fact, many nations within Europe and Africa peg their currencies to the euro to stabilize their exchange rates. With the euro being a widely used and trusted currency, it is very prevalent in the FX market and adds liquidity to any currency pair it trades within. For Latin American currencies there is a key distinction between the US dollar and the euro. For currency management policies, almost all activities are conducted in the domestic currency versus the US dollar. Central bank transactions in the euro are almost purely related to desires to diversify international reserves relative to the risk management goals of the portfolio. As we will see later, this means that for central banks engaged in varying degrees of currency management, we would expect deviations from Benford's Law to be much more extreme relative to the US dollar than to the euro.

5. ESTIMATIONS AND EMPIRICS

The distribution implied in **Benford's Law** can be thought of as a benchmark that permits identification of the deviation in the realization of a variable from equilibrium values. In the absence of any intervention, the exchange rate should reflect fundamental conditions. Realizations of the exchange rate in the long run would follow **Benford's Law**. That is why Equation (2) is a reasonably good measure of the deviations from the implied equilibrium in **Benford's Law**.

The use of at least 10 years of such realizations is justified by the need of taking off the autocorrelation implied in financial variables. As Aggarwal and Lucey (2007) argue, in a short period of time, uniformity of digit distribution is expected and that runs counter to the implications of **Benford's Law**. As Abramantes-Metz (2011) argues, if the variable of interest does not span the nine-digit space, the second-digit data may be expected to naturally do so. Therefore, if the sample is long enough, the study of the second digit would have more meaningful results.

5.1 *Benford's Law and the exchange rate distribution*

We now turn to the main question, which is whether the realization of the interbank exchange rate data can be reasonably well represented by the Benford's second-digit reference distribution implied by Equation (2). In that regard, the Pearson's chi-square test can be used to evaluate if the statistical distribution of a random sample is drawn from **Benford's Law**.

For Equation (2), the corresponding χ^2 statistic can be estimated as:

$$\chi_{stat}^2 = \sum_{i=0}^9 \frac{(e_i - b_i)^2}{b_i} \quad (3)$$

where e_i is the observed frequency in each bin in the observed data and b_i is the expected frequency implied by **Benford's Law**.⁷

The null and the alternative hypotheses to test are:

H_0 : Data are drawn from Benford's distribution.

H_A : Data are not drawn from Benford's distribution.

If the observed data fit **Benford's Law**, χ_{stat}^2 has to be less than the critical value at the convenient statistical significance level, i.e., fail to reject H_0 . If χ_{stat}^2 is greater than the critical value, reject H_0 .

The critical statistical evaluation in this study is based on the Chi-Square statistic. The χ_{stat}^2 works as a measure of a gap in between the realization observed in the data and that implied in Benford's distribution. The larger χ_{stat}^2 is, the stronger the deviation from the implied distribution is.

In Table 2, we show that most currencies relative to the US dollar tend to deviate from **Benford's Law**'s implied distribution. Argentina and Venezuela, countries that experienced strong exchange rate management policies, have the largest χ_{stat}^2 . By contrast, Chile and Ecuador register the lowest χ_{stat}^2 . This reflects the adherence to a free-floating exchange rate and lower intervention in the exchange rate market of Chile, as well as the dollarization of the exchange rate policy in Ecuador.

⁷ This statistic has 9 degrees of freedom.

