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DOMESTIC DEBT INTOLERANCE AND BAD EQUILIBRIUM: AN EMPIRICAL DEFAULT MODEL

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Abstract

The Turkish financial crises 1994 and 2000-2001 are spaced some years apart, creating an illusion that this time is different among policymakers and investors. Suppose that the dynamics of the macroeconomy generates multiple values for the domestic interest rate premium : "low" and "high." The sudden shifts in financial markets that characterize financial crises are then interpreted as a shift from one equilibrium to another. In this paper, we specify a dynamic model in which debt default through inflation is possible, determine its closed-form solution and multiple equilibria. We estimate the model using the properties of chaos theory, against post-liberalization period (1989-2010) data for Turkey. The problem takes as given our model economy with multiple equilibria and asks whether the multiple equilibria can be verified by the data. To make progress on this problem we introduce phase-space portrait of the considered economy and identify path for debt dynamics moving from low and diverging through high interest levels. Second, we measure how the default episodes 1994 and 2000-2001 converge/diverge apart on phase-space, depending on the maximal Lyapunov exponent. Since the data show support for the multiple-equilibrium explanation of the serial defaults, we better understand the significance of domestic debt behind the high inflation, banking crises and currency crashes that Turkish economy frequently experienced in its post-liberalization period.

Keywords: Defaults; Multiple equilibria; Phase-space; Lyapunov exponent; Interest rates; Turkish financial crises

JEL Codes: C65;D84; E43; H63; O52

1 Introduction

In a recent paper, Reinhart and Rogoff (2011) note that, over the past decade or so, a number of emerging market economies have seen a rapid expansion in domestic, market-based debt. Moreover the authors' extensive new database sheds light on the history of financial crises and reveals that many of the major debt crises of the past ten years have involved domestic debt, and that the countries experiencing domestic debt "intolerance" are indeed serial defaulters. Among those serial defaulters Argentina, Brazil, Mexico, Venezuela and Turkey, have been a center of attention of late, have at times defaulted, de facto, on their internal obligations over the past 175 years, including through high inflation or hyperinflation. In some cases, the domestic debt is repudiated through "surprise" inflation, in other

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cases, governments default on external debt. In fact, since the problems of external default, domestic default and inflation are all integrally related, the overt default on (or repudiation) and rescheduling of domestic public debt are hidden behind the high inflation, banking crises, currency crashes, and debasements which often go hand in-hand with default (Reinhart and Rogoff 2008).

Despite the fact that the empirical literature on domestic debt crisis has lagged behind, in part because of lack of data, Ronald McKinnon interestingly took our attention to the emergence of domestic government debt as a problem: "One of the most striking developments of the late 1980s was the extent to which the governments of Mexico, Argentina and Brazil went into debt domestically. Because of the cumulative effect of very high interest rates (over 30 percent real was not unusual) on their existing domestic liabilities, government-debt-to-GNP ratios have been building up in an unsustainable fashion even though most of these countries are not paying much on their debts to international banks. In many developing countries, people now anticipate that governments will default on its own domestic bonds-as in March 1990 with the Brazilian government's freeze of its own outstanding liabilities" (McKinnon 1991, p.6).

On theoretical side, in addition to bank runs, currency crises or asset price crashes, there is a large literature suggesting multiple equilibria models of sovereign debt crises. Multiple equilibria arise when there are multiple values for the domestic interest rate premium that are consistent with uncovered interest parity. In one equilibrium, the interest rate tends to be low, reserve losses are small, and there is a low likelihood of devaluation. In another equilibrium, interest rates are high, reserve losses are large, and there is a high chance of a devaluation. The sudden shifts in financial markets that characterize financial crises are then interpreted as a shift from one equilibrium to another[1]. Models that explain sovereign debt crises as arising from multiple equilibria include Sachs (1984); Calvo (1988); Obstfeld and Rogoff (1996, ch. 6), among others. Multiple equilibria in debt markets, are clearly general, and thus consistent with the near universality of crises. The buildup in domestic debt just before the financial crises, which is documented by Reinhart et al. (2003) certainly increases a country's vulnerability to panics and runs, and is consistent with multiple equilibria. Some policymakers have recognized the problem at least since the Mexican debt crisis of 1994. However, this prompts the question as to whether

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[1] For related multiple equilibria analyses of bank runs, currency crises or asset price crashes, among others see Diamond and Dybvig (1983), Obstfeld (1986), Obstfeld (1996), Gennotte and Leland (1990), Barlevy and Veronesi (2003), Hellwig et al. (2006) .

the policymakers are able to detect the presence of multiple equilibria and to avoid it, or economize on interest rate costs as debt rises, a usual policy implication of the buildup.

More precisely, to make progress on answering the question that bear on the ability of models on debt crisis to confront economic observations, we propose a model of implicit default on domestic, market-based debt consistent with results from the literature on debt crises and test the outcome against data for Turkey.

Over the period from 1824 to 1999, the debts of Brazil, Argentina and Turkey were either in default or undergoing restructuring roughly a quarter of the time, those of Venezuela and Colombia almost 40 percent of the time, and that of Mexico for almost half of all the years since its independence. On average, the serial defaulters have had annual inflation exceeding 40 percent a quarter of the time as well. More recently, in emerging markets many common factors contributed to the alarming rise in domestic government debt. Key among these have been the revenue losses from the wide-ranging liberalizations undertaken by those countries since the late 1980s. The trade liberalization typically entailed revenue losses and declining trade taxes were among the causes of erosion of the traditional sources of revenue in emerging market economies (see Reihart and Rogoff 2003, tables 14-16). All of these factors are shown to deteriorate "financial repression[2] policy", which has been an important policy implication discriminating serial defaulters from advanced economies and no-default emerging markets such as Singapore and Thailand (Reinhart and Sbrancia 2011). The authors find that financial repression in combination with inflation played an important role in reducing lofty mountains of public debt in many of the advanced economies in the decades following World War II and subsequently in no-default emerging markets, where financial liberalization is of more recent vintage.

