The dynamics of limits to arbitrage: An empirical investigation*

Andrea Buraschi †  Emrah Sener ‡  Murat Menguturk §

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Abstract

The Law of One Price (LOP) suggests a simple arbitrage relation that must link prices of Treasury bonds when issued by the same issuer in different currency denominations. This relation was widely violated during the 2007-2008 Crisis. We construct an empirical proxy of limits to arbitrage (LtA) and run a comprehensive investigation about the economic drivers of this violation for different issuers and maturities. A key source of information is a unique dataset that provides details on the cost of borrowing and the inventory of lendable bonds at broker-dealers. We compare the importance of financial frictions and economic risk factors to explain the dynamics of LtA during the Crisis period. We find that financial frictions are significant in explaining these deviations, though their impact is subsumed by global measures of discount rate, cash flow and funding risks that have significant explanatory power after Lehman’s collapse. We also explore the extent to which monetary policy interventions helped to reduce LtA deviations, and enabled price discovery.

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†Andrea.Buraschi@ChicagoBooth.edu and a.buraschi@imperial.ac.uk. Visiting Professor of Finance at The University of Chicago Booth School of Business, 5807 South Woodlawn Avenue, Chicago IL 60637, US. Professor of Finance at Imperial College London Business School; South Kensington Campus, London SW7 2AZ, UK.

‡Emrah.Sener@ozyegin.edu.tr; Director of Center for Computational Finance, Ozyegin University; Kusbakisi Cad Altunizade, Istanbul 34662, Turkey.

§M.Menguturk10@imperial.ac.uk, PhD candidate at Imperial College Business School; Imperial College London, South Kensington Campus, London SW7 2AZ, UK.
It is good for a scientific enterprise, as well as for a society, to have well established laws. Physics has excellent laws, such as the law of gravity. What does economics have? The first law of economics is clearly the law of supply and demand, and a fine law it is. We would nominate as the second law “the law of one price”, hereafter simply the Law.

Lamont and Thaler (2003a, p. 191)

1 Introduction

This paper is an empirical study of the dynamic properties of the violations of the law of one price in sovereign bond markets around periods of market distress. We investigate the extent to which limits to arbitrage are time-varying, how they are related to specific market frictions and risk factors, and how they have changed before, during and after the 2007-2008 liquidity/credit crises. An important component of this study is a unique dataset that provides the most extensive coverage on security lending currently available. It includes detailed information on total amount lent out, total available lending supply, loan transactions, loan fees (cost of borrowing), and active loan utilizations of both euro- and usd-denominated sovereign bonds, provided on a weekly basis by the major prime brokers, custodians, and the lending desks of large firms that actually lend/borrow these securities. We use this detailed information to help distinguish between the role of financial frictions and economic risk factors in explaining the dynamics of limits to arbitrage.

Was the law of one price genuinely impaired in the markets after carefully accounting for transaction costs? Indeed, while we find no evidence of a violation before the 2007-2008 Crisis, a significant anomaly emerges that did not last just a few days but persisted for over a year. This phenomenon begs a series of fundamental financial economics questions related to the type of limitations that may prevent price convergence. Four main channels are suggested in the extant literature: (a) Limited supply of lendable securities and associated short-selling constraints and borrowing costs (financial frictions); (b) Increased funding costs affecting capital availability to arbitrageurs (funding risk); (c) Increased risk premia affecting the required return on risky arbitrages (risk premia); (d) market irrationality. We first focus on the role of frictions and document the extent to which they help to explain the dynamics of the deviations. Then, we control for funding risks and risk premia and study if frictions are endogenous and document the relative importance of these risk factors. Finally, we investigate how different type of policy interventions during the Crisis helped (or not) helped eliminating these deviations.

We focus on unexploited violations of the law of one price for sovereign securities in large supply, with a fixed terminal maturity, and occurring at the same time across different geographical areas. Thus, it is different than earlier studies that looked at small markets or securities with no terminal resolution of uncertainty. A large number of sovereigns and multinational corporations issue debt denominated in more than one foreign currency. Brazil, for instance, issues a considerable amount of both usd- and euro-denominated bonds having similar, if not identical time-to-maturities. If expected recovery rates in different foreign currencies are the same (as is the case for EM countries), yield spreads of the same bond (across two currencies) must satisfy a simple no-arbitrage restriction. The price of a usd-denominated Brazilian bond should be equal to its eur-denominated equivalent.
(with same maturity) once the foreign exchange rate risk is swapped/hedged in the usd-eur FX swap market.\footnote{Notice that we are comparing two bonds which are both denominated in a foreign currency to the issuer, as opposed to a domestic and a foreign bond. In the latter case, obviously, credit risks are different.} In December 2008, however, Brazil’s euro-denominated yield spread on 10-year Eurobonds was nearly 25% higher than the yield spread on the same maturity bond denominated in usd; this difference was only 4% in November 2005. A similar phenomenon in the CDS market was widely reported in the press. However, the CDS-bond basis refers to a spread between two somewhat different assets: The CDS is an over-the-counter contract, while a bond is a traded security. Thus, the negative basis may partially reflect liquidity and counterparty risks. By studying two homogeneous traded assets, we circumvent this issue.