TABLE 2 – SOUTH AMERICAN COUNTRIES RELATIVE TO THE US DOLLAR

Digit	Argentina 1992-2012	Bolivia 1993-2012	Brazil 1992-2012	Chile 1992-2012	Colombia 1992-2012	Ecuador 1993-2000	Paraguay 1993-2012	Peru 1992-2012	Uruguay 1993-2012	Venezuela 1998-2012
0	0,36	0,29	0,22	0,12	0,13	0,11	0,12	0,05	0,13	0,00
1	0,07	0,04	0,13	0,18	0,08	0,17	0,11	0,11	0,12	0,35
2	0,02	0,04	0,05	0,11	0,13	0,14	0,08	0,14	0,08	0,22
3	0,02	0,03	0,05	0,10	0,15	0,10	0,09	0,09	0,16	0,02
4	0,02	0,05	0,03	0,07	0,04	0,08	0,08	0,21	0,12	0,01
5	0,02	0,08	0,04	0,05	0,06	0,09	0,09	0,09	0,04	0,10
6	0,02	0,08	0,07	0,09	0,05	0,06	0,06	0,10	0,05	0,12
7	0,03	0,07	0,13	0,10	0,11	0,06	0,11	0,08	0,06	0,08
8	0,08	0,06	0,15	0,09	0,13	0,08	0,11	0,09	0,07	0,01
9	0,35	0,27	0,14	0,08	0,13	0,11	0,15	0,06	0,16	0,09
χ^2 - stat	163,55	83,66	33,29	6,28	17,05	6,92	9,05	17,70	17,76	92,19
p - value	0,00	0,00	0,00	0,71	0,05	0,65	0,43	0,04	0,04	0,00

Table 3 presents results for other Latin American countries relative to the US dollar. All of them deviate from **Benford's Law**. As expected, the crawling-peg exchange rate policy followed in most of these countries affected the observed distribution of the spot exchange rate.

TABLE 3 – OTHER LATIN AMERICAN COUNTRIES

Digit	Costa Rica 1994-2012	Dominican Rep. 1993-2012	El Salvador 1993-2012	Guatemala 1993-2012	Mexico 1992-2012
0	0,17	0,02	0,00	0,09	0,25
1	0,19	0,02	0,00	0,05	0,22
2	0,08	0,10	0,00	0,05	0,13
3	0,06	0,13	0,00	0,05	0,14
4	0,05	0,09	0,00	0,02	0,07
5	0,08	0,17	0,00	0,08	0,05
6	0,06	0,20	0,02	0,19	0,03
7	0,07	0,13	0,98	0,19	0,03
8	0,09	0,08	0,00	0,17	0,04
9	0,14	0,07	0,00	0,13	0,04
χ^2 - stat	17,37	34,96	957,48	48,16	42,91
p - value	0,04	0,00	0,00	0,00	0,00

5.2 The euro: A Benchmark

As we have argued earlier, we would expect different results for euro than for the US dollar. The US dollar is the currency of choice for exchange rate management in Latin America, while the euro plays a lesser role related mainly to the diversification and risk

management of international reserves. Thus, we expect the domestic currencies relative to the euro to follow Benford's Law much more closely than in the US dollar case.

A natural extension of this analysis is to make homogeneous samples for all countries. First of all, we estimate the exchange rate against the U.S. dollar for the period from 1994 through 2012. Then, we calculate a similar distribution for the euro spot exchange rate. Given the fact that the euro appeared in 1999, we re-estimate the distribution of the U.S. exchange rate. Finally, we re-estimate the distribution of the U.S. and the euro exchange rate for sample periods at least 10 years longer.

Table 4 presents the outcome from the homogeneous sample period for all countries. There are no surprises here. When the euro exchange rate is considered, **Benford's Law** holds for most countries. This fact may have support from the little intervention that occurs in the euro exchange rate market. In order to make a reasonable comparison between these two currencies, we consider a similar sample for the U.S. exchange rate. Only Chile and Paraguay have exchange rate distributions in line with the distribution suggested by **Benford's Law**.