This paper develops a simple model of debt repudiation through inflation in which relatively low foreign interest rates allow heterogeneity in domestic lenders' endowment sources being invested in non-indexed government bonds (G-bonds) and domestic interest rates on bonds are endogenously determined in a rational expectations equilibrium. The lack of financial repression, a common feature of serial defaulters is introduced into the model in terms of "heterogeneity in domestic lenders' endowment sources". That is we allow private incumbent banks to borrow from foreign creditors and to purchase government securities. The motivation behind involves the structure of domestic debt market in Turkey. First, there is persistent gap between the public sector borrowing requirement and the size of the domestic capital markets a fact emphasized by various authors (Eichengreen 2001; Akyuz and Boratav

[2] To conserve space, we do not give here the formal definition. Please refer to Reinhart and Sbrancia 2011 pg.6.

2003; Ozkan 2005). Second, in 90's the number of private incumbent banks has significantly increased by %35 and has reached 81 in 2000, which is the maximum level for Turkish banking sector[3]. Since the structure of domestic debt markets may vary across countries, one may easily adopt our model to any other debt intolerant economy simply by introducing the observed policies inconsistent with the financial repression framework. Another important feature of the Turkish case is that in the wake of financial liberalization, Turkish economy experienced frequent financial crisis episodes -in 1994, 1999 and 2000-2001 and suffered a loss of 10–20% of real gross domestic product (GDP) in a single year (see Özatay 2000; Eichengreen 2001; Ozkan 2005; Akyüz and Boratav 2003;), which makes Turkey a good representative of debt intolerant countries and a richer laboratory for the literature on default and policy implications.

Our study is not entirely new, there are studies focusing on the 1994 and/or 2001 crises, both in theoretical and empirical perspective. These studies are based on currency crisis models (Solomon 2003, 2004; Cornell and Solomon, 2007; Ozkan 2005; Cesmeci and Önder 2008; Tamgac 2011; Ari 2012). To the best of our knowledge, there is no study focusing on effect of domestic debt structure on financial crisis 2001. Hence, this paper aims to fulfill this shortage by covering the domestic debt structure over the entire post-liberalization period (1989-2010) rather than focusing only on certain crisis episodes.

A second, and related, motivation for this work is the improved conduct of equilibrium multiplicity in policy analysis. In some cases, multiple equilibria models have been used, often informally, as a basis for policy interventions. But, to many economists, model economies that exhibit multiple equilibria are viewed as poorly suited for economic analysis. In particular, it is sometimes claimed that these models have no testable implications and thus cannot be falsified[4]. Further, with multiple equilibria, it is not clear how policy variations will effect outcomes.

More precisely, our goal is to make progress on answering the question that bear on the ability of our model with multiple equilibria to confront economic observations:

- Can a model with multiple equilibria be accepted?

The question takes as given our model economy with multiple equilibria and asks whether the multiple equilibria can be verified by the data. This is not a new phenomenon, a general framework for the discussion of these issues was first studied in principle by Jovanovic (1989) and in greater detail by

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[3] see the dataset released by Central Bank of Republic of Turkey, www.tcmb.gov.tr.

[4] See, for example the discussion in Woodford (1987) and the comments in Aiyagari (1995) on these points. For a recent survey see Cooper (2002).

Dagsvik and Jovanovic (1994) and Cooper (2002). The fundamental quantitative analysis requires in the first place the specification of a mapping from the set of equilibria into a time series (or panel) of outcomes. Then several estimation techniques such as methods of moments, maximum likelihood[5], full information maximum likelihood[6] are applied to test the model outcomes.

We extend this literature to another direction. We introduce the reconstruction of phase-space portrait of the considered "economy". The approach we take is to treat multiple equilibria as "parallel in time[7]" rather time sequential. The motivation behind is twofold. First, the observation and the treatment of a real process on time-domain may not yield all possible state variables. Either not all state variables are known or not all of them can be measured. However, due to the couplings between the system's component, we can reconstruct a phase-space trajectory from a single observation by a time delay embedding (Takens 1981). Second, the phase-space construction is the fundamental starting point of many approaches in nonlinear data analysis[8] and Russel Cooper states: "Economies that generate multiple equilibria are inherently nonlinear so that simple linear representations may be inadequate" (Cooper 2002 pg.7). The simplicity of the phase-space construction is essential for our purposes. The key point of our empirical analysis has been to show that the multiple equilibria generated by the model economy can be verified by the observed sequence of real ex-post domestic interest rates. This can be subject to the policy making if we better understand whether a shift from low interest levels (good equilibrium) to high (bad one) has sensitive dependence to initial conditions, or in other words whether it is deterministic. Given the limitations of conventional debt sustainability analysis[9], the nonlinear dynamical analysis methods provide different insights into debt analysis, and the fiscal policy may exhibit deterministic character in most of its duration (Fincke and Greiner 2011).To the best of our knowledge, this paper is first to apply the implications of chaos theory for analyzing debt dynamics.