While significant deviations from the law of one price are certainly not common, the recent credit crisis offers a unique laboratory to study such an important phenomenon. While one may not be surprised to see scattered evidence of violations of the LOP in small and illiquid markets, it is more significant when we see these violations in large and liquid markets, as the case for sovereign Treasury bonds. For this reason, we select the three most important emerging sovereign bond markets (by notional amount outstanding) with issues denominated in both usd and euro (i.e. Turkey, Brazil and Mexico). These countries have three important features: (a) they have large and liquid bond markets, in which search and trading costs were small before the crisis; (b) they were “remote” to the epicenter of the Crisis; (c) their bond prices satisfied the law of one price before the Crisis.

The law of one price (LOP) plays a key role in financial economics. Lamont and Thaler (2003b, p. 228) suggest that understanding the role of market institutions in favoring (or limiting) arbitrage is one of the most important endeavors in finance: “Arbitrage is the basis of much of modern financial theory, including the Modigliani-Miller capital structure propositions, the Black-Scholes option pricing formula, and the arbitrage pricing theory.” Empirical studies of the law of one price are important for several reasons. The law of one price is linked to tests of efficient market hypothesis, which argues that prices ought to reflect fundamental values, at least under some general informational conditions. A vast literature tested different definitions of market efficiency; however, traditional tests are not simple, mainly because fundamental values are unobservable. Fama (1991, p. 1575) describes this difficulty as the “joint-hypothesis” problem: “[...] market efficiency per se is not testable. It must be tested jointly with some model of equilibrium, an asset-pricing model.” For instance, to conclude that value stocks are cheap with respect to growth stocks, one needs notions of risk and equilibrium expected excess returns. Tests of the law of one price, on the other hand, are tests of relative valuation: they do not require an asset pricing model to be able to state that identical assets need to have identical prices. Violations of the law of one price are easier to identify, thus potentially easier for arbitrageurs to eliminate. If two identical securities A and B are trading at two different prices, say 101 and 100 dollars, respectively, an arbitrageur can sell security A and buy security B. If access to capital markets is such that sufficient amount of liquidity can be supplied to this trade, the price of security B would increase and the price of security A would drop. When the two prices converge, the arbitrageur can lock-in a profit. Arbitrageurs, in this sense, can play an essential role in eliminating mispricings and providing liquidity, thus allowing asset prices to reflect market fundamentals. However, access to capital markets may be limited, and/or the institutional characteristics may prevent an arbitrage trade from being risk-free. For instance, the price differential may widen even further, the cost of rolling over the position may change, or the prime broker
may force the liquidation of the portfolio. If the arbitrageur relies on a fragile capital structure, in some states of the world this may reduce the ability of capital markets to close the price gap and to allow for price discovery. This risk can be either systematic, if the widening occurs in general bad states of the economy, or idiosyncratic (see Lee et al., 1991). When the assets are known to converge in value in a finite time, then this risk is substantially smaller. An example of this is the case of two bonds issued by the same issuer with 1-year maturity in two currency denominations: they must converge in value at maturity. This finite maturity eliminates another important risk as well: bond holders redeeming the bonds at due date are not affected by liquidity risk. But still, an important risk in arbitrage relates to frictions and transaction costs. If capital becomes scarce or expensive, then it may be difficult for the market to provide enough capital to induce convergence. It may also be highly difficult (or costly) to short sell a bond. If the cost is high, the arbitrage opportunity may go unexploited. These issues have been studied in the emerging limits to arbitrage literature.

We proceed in four steps. First, we calculate a proxy of the deviation from the LOP based on the two yield spreads of pairs of bonds from the same issuer, but denominated in different currencies. This measure, which we call the Limit to Arbitrage proxy (LtA), accounts for both transaction costs and exchange rates. We decompose this variable in two parts. The first results from a violation of the covered interest rate parity condition, and the second from violations in the each specific bond market. If the LOP holds, both components must be equal to zero. We focus mostly on the second component ($LtA_{bond}$) since this is, at the same time, the largest and least researched component. Second, we investigate whether $LtA_{bond}$ is state-dependent, and what drives its dynamics. This involves dividing the period into four sub-samples (i.e. Pre-Crisis, Liquidity Crisis, Credit Crisis and Post-Crisis), and investigating which potential market factor drives the dynamics of $LtA_{bond}$ in each sub-sample. We study the four channels by quantifying (a) the tightening impact of the stock of lendable assets and associated borrowing costs at security levels; (b) the dynamics of different funding markets; and (c) the dynamics of different risk premia (liquidity risks, global cash-flow risks, global discount rate risks, economic uncertainty). We report the relative importance of each of these factors over the 2005 - 2010 period. Third, we evaluate the impacts of the different monetary policies implemented by the Federal Reserve (FED). We frame this part of the analysis in the context of an event study and quantify the impact of the FED’s liquidity interventions, lending facilities, stress tests, and asset purchase programs on the dynamics of $LtA_{bond}$.