TABLE 4 – EXCHANGE RATE AND BENFORD'S LAW

	U.S. Dollar (1994-2012)		Euro (1999-2012)		U.S. Dollar (1999-2012)	
	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value
Argentina	140,26	0,00	13,86	0,13	103,11	0,00
Bolivia	85,80	0,00	38,84	0,00	112,34	0,00
Brazil	29,09	0,00	22,16	0,01	29,11	0,00
Chile	8,07	0,53	2,99	0,96	4,92	0,84
Colombia	19,23	0,02	13,16	0,16	36,38	0,00
Paraguay	8,88	0,45	5,18	0,82	6,88	0,65
Peru	22,46	0,01	13,49	0,14	35,62	0,00
Uruguay	17,56	0,04	7,89	0,55	29,77	0,00
Venezuela			47,62	0,00	92,33	0,00
Costa Rica	17,37	0,04	8,62	0,47	22,05	0,01
Dominican Republic	35,24	0,00	12,17	0,20	40,03	0,00
El Salvador	960,39	0,00	70,45	0,00	956,83	0,00
Guatemala	47,72	0,00	46,60	0,00	60,60	0,00
Mexico	33,63	0,00	17,23	0,05	73,53	0,00

In the case of the U.S. dollar, there are differences, even if small, when the sample is reduced. The χ^2_{stat} , which is the measure of the gap between distributions, suggests that fewer years of observations may distort the original results. Therefore, it is worth it to observe the evolution of the χ^2_{stat} in a sample period that has at least 10 years' worth of observations and still stay in the long-run view of the exchange rate.

Table 5 provides the χ^2_{stat} for the U.S. exchange rate for samples of 14, 13, 12, 11, and 10 years. From Table 5 it is possible to infer that for most countries, **Benford's Law** does not hold. Some countries have a bigger gap than others, some countries keep experiencing an increasing upward trend, and some countries tend to reduce this gap. At the margin, some countries sort of have a fixed exchange rate, which clearly differs from **Benford's Law**.

On the other hand, Table 6 shows a similar comparison for the euro exchange rate. In this case, **Benford's Law** holds for most countries at different sample sizes. The absence of an explicit exchange rate policy with respect to the euro may explain this result.

TABLE 5 – U.S. EXCHANGE RATE AND BENFORD'S LAW

	1999-2012		2000-2012		2001-2012		2002-2012		2003-2012	
	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value
Argentina	103,11	0,00	89,98	0,00	67,91	0,00	53,57	0,00	70,25	0,00
Bolivia	112,34	0,00	122,48	0,00	139,96	0,00	175,49	0,00	202,65	0,00
Brazil	29,11	0,00	24,33	0,00	16,10	0,06	20,81	0,01	26,60	0,00
Chile	4,92	0,84	4,33	0,89	4,79	0,85	5,23	0,81	8,29	0,50
Colombia	36,38	0,00	38,77	0,00	46,62	0,00	47,47	0,00	50,87	0,00
Paraguay	6,88	0,65	6,41	0,70	11,07	0,27	14,37	0,11	15,58	0,08
Peru	35,62	0,00	35,17	0,00	25,34	0,00	23,61	0,00	23,78	0,00
Uruguay	29,77	0,00	36,62	0,00	50,53	0,00	53,38	0,00	67,88	0,00
Venezuela	92,33	0,00	106,73	0,00	134,05	0,00	168,59	0,00	212,07	0,00
Costa Rica	22,05	0,01	23,71	0,00	17,50	0,04	27,19	0,00	38,45	0,00
Dominican Republic	40,03	0,00	35,70	0,00	32,88	0,00	26,13	0,00	21,43	0,01
El Salvador	956,83	0,00	992,84	0,00	1006,78	0,00	1006,78	0,00	1006,78	0,00
Guatemala	60,60	0,00	64,92	0,00	58,01	0,00	55,07	0,00	51,63	0,00
Mexico	73,53	0,00	85,12	0,00	103,86	0,00	116,81	0,00	127,21	0,00