2 The model

This section focuses on a monetary economy with non-indexed government bonds (G-bonds) and proposes a simple model in which dept repudiation through inflation is possible. With a large burden of debt service, the probability of a future default also increases, and a large enough increase can validate

[5] See Cooper (2002)
[6] See Solomon (2007)
[7] See Eckmann and Ruelle (1985).
[8] The phase-space construction is the fundamental starting point of many approaches in nonlinear data analysis For details please refer to Kantz and Schreiber (1997).
[9] For a detailed discussion please refer to section 3, Rogoff et al. (2003).

expectations on inflation rate. This mechanism is firstly introduced by Calvo (1988) in a model of domestic government borrowing in which the debt is nominal and default takes place through "surprise" inflation. In order to examine Turkish debt crises in 1994 and 2001 in terms of a standard monetary model, we follow Calvo (1988) and extend the model by allowing private incumbent banks to borrow from foreign creditors[10] and to purchase government securities which are not indexed to price-level. In 90's the number of private banks has significantly increased by %35 and has reached 81 in 2000, which is the maximum level for Turkish banking sector (see www.tbb.org.tr and www.tcmb.gov.tr).

The concept of repudiation takes more familiar form in the context of a monetary model, since when variables are expressed in real terms, changes in the rate of inflation, π imply changes in the real value of assets which are not indexed to the price-level.

There is one borrowing-cycle[11] consisting of two periods: T and T+1, and three types of agents: identical competitive domestic-saving households, identical competitive private banks borrowing from foreign creditors with a nominal interest factor R_b^f, and the government. In period T, let the government issue G-bonds that amount to *B* in domestic currency with a nominal interest factor R_b^g, $R_b^f < R_b^g$ on bonds. That is in period T+1 the traders will receive R_b^g (i.e., $R_b^g = 1 + r_b^g$, where r_b^g is the nominal interest rate from period T to T+1) which has not being repudiated by inflation. Thus, if we let P_t stand for price-level at date *t* = T,T+1 then the real interest factor on G-bonds issued at period T would be $R_b^g . \frac{P_T}{P_{T+1}}$, where $P_{T+1} = (1 + \pi_{T+1}).P_T$ and π_{T+1} signifies the rate of change in price-levels[12] over the period T to T+1. We can therefore, consider the ratio $\frac{P_T}{P_{T+1}}$ as the share of the debt which is not repudiated at the end of period T+1; hence we have $\frac{P_T}{P_{T+1}} = (1 - \theta)$. Thus, if a trader expects that θ repudiation will take place, where $\theta = \frac{\pi_{T+1}}{1 + \pi_{T+1}}$; $0 \le \theta < 1$ then the net-interest factor or real interest factor would be $(1 - \theta).R_b^g$.

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[10] For solely external borrowing of a government, Detragiache (1996) propose a model very similar to Calvo (1988). However, different from Calvo (1988), Detragiache (1996) conjecture more than one atomistic trader.

[11] Borrowing-cycle refers to the process beginning with the government's announcement of auction and ending with first-type lenders' demand for foreign currency in order to pay out their debt service.

[12] We do not take into account of negative inflation.

Let private banks borrow from foreign creditors and purchase the A percentage ($0 < A \leq 1$) of total G-bonds issued, which amounts to $A.B$ in domestic currency, and let the domestic-saving households purchase the rest, $(1-A).B$. Traders are assumed to be atomistic, implying that neither of them affect[13] the interest rates. The households consume all of the return while the private banks pay out their debt service to foreign creditors, and consume the net-profit. We assume that traders can accumulate physical capital with a constant net-interest factor equal to $R > 1$. Thus, in a perfect foresight equilibrium with positive stocks of capital and G-bonds, traders should be indifferent between these two types of assets, and consequently Eq.(1) holds.

$$(1-\theta).R_b^g = R + R_b^f - (1-\theta) + R_b^f \left[\frac{\Delta rer_T^{T+1} - \pi_{T+1}}{1+\pi_{T+1}} \right] \tag{1}$$

where $R_b^f = (1 + r_b^f)$ denotes the interest-factor on receipts from foreign creditors, and r_b^f stands for foreign interest rate. $\Delta rer_T^{T+1} = \frac{\left(curr^f / curr^d \right)^{T+1} - \left(curr^f / curr^d \right)^{T}}{\left(curr^f / curr^d \right)^{T}}$ denotes % change in nominal exchange rate over the period T to T+1. Upper script *f* denotes "foreign", while *d* denotes "domestic". Therefore, the last term in RHS of Eq.(1) shows the % change in nominal exchange rate adjusted by rate of inflation. Consequently, each inflation rate is associated with a unique rate of repudiation, θ. Let the supply of high-powered money at date *t*, *t*=T,T+1 be denoted by S_t. For the sake of simplicity, we assume that the money authorities can directly determine the price level *P*, by, for example, setting the exchange rate. Furthermore, we assume that the demand for money satisfies

$$\frac{S}{P} = M \ , \ M > 0. \tag{2}$$

The revenue from inflation is conventionally defined as the amount of real resources that the government can obtain by associated sale of high-powered money: thus in period T+1 it would be given in Eq.(3).

$$\frac{S_{T+1} - S_T}{P_{T+1}} = M.\theta \tag{3}$$

The budget constraint of the government in period T+1 is given in Eq.(4).

$$\mathrm{X} = (1-\theta)B.R_b^g + G - M.\theta \tag{4}$$

[13] For further information the reader is referred to Detragiache (1996)

where X is revenue from tax, and G is government expenditures in period T+1. According to Eq.(4), inflation is assumed not to be costly for the government, and the inflation tax is substracted from total government expenditure (inclusive of debt service) in order to compute the amount of required conventional taxes. Effective consumption, E, is defined in Eq.(5). In period T+1, individuals consume all of their wealth excluding borrowed foreign savings. Then we have

$$E = N - D(X) + \lambda.R + (1-A).B.(1-\theta).R_b^g + A.B.(1-\theta)\left[R_b^g - \left(1+\Delta rer_T^{T+1}\right).R_b^f + 1\right] - X - M.\theta - F(\theta) \qquad (5)$$

where N is endowment income, $D(X)$ is a function representing the "deadweight" cost of taxation, and λ is per capita physical capital[14]. We assume that Eq.(6) holds.

$$D(0) = D'(0) = 0$$

$D''(0) > 0$ for all X,

$$\lim_{X\to\infty} D'(X) = \infty \quad and \quad \lim_{X\to-\infty} D'(X) = -\infty \qquad (6)$$

where $F(.)$ is the inflation-cost function. Without no loss of generality the inflation is reflected in a direct welfare cost for consumers.Thus, we have Eq.(7).

$$F(0) = F'(0) = 0 \qquad (7)$$

$F''(0) > 0$ for all θ.