We find a number of novel empirical results. First, $LtA_{bond}$ is state-dependent. During normal conditions (i.e. Pre-Crisis), it is not significantly different from zero and broadly within its bid-ask bounds: the sovereign bond market is sufficiently liquid that any deviation from the LOP is quickly arbitraged away. However, this does not hold true for an extended period of time during the Credit Crisis when the $LtA_{bond}$ becomes large, persistent and highly volatile. Arbitrageurs are either unable or unwilling to enforce the simple equilibrium relation.

Second, the time-variation in the inventory of lendable securities at broker dealers and short-selling loan fees helps to explain the dynamics of $LtA_{bond}$ deviations (with an $R^2$ between 13% and 15%). Arbitrage deviations tend to decrease with higher loan availability and lower loan fees. This is consistent with recent findings in equity markets about the impact of the short-selling bans on price efficiency. However, when we control for additional time-varying risk factors, the significance of financial frictions disappears. Indeed, during the Credit Crisis more than 60% of the total variation
in the $LtA_{bond}$ proxy can be explained by risk factors, of which a global discount rate risks (measured from assets unrelated to those used to compute $LtA_{bond}$), cash-flow risks and funding risks account for the largest component. This is an important result, which is consistent with frictions being themselves endogenous and affected by market conditions and risk premia. Moreover, it highlights how sensitive Eurobond arbitrage relationships are to spillover effects from large funding capital markets and the significance of a global discount rate channel in explaining deviations from the LOP.

Another interesting result relates to the difference in the significance between the secured and unsecured markets as a source of funding risk. The unsecured interbank funding market is statistically insignificant in explaining the dynamics for $LtA_{bond}$. On the other hand, the secured funding risk factor is highly significant. This is interesting, since in its first phase of policy interventions, the FED decided to focus on the unsecured lending market with a series of emergency measures to extend swap lines. Our Event Analysis reveals that the first set of policies has not been as effective as expected in reducing $LtA_{bond}$ levels. Notwithstanding these policy measures, we find that $LtA_{bond}$ remained at stressed levels for a protracted period of time. During the second phase of the market distress (i.e. Credit Crisis), the global discount rate risk factor is still strongly significant. After the decision of the FED to publish the stress test results (of financial institutions), this factor becomes less significant in explaining the $LtA_{bond}$ dynamics. Thereafter, $LtA_{bond}$ levels compress considerably. This has important policy and welfare implications.

Our fourth finding is related to the price discovery in the corresponding bond spreads, which sheds light on the importance of the funding markets for arbitrageurs. First, our findings suggest that Brazil and Mexico on average pay higher and more volatile risk premia in euro compared to usd, while for Turkey the opposite holds true. Furthermore, usd-denominated bonds in Brazil and Mexico contribute more to the price discovery process than their euro-denominated equivalents. On the other hand, Turkish euro-denominated bonds tend to lead the price variations of their usd-denominated equivalents. The signs of the spread basis deviations (i.e. $Basis_{bond}$) suggest that the limits to arbitrage are country-specific and not currency-specific, as reported in previous studies.

Finally, we find evidence against the market practice of using usd spreads as the de-facto input for the pricing of the same credit risk denominated in different currencies. While this appears to be a popular approach, we find that investors require different premia on usd- and euro-denominated bonds of the same issuer. Thus, the assumption of currency independence may lead to seriously mispriced credit products. It is empirically incorrect to treat usd spread as the de-facto reference currency in the valuation of foreign-denominated credit products of the same issuer: credit pricing models should take into account the funding risks specific to each corresponding currency.

The paper is organized as follows: Section 2 gives the related literature, and Section 3 gives a theoretical framework of the Eurobond no-arbitrage relation. Section 4 details the data selection and summary statistics, and Section 5 outlines the possible determinants of limits to arbitrage. In Section 6, we present the methodology used in the empirical analysis and discuss the empirical results. Section 7 investigates the link between the $LtA$ and different policy announcements. Section 8 presents results of different robustness checks, and Section 9 concludes.
2 Literature Review

This paper is related to three streams of the asset pricing literature. A vast body of the work investigates market anomalies that appear to be unrelated to economic fundamentals. The first part of this stream studies the predictability of asset returns and shows evidence that stock returns are predictable either based on past earnings (the post-earnings announcement drift puzzle by Bernard and Thomas, 1989), or short-run momentum effects (Jegadeesh and Titman, 1993). The second part of this literature investigates the behavior of relative asset prices and violations of the LOP, including the Siamese-Twin stocks puzzle by Rosenthal and Young (1990), the closed-end discount puzzle by Klibanoff et al. (1998), the Palm-3Com spin-off puzzle by Lamont and Thaler (2003b), and the put-call parity deviations by Ofek et. al. (2004). While our study is more directly related to the latter, an important point of differentiation is both the structure of our data and type of the questions we ask. Our empirical analysis is based on data from a large and liquid market (euro- and usd-denominated sovereign bonds), where searching/shorting costs are tiny and symmetrical across currency denominations, and the two assets converge in value at maturity; the potential violations are, on the other hand, systematic and persistent during the crisis, as opposed to being related to a set of isolated events. Our \( LTA_{\text{bor}} \) proxy is obtained in a fairly simple framework, in a context in which security pairs have nearly matching cash flows, and can be analyzed empirically in a market with high liquidity and data accessibility. Moreover, our empirical framework allows us to address a different question than the previous related literature: what are the economic determinants of limits to arbitrage during the different states of the economy (i.e. during a systemic event)? This question also allows us to quantify the relative economic importance of each risk factor during different sample periods.