TABLE 6 – EURO EXCHANGE RATE AND BENFORD’S LAW

	1999-2012		2000-2012		2001-2012		2002-2012		2003-2012	
	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value	χ^2 - stat	p - value
Argentina	13,86	0,13	20,53	0,01	14,53	0,10	11,65	0,23	9,95	0,35
Bolivia	38,84	0,00	42,32	0,00	51,41	0,00	54,25	0,00	60,97	0,00
Brazil	22,16	0,01	28,23	0,00	21,65	0,01	30,44	0,00	39,69	0,00
Chile	2,99	0,96	4,42	0,88	3,04	0,96	4,08	0,91	3,10	0,96
Colombia	13,16	0,16	12,83	0,17	7,43	0,59	6,99	0,64	7,08	0,63
Paraguay	5,18	0,82	5,81	0,76	5,24	0,81	5,72	0,77	6,41	0,70
Peru	13,49	0,14	20,32	0,02	18,53	0,03	15,01	0,09	20,97	0,01
Uruguay	7,89	0,55	8,56	0,48	9,08	0,43	14,73	0,10	12,16	0,20
Venezuela	47,62	0,00	33,02	0,00	22,53	0,01	17,29	0,04	18,33	0,03
Costa Rica	8,62	0,47	5,11	0,82	2,95	0,97	1,56	1,00	0,98	1,00
Dominican Republic	12,17	0,20	12,17	0,20	8,20	0,51	4,69	0,86	6,17	0,72
El Salvador	70,45	0,00	79,86	0,00	98,53	0,00	121,22	0,00	159,00	0,00
Guatemala	46,60	0,00	56,07	0,00	66,77	0,00	76,66	0,00	93,77	0,00
Mexico	17,23	0,05	23,15	0,01	27,65	0,00	34,14	0,00	45,77	0,00

In Figure 2, we present the behavior of the χ^2_{stat} for the case of the U.S. dollar. There are a couple of countries well inside the region of **Benford’s Law** (Chile and Paraguay); there are a couple more that have a clear tendency to reach this threshold (Dominican Republic and Peru, Figure 2A); and there are a couple of countries that reach this area and then tend to diverge (Brazil and Costa Rica, Figure 2B).

FIGURE 2 – χ^2_{stat} FOR THE U.S. DOLLAR

A:

B:

In Figure 3, the χ^2_{stat} for the case of the euro is clearly inside the threshold of **Benford's Law**. In the cases of Mexico and Brazil, the gap tends to increase as the sample considers a fewer number of years (Figure 3A). Surprisingly, as the sample is reduced, **Benford's Law** tends to hold for Venezuela (Figure 3B).

FIGURE 3 – χ^2_{stat} FOR THE EURO

A:

B:

5.3 Deviations from Benford reference distribution

Numerous factors may explain temporal misalignments: transaction costs, heterogeneity of buyers and sellers, speculative attacks on currencies, the presence of target zones, noisy traders causing abrupt changes, and the heterogeneity of central banks' interventions. All these factors imply either a relationship between the exchange rate and the economic fundamentals or an adjustment mechanism with time-dependent properties.

Here, we consider a period long enough that the adjustment process can be viewed as a short-run deviation from the fundamentals of the economy. The detected processes here help at modeling asymmetries inherent to the adjustment process. This is particularly interesting because these asymmetries may explain, for instance, the unequal durations of undervaluations and overvaluations. All we can say is that there are deviations from a long-run equilibrium exchange rate perspective, and these deviations seem to be stronger in some cases, even though a flexible exchange regime is in place.

6. CONCLUSIONS

We have used **Benford's Law** to compare the realization of the exchange rate with respect to long-run implied equilibrium realizations of the U.S. dollar exchange rate. Benford's implied distribution can be viewed as a reasonable alternative to structural models of the fundamental exchange rate to detect deviations from a long-run perspective. Deviations from this implied distribution may be reflecting factors such as transaction costs, changing regimes fluctuations, or open market operations. Moreover, such an approach helps to understand delays that are inherent to the adjustment process. This is particularly interesting because these delays may explain the unequal likelihood of undervaluations or overvaluations. As a second step, we make a comparison against a currency that has a less active monetary policy: the euro.