There are two possible cases that generates the value of inflation rate. One derives from the government's precommitment on the value of inflation rate in period T, the other case arises from no precommitment strategy. Under no precommitment traders' reactions determine the rate of interest-return R_b^g as a function of their rational expectations on next period's inflation. We focus on the second case. The second case yields an optimization problem, which is identical to maximizing E with respect to the expected value of θ.

Consequently, a "benevolent" government tries to maximize E in period T+1 subject to its budget constraint given in Eq.(4). Taking R_b^g as given (recall that, by assumption, R_b^g was determined in period T), the government will choose X so as to minimize the function f:

[14] There is no real need to keep track of the non-negativity of E, because in this model one can always ensure that by setting endowment income, N, sufficiently large.

$$f\left(\theta, R_b^g, \Delta rer_T^{T+1}\right) = \left[D\left(G+(1-\theta)B.R_b^g - M.\theta\right) + A.B.(1-\theta)\left(R_b^g + \Delta rer_T^{T+1}.R_b^f - 1\right) + F(\theta)\right]$$

Since precommitment is not allowed, the government maximizes social welfare in period T+1, taking as given both interest rate factor R_b^g and inflationary expectations in period T. Using Eq.(4) and Eq.(5), this problem is equivalent to the minimization problem given in Eq.(8).

$$\underset{\theta\leq 1}{Min} \quad f\left(\theta; R_b^g, \Delta rer_T^{T+1}\right)$$

$$= \underset{\theta\leq 1}{Min} \quad \left[D\left(G+(1-\theta)B.R_b^g - M.\theta\right) + A.B.(1-\theta)\left(R_b^g + \Delta rer_T^{T+1}.R_b^f - 1\right) + F(\theta)\right] \qquad (8)$$

which is identical to $\left[-D'(X)\left(B.R_b^g + M\right) - A.B.\left(R_b^g + \Delta rer_T^{T+1}.R_b^f - 1\right) + F'(\theta)\right] = 0$

Using Eq.(8) , at an interior optimum we have

$$\frac{\partial f}{\partial \theta} = \left[-D'(X)\left(B.R_b^g + M\right) - A.B.\left(r_b^f + \Delta rer_T^{T+1}.\left(1+r_b^f\right)\right) + F'(\theta)\right] = 0 \qquad (9)$$

2.1 Derivation of multiple equilibria

The natural question that arises is whether this theoretical model can generate multiple equilibria. Using Eq.(6) and Eq.(7), Eq.(9) implies that the optimal θ depends on the value of the exchange rate, Δrer_T^{T+1}. Since the economy is under fixed exchange rate regime[15], the government may signal one-period ahead level of the exchange rate. Thus in period T, there are two possible cases in which change in exchange rate can be determined. These are $\Delta rer_T^{T+1} = 0$ and $\Delta rer_T^{T+1} > 0$.

2.1.1 Signaling no change, $\Delta rer_T^{T+1} = 0$.

Eq.(9) yields Eq.(10).

$$\frac{\partial f}{\partial \theta} = \left[-D'(X)\left(B.R_b^g + M\right) - A.B.\left(r_b^f\right) + F'(\theta)\right] = 0 \qquad (10)$$

[15] Starting in 1987, in a managed float exchange rate regime, the Central Bank of the Republic of Turkey (hereafter, the CBRT) announced daily quotations, and the domestic currency was depreciated continuously parallel to inflation expectations. (www.tcmb.gov.tr; Ozkan 2005; Özatay 2000; Akyüz and Boratav 2003). The 1999Q4 is the last quarter of the managed float regime before the implementation of the crawling peg regime of the Year 2000 Disinflation Program backed by the IMF[15]. At the end of February 2001, Turkish authorities switched the exchange rate regime to a floating regime.

It can be easily seen in Eq.(10) that the solution is unique and positive, $\theta > 0$.

Thus, according to Eq.(1) we have the net-interest return on government bonds in Eq.(11).

$$R_b^g = R.(1+\pi_{T+1}) + r_b^f \tag{11}$$

2.1.2 Signaling depreciation, $\Delta rer_T^{T+1} > 0$.

Eq.(9) yields Eq.(12).

$$\frac{\partial f}{\partial \theta} = \left[-D'(X)(B.R_b^g + M) - A.B.\left(r_b^f + \Delta rer_T^{T+1}(1+r_b^f)\right) + F'(\theta)\right] = 0 \tag{12}$$

Likewise, the solution is unique and positive, $\theta > 0$. Therefore, according to Eq.(1) the net interest-return on government bonds is obtained in Eq.(13).