The second stream of the literature studies the implications of financial constraints on the equilibrium asset prices. This literature has taken two directions. The first deals directly with different type of financial constraints and frictions, such as short selling (Tuckman and Vila, 1992), equity capital borrowing (Shleifer and Vishny, 1997) and the role of collateral value (Bernanke and Gertler, 1989; Fostel and Geanakoplos, 2008), limited risk capital (Gabaix et al., 2007; Garleanu and Pedersen, 2007), margin requirements (Brunnermeier and Pedersen, 2009, Garleanu and Pedersen, 2011), leverage constraints (Gromb and Vayanos, 2002), banking frictions (Allen and Gale, 2004; Acharya and Viswanathan, 2010), the role of market liquidity risk (Mitchell et al., 2007) and market liquidity (Amihud and Mendelson, 1986; Duffie et al., 2007). The second part of this literature studies the implications of these frictions in terms of welfare and public policy. Gromb and Vayanos (2010) highlight the role of specialized institutions in the optimal allocation of capital, and their impact on socially optimal decisions, and whether this has relevant public policy implications. Krishnamurthy (2010) argues that the financial crises, including the subprime and Lehman’s collapse, provide a compelling example of how government intervention can play a role in the smooth functioning of financial markets. One can view these government interventions as a way to reduce limits of arbitrage in financial markets, thus restoring the link between market prices and fundamental values. Since the financial sector can have a systematic role in the allocation of resources in the real economy, financial distress may lead to welfare costs. Geanakoplos and Polemarchakis (1986) show that in the presence of market frictions, market incompleteness creates the possibility of Pareto improve-

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2 Refer to Gromb and Vayanos (2010) for an excellent treatment of the main literature on market anomalies.
ments triggered by public intervention. In that sense, the research on limits to arbitrage is linked to the debate on the optimal design of public policies during financial crises. Another contribution of our paper is related to the impact of the FED interventions on the compression of large arbitrage anomalies in the Eurobond market.

Our paper is also related to a third stream of the literature that deals with credit risks and derivatives pricing. This stream has taken two directions. The first deals with the decomposition of credit spreads in a single currency setting (Elton et al., 2001; Collin-Dufresne et al., 2001; Longstaff et al., 2005). These studies show that credit spreads levels and dynamics are difficult to be reconciled with traditional structural credit risk models with additive preferences when calibrated to historical default and recovery rates. Collin-Dufresne et al. (2001) argue about the existence of a systematic factor which is not identifiable from traditional priced risk factors. The second stream deals with credit spreads (of a single issuer) in a multi currency setting. Examples include studies on currency dependence in credit factor risk models (Kercheval et al., 2003), the impact of sudden devaluations (Ehlers and Schonbucher, 2006) and the impact of the correlation between default variables and exchange rates (Jankowitsch and Pichler, 2005). These questions are important among practitioners since it is common market practice among investment banks, data suppliers (i.e. Reuters and Bloomberg) and rating agency companies (i.e. Moody’s and Standard Poors) to employ usd as an input to price the credit risk of products that make reference to the same issuer, even across different currency denominations (Merrill Lynch, 2000). The implicit assumption is that the FX market is liquid and deep enough to make the usd a perfect substitute for other currencies, and that the credit spreads (across two currencies) are functions of only the underlying risk-free rates and the default credibility of the issuer.

3 Theoretical Framework

In order to explore the concept of limits to arbitrage in the sovereign Eurobond market, we consider an asset (i.e. Eurobond) sold by the same issuer in two (foreign) markets. Thus, the only difference between these two bonds is their currency denomination (usd and euro, respectively). We use the Law of One Price to define a variable called $\text{LtA}_{\text{bond}}$ (Limits to Arbitrage) that is defined as the deviation from a no-arbitrage relation that should prevail in a frictionless economy. In the empirical section, we use the dynamics of this variable to study the extent to which it correlates with traditional risk factors, as opposed to unaccounted (perhaps behavioral) variables.