In the case of the U.S. dollar, **Benford's Law** holds for two countries (Chile and Paraguay); however, in the case of the euro, the law seems to hold for most Latin American countries. Although the U.S. dollar is important for most transactions in these economies and there are explicit policies associated with it, the euro has become an important currency and

an alternative to the U.S. dollar in these countries as well, even though there are not active policies regarding the exchange rate observed in the market.

Finally, we find that the gap for this law to hold true became lower in the U.S. dollar exchange rate market for the case of Dominican Republic and Peru, which suggests that if the exchange rate is deviated, this deviation seems not to hold under a long-run perspective.

REFERENCES

- Abrantes-Metz, R., Villas-Boas, S., Judge, G., 2011. Tracking the Libor rate. *Applied Economic Letters* 18, 893 – 899.
- Abrantes-Metz, R., Bajari, P., 2009. Screens for conspiracies and their multiple applications. *Antitrust Magazine*, December.
- Aggarwal, R., Lucey, B., 2007. Psychological barriers in gold prices? *Review of Financial Economics*, 16, 217–230
- Benford, F., 1938. The Law of Anamalous Numbers. *Proceedings of the American Philosophy Society*, 78, 551 – 572.
- Béreau, S., López, A., Mignon, V., 2010. Nonlinear adjustment of the real exchange rate towards its equilibrium value: A panel smooth transition error correction modeling. *Economic Modelling*, 27, 404–416.
- Clippe, P., Ausloos, M., 2012. **Benford's Law** and Theil transform of financial data. *Physica A*, 391, 6556–6567.
- De Ceuster, M., Dhaene, G., Schatteman, T., 1998. On the hypothesis of psychological barriers in stock markets and **Benford's Law**. *Journal of Empirical Finance*, 5, 263–279
- De Grauwe, P., Decupere, D., 1992. Psychological barriers in the foreign exchange market. *Journal of International and Comparative Economics* 1, 87–101.
- Donaldson, R., Kim, H., 1993. Price barriers in the Dow Jones Industrial Average. *Journal of Financial and Quantitative Analysis* 28 (3), 313–330.
- Dufrénot, G., Lardic, S., Mathieu, L., Mignon, V., Péguin-Feissolle, A., 2008. Explaining the European exchange rates deviations: long memory or non-linear adjustment? *Journal of International Financial Markets, Institutions & Money* 18 (3), 207–215.
- Dorfleitner, G., Klein, C., 2009. Psychological barriers in European stock markets: Where are they? *Global Finance Journal* 19, 268–285.

- El Sehity, T., Hoelzl, E., Kirchler, E., 2005. Price developments after a nominal shock: **Benford's Law** and psychological pricing after the euro introduction. *International Journal of Research in Marketing*, 22, 471–80.
- Gottwald, G., Nicol, M., 2002. On the nature of **Benford's Law**. *Physica A*, 303, 387–396.
- Koedijk, K., Stork, P., 1994. Should we care? Psychological barriers in stock markets. *Economics Letters*, 44 (4), 427–432.
- Ley, E., 1996. On the peculiar distribution of the U.S. stock indexes' digits. *American Statistician*, 50 (4), 311–313.
- Ley, E., Varian, H., 1994. Are there psychological barriers in the Dow-Jones Index? *Applied Financial Economics*, 4 (3), 217–224.
- Lolbert, T., 2008. On the non-existence of a general **Benford's Law**. *Mathematical Social Sciences*, 55, 103–106.
- Mitchell, J., Izan, H., 2006. Clustering and psychological barriers in exchange rates. *Journal of International Financial Markets, Institutions & Money*, 16, 318–344.
- Nigrini, M., 1999. I've got your number. *Journal of Accountancy*, 187(5), 79-83.
- Varian, H., 1972. **Benford's Law**. *American Statistician*, 26, 65.