$$R_b^g = R.(1+\pi_{T+1}) + r_b^f + \Delta rer_T^{T+1}.R_b^f \tag{13}$$

Since $\theta > 0$ holds under both of the two cases, and hence $\pi_{T+1} > 0$, the equilibria set is multiple and can be represented by two equilibria sets. Each is generated by the interest factors, given in Eq.(11) and Eq.(13), respectively. Since each solution for both Eq.(10) and Eq.(12) is unique, the interest factor given in Eq.(11) corresponds to the first-best choice of θ, θ^{FB}, and hence $\pi_{T+1}^{FB} > 0$, which is always above zero. On the other hand, nominal interest factor given in Eq.(13) corresponds to the second-best choice θ^{SB}, and hence the inflation choice $\pi_{T+1}^{SB} > 0$. In our model, these two Pareto inefficient multiple equilibria result from the role that the interest rate plays in determining inflation and reserve changes. Under the first case the interest factor that a trader expects is smaller than that is determined under the second case where depreciation occurs, $R.(1+\pi_{T+1}) + r_b^f < R.(1+\pi_{T+1}) + r_b^f + \Delta rer_T^{T+1}.R_b^f$. Therefore we have the following relation on government's choices for repudiation level: $0 < \theta^{FB} < \theta^{SB}$, which generates the multiple equilibria sets. Both of these cases enable us to define θ by a function $\Phi(.)$, such that

$$\theta = \Phi\left(\overset{+}{BR_b^g}, \overset{+}{G}, \overset{+}{R_b^f}, \overset{+}{\Delta rer_T^{T+1}} \right) \tag{14}$$

where signs over the variables indicate those of the corresponding partial derivatives at an interior solution. Consequently, each (first-best and second-best) equilibrium inflation rate is an increasing function of nominal debt service, $B.R_b^g$; government expenditure, G; interest demanded by foreign creditors, R_b^f; the change in nominal exchange rate over the period T to T+1, Δrer_T^{T+1}. An important implication of the above argument is that if there exists a positive stock of non-indexed bonds *B*, then θ is an increasing function of the nominal interest rate factors R_b^g and R_b^f, moreover of Δrer_T^{T+1}. Since the interest factor determined in Eq.(13) is greater than that in Eq.(11), to pay out minimum interest the government should not change exchange rate over period T to T+1, $\Delta rer_T^{T+1} = 0$. Even though the government has signaled as $\Delta rer_T^{T+1} = 0$, traders expect positive inflation rate, π_{T+1}. Using Fisher equation Eq.(1) we have equilibrium θ increasing in R_b^g, which gives rise to the multiple equilibria with $\pi_{T+1} > 0$ at the end of period T+1.

According to our model, both first-best and second-best nominal interest factors, respectively given in Eq.(11) and Eq.(13) generate positive inflation. Let us empirically test whether the expectations have been such that the rate of inflation was always positive. To do this we analyze the phase-space characteristics of the real ex-post interest rates. The following section deals with this task.

3 Empirical approach to the model economy

The empirical approach to the model is conducted using the data of real ex-post interest rates on domestic market-based public debt stock in Turkey. The data are publicly available on two locations: first, on the website of the Central Bank of the Republic of Turkey, at http://www.tcmb.gov.tr., and second, on the website of Undersecretariat of Treasury, www.treasury.gov.tr. Our quarterly data set begins in 1989Q1 and ends in 2009Q4, which includes 84 observations covering the episodes of the crisis periods 1994, 1999 and 2001. First step involves phase-space construction of the real ex-post interest rates. Secondly, we test the sensitive dependence to initial conditions.

Let us define the interest payments on domestic market-based public debt in period T: $(IP)_T = \left(r_b^g\right)_T . B_{T-1}$, where *IP* denotes the interest payments, *B* stands for debt stock and r_b^g denotes nominal ex-post interest rate on government bonds[16]. The nominal ex-post interest rate is obtained by $\left(r_b^g\right)_T = \frac{(IP)_T}{B_{T-1}}$. By definition we may compute real ex-post interest rate as $i_T^r = \left(\frac{\left(r_b^g\right)_T - \pi_T}{1+\pi_T}\right)$ or real interest factor as $1 + i_T^r = R_b^g\left(1-\theta\right)$, where θ is the repudiation that took place in period T.

[16] We conserve the notational use in section 2.

3.1 Phase-space portrait

Let us denote the dynamical system, $f : R^n \to R^n$, with the trajectory,

$$x_{t+1} = f(x_t) + \eta_t,\ \ t = 0,1,2,....,\ \text{and where } \eta_t \text{ is an } i.i.d. \text{ process} \tag{15}$$

Associated with the dynamical system in Eq.(15) there is a measurement function $h : R^n \to R$ which generates the time series, $z_t = h(x_t)$. It is assumed that all that is available to observer is the sequence $\{z_t\}$. The dynamical system itself may be assumed to be contaminated by noise, or the observed time series z_t may be assumed to convey noise[17]. According to the Takens' theorem (Takens 1981), from observed time series $\{z_t\}$, we can generate the data vector shown in Eq.(16).

$$y_i = \left(z_i, z_{i+d}, ..., z_{i+(m-1).d}\right) \text{ for all } i \in \left(N - (m-1).d\right) \tag{16}$$

where *N* is the length of the observed sequence $\{z_t\}$; *d* is the time delay. This vector indicates a point of *m*-dimensional reconstructed phase-space R^m, where *m* is embedding dimension. The reconstructed trajectory is an embedding of the original trajectory when the *m* value is sufficiently large, $m \geq 2n+1$, which is upper-worst case. Depending on the data, embedding can be established even when *m* is less than 2*n*+1 (Gencay and Dechert 1992). Abarbanel (1995) suggest how to select *m* and *d*. From now on the time delay *d*, is taken to be equal to 1, corresponding to observation interval on time domain. Let us present Figure 1, output of Eq.(16), namely reconstructed phase-space for real ex-post interest rate data. Figure 1 enables us to visualize the orbit of interest rates. Figure 1 explicitly depicts the attractors[18] on the observed data. We find out that there are two attractor sets one of which is more forceful and represents low interest levels. The two attractors determine the distribution of other points until the system reaches the maximum iteration, $\tau_{\max}$. The maximum iteration represents the critical maturity level. The points which are located extremely far from the foreceful attractor signify higher interest rate levels and show the crisis episodes . The incidence of two attractors on the orbit in Figure 1 coincides with the Pareto inefficient multiple equilibria sets obtained in Eq.(11) and Eq.(13). Figure 1 enables us to locate the dynamical path of interest levels with respect to the multiple equilibria.