3.1 Sovereign Default and the Paris Club

Defaults of sovereign bonds denominated in foreign currencies are usually governed by the debt treatment clauses of the Paris Club, the organization of official creditors that coordinates the payment process of the debtor countries. The main objective is to ensure the sustainability of equal conditions for all investors, both in terms of bond maturity and recovery rates, based on the “comparability of treatment” clause, which states that “all external creditors must be subject to a balanced treatment for the outstanding debts of the debtor countries”. The clause aims to avoid cases of selective default and to ensure, in case of restructuring, equal exposure of all creditors independent of their currency.
denomination. This explains the common practice in the literature to model sovereign credit risk assuming that recovery rates are equal across different (foreign) currencies. This would ensure that securities have identical credit risks, and do not vary in terms of priority.\footnote{This, obviously, does not apply to recovery rates of domestic bonds which are subject to domestic rules and may from the recovery rates of foreign currency denominated Eurobonds.}

Sometimes things are complicated by the issuance of bonds under different jurisdictions (British and Japanese law operates under collective-action clauses, which allows a majority of bondholders to make binding decisions for all; US, German and Italian law requires multiple class action, so that individual law suits have to be filed). Since 2003, many EM sovereigns including Brazil, Mexico and Turkey have adopted the use of collective action clauses (majority restructuring provisions and majority enforcement) in sovereign bond contracts. Starting in June 2003, collective action clauses were also agreed by the EU in their “foreign jurisdiction” bonds. All bonds issued by Mexico, Brazil and Turkey included in our analysis are regulated by British law, which dictates equal recovery rates across all denominations.\footnote{For collective action clauses refer to http://www.icmagroup.org/ICMAGroup/files/0c/0cdbed22-156c-4ce0-aaa1-29cf9d87625b.PDF.}

Ukraine’s default provides another useful example of how equal conditions apply across currency denominations. Following its independence, Ukraine sustained its development by issuing large amounts of foreign denominated debt. In February 2000, however, its Finance Ministry declared that Ukraine would have failed to meet its coupon repayment for a specific Eurobond issue denominated in DM (i.e. the 16% DM bonds). In January, Ukraine also defaulted on the coupon payment for the 16.75% USD eurobonds. After several rounds, a restructuring plan was coordinated to give bondholders the option to choose between two 7-year coupon amortization bonds (with average term of 4.5 years) denominated either in US dollar or Euro in exchange for the old debt.\footnote{Argentina default is another a useful recent example of how equal recovery rates apply across currency denominations even under different jurisdictions. In December 2001 Argentina defaulted on approximately 80 billion USD worth of foreign bonds, denominated in seven different currencies, subject to eight jurisdictions, which made it an increasingly difficult issue to resolve across five thousand creditors in the market. In December 2004, creditors were offered to swap old bonds, regardless of currency denomination, into new bonds worth 35% of one dollar value, enforcing equal recovery rates.} The terms of the restructuring were symmetric for both euro and US dollar bond holders. A detailed calculation lead to estimates for the US dollar and Euro haircuts that differ only by a decimal of a percent (see Sturzenegger and Zettelmeyer, 2005, for details). This experience supports the idea that recovery rates follow the effect of “comparability of treatment” clause in sovereign Eurobonds.\footnote{Davydenko and Franks (2008) argue that bonds issued in local and foreign currencies are subject to different jurisdictions, which have varying impacts on the corresponding recovery rates. Nevertheless, an issuer’s CDS denomination in different currencies are subject to the same International Swap Dealers Association (ISDA) conditions, enforcing identical recovery rates across the corresponding denominations (see Ehlers and Schonbucher, 2006).}

### 3.2 A Two Period Model with Deterministic Default

According to the covered interest rate parity condition, the following condition must hold for a riskless investment between period $t$ and $T$:

\[
(1 + R^d(t, T)) = \frac{X(t)}{F(t, T)} (1 + R^e(t, T)),
\]

\(1\)

\[\]
where \( R^i(t, T) \) is the arithmetic risk-free rate in the two corresponding currencies \( i = (d, e) \), being usd and euro, respectively, and \( X(t) \) and \( F(t, T) \) are the EUR/USD (euro per usd) spot and forward exchange rates, respectively. The idea is that an investor who borrows 1 dollar today, thus owing \([1 + R^d(t, T)]\) at time \( T \), can convert 1 dollar to \( X(t) \) euros at time \( t \), invest them in euro deposits, thus receiving \( X(t)[1 + R^e(t, T)] \) euro at maturity. If the forward exchange rate is \( F(t, T) \), the dollar value today of this investment is \( X(t)[1 + R^e(t, T)]/F(t, T) \), which needs therefore to equate \([1 + R^d(t, T)]\) unless an arbitrage opportunity exists. One can extend the previous argument to sovereign defaultable bonds. Consider that Brazil, for instance, issues two pure discount bonds with maturity \( T \) in two different currencies (i.e. usd and euro). If the bond can only default at the time the face value is due, i.e. at time \( T \); and if \( \delta^d \) and \( S^d(t, T) \) are the recovery rates and arithmetic credit spreads (yield spreads), respectively, then the following condition must also hold in a frictionless market:

\[
\delta^d \times (1 + R^d(t, T) + S^d(t, T)) = \frac{X(t)}{F(t, T)} (1 + R^e(t, T) + S^e(t, T)) \times \delta^e. 
\]

(2)