[17] Kantz's algorithm allows us to make this assumption, Kantz (1994).
[18] The attractors are determined by using Tisean Package (Hegger et al. 1999).

Figure 1. The orbit of real ex-post interest rates, i_T^r and the attractors on the orbit.

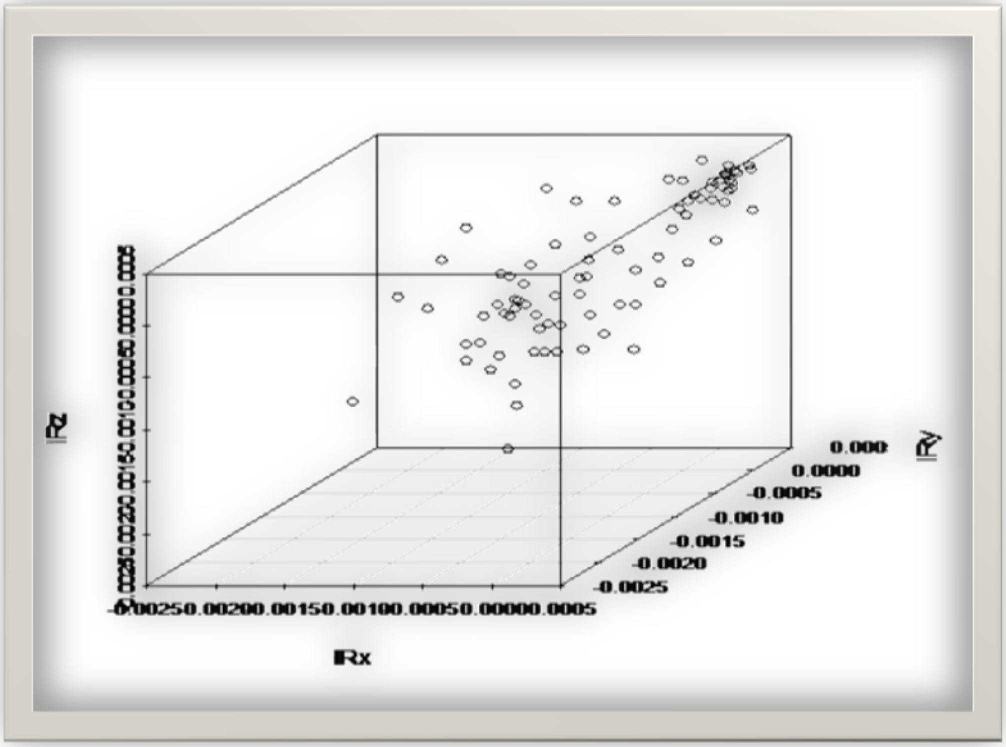

Figure 1 depicts the orbit of Turkish real ex-post interest rates data[19] i_T^r . In Figure 1 the *x-axis* (IRx) shows i_T^r ; *y-axis* (IRy) shows i_{T+1}^r and *z-axis* (IRz) shows i_{T+2}^r , given the embedding dimension, $m = 3$.

3.2 Sensitive dependence to initial conditions

To deepen our analysis we have to determine whether the interest levels on dynamical path diverge from equilibrium sets shown in Figure 1. If so, can we obtain a threshold value for the "time" of this divergence?. To answer this question we determine the structure of the attractor sets. A chaotic attractor is characterized by the maximal Lyapunov exponent (max LE) being greater than zero. It measures expansion[20] in phase-space and represents the divergence of points in phase-space, or the sensitive dependence on the conditions represented by each point. To compute max LE directly, based on the algorithm of Wolf et al. (1985), Rosenstein (1993) and Kantz (1994) use the fact that the distance between two trajectories in R^m typically increases with a rate given by the max LE. Therefore we

[19] The data can be obtained from website of Central Bank of Republic of Turkey, www.tcmb.gov.tr or can be supplied upon to request. 1987=100 Consumer Price Index is used to obtain real values, Turkish National Statistical Association, www.tuik.gov.tr

[20] A negative one measures contraction in phase-space.

define the distance between a reference trajectory y_t and one of its $\varepsilon-$ neighbor(s) $y_t^{(\varepsilon)}$ after the relative time (iteration) τ by a function :

$$K(.): R^m \to R \quad \text{and} \quad K\left(y_t, y_t^{(\varepsilon)}; \tau\right) = \left| y_{t+\tau} - y_{t+\tau}^{(\varepsilon)} \right| \tag{17}$$

Eq.(17) gives the magnitude of the difference vector $\left(y_{t+\tau} - y_{t+\tau}^{(\varepsilon)}\right)$ lying between the point $y_{t+\tau}$ and the point $y_{t+\tau}^{(\varepsilon)}$. The logarithm of *K(.)* is needed to smooth the output of the function. We compute it for all *t=1,2,..,T* , where *T* is the number of reference points[21] on the orbit. Thus we obtain Eq.(18).

$$L(\tau) = \frac{1}{T} \sum_{t=1}^{T} \ln\left(\frac{1}{|U_t|} \sum_{y_t^{(\varepsilon)} \in U_t} K\left(y_t, y_t^{(\varepsilon)}; \tau\right) \right) \tag{18}$$

where $|U_t|$ denotes the number of elements of set of $\varepsilon-$neighbors of y_t. Finally, the slope of the curve $L(\tau)$ gives us the maximal Lyapunov exponent a la Kantz:

$$\frac{\partial L(\tau)}{\partial \tau} \cong \lambda^{\max}(t) \text{ for any } \tau \text{ in the scaling region, } \tau \le \tau_{\max} \tag{19}$$

In summary, our numerical value for the max LE is the slope of the curve $L(\tau)$ in the scaling region. The result of the chaotic approach[22] is obtained by Eq.(19). According to Eq.(19), the real ex-post interest rates exhibit chaotic process with positive max LE, $\lambda^{\max}(t) > 0$. The τ value(s) where the slope of the $L(\tau)$ curves approximates zero is denoted by $\tau_{\max}$ and signifies the last step of scaling range. At this value of $\tau_{\max}$ the dynamical system is still deterministic and hence the output is predictable. Theoretically the higher $\tau_{\max}$ is the more deterministic is the system until the $\tau_{\max}$ value is reached (in other words, until the points on the orbit escape from attractors). Through the iterations exceeding $\tau_{\max}$ the system under consideration jumps into unstable state and the observed process becomes unpredictable.

4 Results

Our findings can be summarized as follows. The incidence of two attractors on the orbit in Figure 1 coincides with the multiple equilibria sets obtained in Eq.(11) and Eq.(13). The $\tau_{\max}$ value that we determine is $\tau_{\max} = 4$, which shows the threshold level for the policy response -i.e., buildup of domestic

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[21] Reference point is the point on the orbit which has at least one ε - neighbor.

[22] Tisean Package (Hegger et al. 1999) is used to compute Eq.(18) and Eq.(19).

debt[23]. Using Eq.(19), we compute that the real ex-post interest rates exhibit chaotic process with positive max LE, $\lambda^{\max}(t) > 0$, which shows that the attractors are strange and the process diverges at $\tau_{\max} > 4$. By definition the positive max LE represents the sensitive dependence on initial conditions, which corresponds to the sensitivity to small changes in market expectations on repudiation. Therefore interest rates can be predictable only for 4 iterations. Through the iterations exceeding 4 quarters the fiscal and monetary policies are no more sustainable and a major shift from low to high interest levels eventually occurs at any "time". The lower $\tau_{\max}$ value is the higher is domestic debt intolerance[24]. The $\tau_{\max}$ value together with positive max LE show that the velocity of the divergence is higher, a fact emphasized by Ozkan (2005); Akyuz and Boratav (2003). The two studies report that given the gap between the "observed" public sector borrowing requirement (PSBR) and the size of the domestic capital markets the outcome was ever-increasing real interest rates on domestic borrowing, which, in turn, became the source of further deterioration in public balances. On the other hand Eichengreen (2001) point it out that in 1999 the contingent liabilities of public sector reached %15 of GDP, which certainly shows that the "true" gap was more greater than observed. Following from the IMF stabilization programme in 1999, at least a share of contingent liabilities is converted to direct liabilities by issuance of special type G-Bonds to public sector enities and servicing of this stock was performed over the period 1999 to 2002 (Yeldan 2001; Dikec 2001; Evrensel 2004). Therefore focusing on real ex-post interest rates on domestic debt enables us to take into account the effect of contingent liabilities on 2000/2001 crisis.

Our findings have further implications. In the presence of two Pareto inefficient multiple equilibria, the two attractors observed on the orbit enable us to conclude that the probability of switching from first-best equilibria set { $R_b^g = R.(1+\pi_{T+1}) + r_b^f \; ; \theta^{FB} > 0$ } to the second-best equilibria set { $R_b^g = R.(1+\pi_{T+1}) + r_b^f + \Delta rer_T^{T+1}.R_b^f \; ; \; \theta^{SB} > 0$ } is equal to 1. The certainty arises from the two-fold properties of chaotic attractors. First, every point on the path that is established between two attractors

[23]During the 1990s interest rates on government debt exceeded the inflation rate, on average (Dikec 2001). Akyuz and Boratav (2003) find that two factors appear to have played a crucial role in pushing up the rate of interest on domestic government debt. First, dollarization reduced the transaction costs of entry and exit into foreign assets, raising their net return. Second, instability of the inflation rate raised the risk of assets denominated in domestic currencies The outcome was a rapid buildup of public debt and the emergence of a financial system which came to depend on arbitrage margins offered by high rates on government debt in comparison with international borrowing and domestic deposits, including forex deposits, at the cost of large currency risks (Akyuz and Boratav 2003, pg 1551).

[24] For Turkey, Reinhart et al. (2003) report that Turkey exhibits high debt intolerance and that domestically issued, market-based government debt has become increasingly important, both as a source of government financing and as a trigger for generalized debt and financial crises.