The same argument of the CIRP applies.\(^7\) If the recovery rates across foreign bonds is the same, i.e. \( \delta^d = \delta^e \) (refer to Section 3.1), and if Eq. (1) holds, then we can rearrange Eq. (2) as follows:

\[
\left[ (1 + R^d(t, T)) - \frac{X(t)}{F(t, T)} (1 + R^e(t, T)) \right] + \left[ S^d(t, T) - \frac{X(t)}{F(t, T)} S^e(t, T) \right] = 0. 
\]

(3)

The first component represents the CIRP condition and the second component is related to the specific pricing of the two Eurobond spreads. This naturally implies that if CIRP holds, a necessary condition for no-arbitrage is that \( S^d(t, T) - [X(t)/F(t, T)]S^e(t, T) = 0 \), which leads to the following condition on credit spreads: \( S^e(t, T)/S^d(t, T) = [1 + R^e(t, T)]/[1 + R^d(t, T)] \), see also Kercheval et al. (2003). This implies that by no-arbitrage the ratio of credit spreads in different currencies must be equal to the ratio of their respective risk-free rates. According to this relationship, if the risk-free rates are unequal but time-varying, the spreads will be unequal but still perfectly correlated. The intuition is simple. The face value of the bond denominated in the highest interest rates currency is subject to a higher expected depreciation. This expected loss needs to be compensated ex-ante by a larger spread. The higher the \( \text{euro} \) risk-free rate, the higher the \( \text{euro} \) yield spread. Assuming that CIRP violations do not exactly offset the spread no-arbitrage violations, a necessary condition for no-arbitrage in Eurobonds is therefore that \( S^e(t, T) - [F(t, T)/X(t)]S^d(t, T) = 0 \).

Remark. For modeling reasons, it is common to work with log returns and continuously compounded interest rates.\(^8\) If we were to repeat the previous argument, using compound rates and spreads, \( r_d \) and \( s_d \) with \([1 + R_d(t, T) + S_d(t, T)] = e^{(r_d + s_d)(T-t)}\), equation (2) would reduce to \( e^{r_d + s_d} = [X(t)/F(t, T)]e^{r_e + s_e} \). This implies that the familiar covered interest rate parity relation \( F(t, T) = X(t)e^{r_e - r_d} \) is satisfied if and only if:

\[
s_d = s_e. 
\]

(4)

This also implies that spreads of the same asset across different currency denomination should be

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\(^7\)One can borrow 1 dollar of an issuer’s usd-denominated bond, exchange it to \( X_e \) euros, buy \( X_e \) euros of the same issuer’s euro-denominated bond, and enter a forward contract to convert \( X_e(1 + R^e(t, T) + S^e(t, T)) \) euros to dollars at \( F(t, T) \).

\(^8\)While this is a more standard approach in modeling, it is a common market practice to quote Eurobonds in terms of (arithmetic) yield spreads \( S_d \).
perfectly correlated, i.e. $\rho(ds_e, ds_d) = 1$. Violations of this relationship imply positive expected profits.

3.3 Multiperiod Implications when Default is Stochastic

The previous no-arbitrage relations assume that the time of default is known, since the arbitrageur can hedge its FX exposure using a forward contract with the correct maturity. However, if the time of default is stochastic (i.e. the default state depends on the realization of stochastic future events) arbitrageurs do not know the exact maturity of the forward contract to use in hedging out the exchange rate risk. Nonetheless, it is still possible to derive a no-arbitrage condition that needs to be satisfied in a general multiperiod dynamic context. Interestingly, under the assumption that the default spread process is not correlated with the exchange rate, the no-arbitrage condition is the same as the one holding in the deterministic two-period case. The intuition for this result is simple. Let $\tau^* \leq T$ be the time of default of the bond and let $P^*(\tau^*)$ be the terminal value of the bond, which in case of default is less than its face value: $P^* = \delta 1_{\{\tau^* \leq T\}} + (1 - 1_{\{\tau^* \leq T\}})$. The time of default $\tau^*$ is a random process since it depends on the random events that precipitate the default. Using martingale methods it is possible to show that if $\text{Cov}(X(\tau^*), P^*(\tau^*)) = 0$, then no-arbitrage still requires the equality of credit spreads across two currencies.\(^9\) We can summarize the result in the following proposition:

**Proposition 1.** If the risk neutral probability of default of foreign denominated bonds and the recovery rates are independent of the currency denomination of the foreign bonds and default is independent of the exchange rate between the two foreign countries, then no-arbitrage in frictionless markets implies that the continuously compounded time spreads must satisfy the restriction $s_d = s_e$.

**Proof.** See Appendix 1.

To control for the potential impact of the time-variation in this correlation, we select countries that are remote to the Crisis, whose credit rating have not been challenged during the sample period.

3.4 The Sovereign Covered Bond Basis

Based on the previous relations, we can thus define a time-$t$ measure of price deviation which we can call the “sovereign covered bond basis” as follows:

$$Basis^*(t, T + t) = \frac{F_{t, T+t}}{X_t} (1 + R^d_{t, T+t}) - (1 + R^e_{t, T+t}) + \frac{F_{t, T+t}}{X_t} S^d_{t, T+t} - S^e_{t, T+t}. \quad (5)$$

The Basis can be decomposed into two parts: (i) a CIRP component, which is related to the functioning of the FX market and (ii) the bond spread component, which may be linked to differences in the funding channels for bonds denominated in different currencies and other institutional frictions.