(orbit) should be visited by the process and second, the positive value of max LE which makes the process diverge on that path. This result shows that domestic currency depreciation $\Delta rer_T^{T+1} > 0$ inherently became a fiscal policy implication of Turkish government over the post-liberalization period. Over the period 1987 to 2000, in a managed float exchange rate regime, the Central Bank of the Republic of Turkey (hereafter, the CBRT) announced daily quotations, and the domestic currency was depreciated continuously parallel to inflation expectations. (www.tcmb.gov.tr; Ozkan 2005; Özatay 2000; Akyüz and Boratav 2003). The 2000Q1 is the first quarter where the crawling peg regime is implemented under Disinflation Program backed by the IMF[25]. At the end of February 2001, Turkish authorities switched the exchange rate regime to a floating regime. Even though the CBRT has initially managed the sequential depreciations, when the evolution of small changes in expectations yields considerable market pressure in crisis episodes, large devaluations occurred. In nominal terms the Turkish Lira depreciated[26] by 70% against the United States Dollar in 1994, 53% in 2001. Our findings confront with these economic observations. The two equilibria sets on the orbit and their strange character together imply that the crises (1994 and 2000/2001) were inevitable. Berument and Pasaogullari (2003) report that there is no evidence in post-liberalization period that large depreciations of the real exchange rate are caused by large declines in the prices of non-tradable goods. Large depreciations in real terms result from large nominal exchange rate depreciations like the1994 and 2000/2001 crises. These findings are later confirmed by Ozkan (2005). Focusing on the post-liberalization period, the author points it out that there was a steady real appreciation of the Turkish lira up until 1994. This was partly due to the combination of expansionary fiscal and tight monetary policy during this period. The pace of this real appreciation was fastest between 1989 and 1991. The 1994 crisis brought about a considerable reversion of this process with a large depreciation of the nominal exchange rate. However, the real exchange rate started on a new appreciation path from 1996 and reached very high levels prior to the drastic devaluation in February 2001. The phase-space portrait of the real ex-post interest rates sheds light on the depreciation/appreciation path that is determined by Ozkan (2005).

A crisis happens whenever agents' expectations of devaluation increases, i.e. the regime shifts to a bad state from a good state. Given positive max LE, it is straightforward to conclude that if there is

[25] Turkey had implemented 16 stand-by agreements with the IMF previously, all but two of which were abandoned before accomplished.

[26] Turkish government devalued the lira by 20 per cent on April 5, 1994 and the real exchange rate depreciated by 12 per cent in 1994. On February 2001, the value of the U.S. dollar against the Turkish lira increased by 40 per cent. The data are provided by the Central Bank of Turkey and are calculated using the IMF weights for 19 trading partner countries.

small change in market expectations on repudiation, then chaotic process will eventually generate a major sudden shift from good equilibrium to the bad one. We have to note that our results are in particular accordance with the findings of Tamgac (2011). Focusing on the crisis periods 1994 and 2000/2001 the author reports in pg.55 "...The transition probabilities between the two states of expectations cannot be predicted with economic fundamentals, which indicate that the Turkish crisis episodes were driven by sunspot equilibria." First, sunspot equilibria cannot be prevented, and hence it is inevitable. The result of the author is coinciding with our result. Second, our analysis shows that the incapability of Tamgac (2011) to predict the crisis possibly originates from the high-degree ($\tau_{\max} = 4$) chaotic structure of interest rates. Our approach shows that this transition is inevitable.

5 Conclusions

In this paper we have studied the identification of multiple equilibria by analyzing phase-space characterization of the interest rates. The task takes as given our model economy with multiple equilibria and seeks whether the multiple equilibria can be verified by the data.

First, we have introduced a Calvo-type debt repudiation model which is modified by taking into account the country-specific properties of Turkish domestic market-based borrowing structure. Our model results with two Pareto inefficient equilibria. Secondly, we introduce the reconstruction of phase-space portrait of the considered "economy". The phase-space portait enables us to visualize the path for debt dynamics i.e., moving from some initial stable "equilibria" and diverging through unsustainable values. Second, we measure how the default episodes diverge/converge apart on phase-space, depending on the value of maximal Lyapunov exponent. We applied more recent computational methods proposed by Kantz (1994).

Financial markets are always subject to self-fulfilling behavior through agents' expectations and investor confidence (see Cole and Kehoe 2000; Taylor 2009). This simple empirical analysis method for multiple equilibria models is able to identify the evolution of self-fulfilling set(s) of expectations through the attractors lying on orbit. Our results show that chaotic approach can be used in crisis models with multiple equilibria where we observe behavior discontinuity like in the recent financial crisis (see Calvo 2009).

Even though the chaotic structure does not enable us to compute exact visiting "time" of neighboring points on the orbit, -i.e., predicting the incidence of crisis, we can determine a deadline before which governments should give appropriate policy responses. The common knowledge of that deadline may eliminate the crisis (Hellwig et al. 2006).

Turkish crises can be viewed as a case of multiple equilibria where shift in agents' expectations played a role in the incidence of the crises. Different from the other studies focusing on Turkish financial crises in perspective of currency crisis models, our study shed some light on the hidden effect of overhang of domestic market-based borrowing – i.e, the gap between PSBR and change in domestic debt stock, which is "omitted" in the literature. Therefore our results give support to the findings of Reinhart and Rogoff (2008, 2011). These studies show that the overt default on (or repudiation) and rescheduling of domestic public debt are hidden behind the high inflation, banking crises, currency crashes, and debasements which often go hand in-hand with default.

Market expectations can contribute to the occurrence of a crisis that would not have taken place if such expectations could have been prevented at first place. Some examples of such self-fulfilling expectations are the collapse of a fixed exchange rate regime, the burst of an asset bubble, the failure to service the debt, or a bank run. Thus there is good reason to take preventive measures before it is too late. Since chaotic behavior of self-fulfilling expectations are more like sunspot behavior, it may not be possible for policy-makers to prevent such expectations, just as they cannot control external factors. However it is possible for the policymakers to detect the presence of multiple equilibria and to avoid it with an appropriate policy response.

For future agenda we have to note here a technical extension. Consistent with the literature, if we consider multiple equilibria set to be composed of both Pareto efficient equilibria and Pareto inefficient equilibria[27], then on phase-space we expect to observe different kinds of attractors together, which are belong to different dynamical systems and imply regime change or a kind of attack.

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[27] In models of debt repudiation, generally authors report two equilibria sets, one is Pareto efficient (inflation is zero), the other is Pareto inefficient (Calvo 1988; Dreher et al. 2006). Our model in Section 2 results with two Pareto inefficient equilibria.

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