\(^9\)Since the bond price is a function of credit spreads, the same argument holds still for the covariance between the exchange rates and the credit spreads.
We label the second component as Basis. While the former component has been already investigated in the literature, little is known about the latter. In a frictionless market with no arbitrage, both components must be equal to zero. This work focuses primarily on the second component.

A close examination to the second component casts doubts about whether this trade denotes a truly riskless arbitrage, or whether a positive Basis represents instead a compensation for an exposure to some risk factor. In what follows we study the link between the observed basis and expected risk premia, calculated from the returns of long-short strategies aimed to capture these price deviations.

3.5 Expected Risk Premia

To investigate in details the economic forces that may be supporting a non-zero basis, we directly cast the empirical analysis in terms of expected risk premia. We argue that these arbitrage strategies are potentially exposed to a series of risk factors. They assume, for instance, that arbitrageurs have the institutional ability to wait for one or more years between the initiation of the trade and the maturity of the bond, and fund any change in the marked-to-market value of their positions. Notice that the previous arbitrage needs a short position in a usd-denominated bond. This is usually implemented via a reverse repo with a prime broker. Since one year reverse repos are highly unusual, in practice these trades are implemented by rolling shorter tenor repo contracts. This, however, introduces rollover and cash-flow risk in the trade. If the marked-to-market value of the overall position were to become highly negative at some intermediate periods, the trader may be forced out of its positions by its prime broker. In a more complex world, as practitioners say, “things can get much worse before they can become better”. The trade is a risky arbitrage. It would be an arbitrage in a frictionless world; it is risky in a world in which the prime broker recognizes that the relation with the trader is affected by limited information, agency and moral hazard issues, thus making the net wealth of the arbitrageur relevant and the collateral value of its positions important. De Long et al. (1990) call this “noise trader risk”.

While some earlier studies explore the properties of the basis in other markets (see for instance the corporate bond-cds basis), surprisingly few study the pricing implications in terms of expected risk premia. To this end, let us consider a realistic multiperiod strategy intended to capture the basis and let us calculate the value of the arbitrage strategy over time, before the maturity of the bonds. Let $V(t)$ be the value of a long-short arbitrage portfolio whose exchange rate exposure is hedged with a forward contract $F(t, T)$ and let $P_d$ and $P_e$ denote the price of the dollar and euro denominated bonds, respectively. At any point of time, $V(t) = P_d(t, T) - X(t)P_e(t, T) + hF(t, T)$, with $h$ being the quantity of a forward exchange rate contract used to hedge. Using Ito’s Lemma:

$$dV(t) = dP_d - X(t)dP_e - P_eX(t)dt + hF(t, T) - Cov(dX(t), dP_e)dt.$$  

Equation (6) highlights that implementing the no-arbitrage strategy discussed in the previous section generates at least three different forms of risks.

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10Given that the condition $\delta_d = \delta_e$ holds (i.e. recovery rates are positively identical), however, the bond default may still generate a non-negative arbitrage profit, though in the expense of it being proportioned (reduced) by the size of $\delta$. 

11
The first is the marked-to-market risk related to the credit spreads of the two bonds. Even in a context with no exchange rate risk, yield spreads could diverge from the theoretical parity generating marked-to-market risk. In a frictionless economy, an infinitely elastic supply function of capital guarantees that the LOP is satisfied at any time. In some states, however, frictions and other shocks can become responsible for slow moving capital and temporary deviations from the LOP.

The second deviation is due to the basis risk related to the hedging of the exchange rate risk. Even if the trader were to hedge using a forward contract \( F(t, T) \) with the correct effective maturity of the bond \( P_e(t, T) \), he would be exposed to the basis risk of changes in the differential between forward and exchange rates between time \( t \) and \( T \). At maturity the basis risk must eventually converge to zero as long as \( h = P_e \), since by construction \( \int_t^T dX(t) = \int_t^T dF(t, T) \). At any time \( \tau < T \), however, the forward hedge is exposed to an FX basis risk. The total cumulative exposure is equal to \( -P_e \times \int_t^T dX(t) + h \times \int_t^T dF(t, T) \neq 0 \) for \( \tau < T \), which the trader needs to be able to fund until unwinding the position. In some states of the world, the funding costs or forced deleverage risks could be substantial, and may affect the risky arbitrage.

The third form of risk for the arbitrageur is due to the covariance between \( dX(t) \) and \( dP_e \). In general, \( \text{Cov}(dX(t), dP_e) \neq 0 \), and changes in the covariance can affect, in practice, the value of the arbitrage long-short strategy.\(^{11}\)

The willingness of an arbitrageur to commit capital to exploit an arbitrage opportunity can therefore depend on several risk factors: (a) the size of the cash flow risk, (b) the valuation implied by changes in the stochastic discount factor, (c) the cost of capital of the arbitrageur, (d) the institutional or economic uncertainties that the arbitrageur faces. It is of great interest to investigate how these different factors can potentially help to explain observed limits of arbitrage during periods of extreme stress. To construct an empirical proxy of expected risk premia linked to a risky arbitrage, we consider a strategy in which an investor buys euro-denominated Eurobonds and sell its usd-denominated equivalent, issued by the same sovereign. Both bonds are “foreign” denominated, thus fall under the competence of equal capital guarantees that the LOP is satisfied at any time. In some states, however, frictions and other exposures could be substantial, and may affect the risky arbitrage.

\[ E[P_{t,t+\delta}] = \left( E[S^e_{t+\delta,T+t+\delta}] - S^e_{t,T+t} \right) - \left( E[S^d_{t+\delta,T+t+\delta}] - S^d_{t,T+t} \right) \frac{F_{t,t+\delta}}{X_t} \]

where the last equality must hold if CIRP holds, as discussed previously. The underlying risk-free rates \( R^d_{t,t+\delta} \) are captured by the weekly U.S. and Euro repo rates in the corresponding currencies \( i = \)

\(^{11}\) This also suggests that the correlation between the EUR/USD exchange rate and the credit spreads matters in the relative fair pricing of the Eurobonds.

\(^{12}\) One can naturally construct similar strategies for even shorter time intervals (ie. daily).
[d, e]. Similar to the theoretical setting of Gromb and Vayanos (2010), this arbitrage strategy has two interpretations. In the first interpretation (i.e. cross-asset arbitrage), there are two different assets, and arbitrageurs use usd-denominated bonds to hedge their positions in euro-denominated cash flows. In the second interpretation (i.e. intertemporal arbitrage), there is one asset, and arbitrageurs take advantage of the price anomalies of a single asset at different points in time. A sufficient condition for expected profits to be zero (i.e. $E[\Pi_{t,t+\delta}] = 0$) is that $E[dS^e_t + \delta - (1 + R^e_{t,t+\delta})/(1 + R^d_{t,t+\delta})E[dS^d_t + \delta]$ is zero. In the empirical study, we investigate the dynamics of Eq. (7) after adjusting for transaction costs, and quantify the extent to which it is explained by frictional and economic risk factors.

We call the deviations from the zero bound as $LtA_{bond}$.

Since we want to study how deviations depend on bond maturity, we consider the term structure of bond spreads of three EM countries (i.e. Turkey, Brazil and Mexico) for maturities 3-6 years, 6-9 years and 9-15 years.

4 Data Description

We merge two datasets on sovereign bonds. The first provide prices for the three largest EM sovereign debt markets. The second is a unique dataset that provides information at the country-specific level the total inventory value of lendable bonds available at broker dealers and their borrowing costs. In what follows we describe these two datasets.

The Bond Data. The first dataset, obtained from Datastream and Bloomberg, is comprised of weekly bid and ask prices on euro- and usd-denominated bonds at all maturities up to 15 years for the three largest EM sovereign issuers: Turkey, Brazil and Mexico. These countries are the only ones that have issued a large cross-section of bonds across both currencies during the chosen time period. All bonds have fixed coupon rates, and are neither callable, puttable, structured nor convertible. Brady Bonds are excluded. After these filters, we have 11 bond pairs for Turkey, 5 bond pairs for Brazil and 5 bond pairs for Mexico. We use Bloomberg Generic (BGN) bid-ask mid prices, calculated as the weighted average of the quotes submitted by a minimum of five brokers and dealers. Thus, this procedure does not pick the best price offer, but assigns a weight to each contributor based on specific factors, such as the updating frequency.

Note that the number of bonds denominated in euro is usually smaller than in usd.

Instead of simply selecting a subset of overlapping bonds, we use all available bonds to carry out the analysis with Nelson-Siegel methodology. We use the 1-30 year maturity US (Euro) swap rates to calculate risk-free curves (as suggested in Grinblatt, 2001; Houweling and Vorst, 2005; Feldhutter and Laudo, 2008).

We also collect data on risk-free rates, bond prices, repo rates, EUR/USD spot and forward exchange rates from Bloomberg. The constituents of the economic risk factors, discussed under Determinants, are also retrieved from Bloomberg or Datastream, unless otherwise noted.

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13Note that if this arbitrage is not taken in a forward market, we must have a covariance term, $cov(dS^c, X_{t+\delta}/X_t)$ for currency $c$ in Eq. (7), as the trade will also depend on the correlation between the exchange rate and the credit spread.

14We embed the transaction (liquidity) costs based on Fletcher and Taylor, 1996. An arbitrage opportunity exists only if $LtA_{bond} > 0$ (and no arbitrage if $LtA_{bond} \leq 0$).

15As of July 2005, Turkey has 11 euro- and 25 usd-denominated outstanding bonds. Brazil has 6 euro- and 22 usd-denominated bonds and Mexico has 6 euro- and 11 usd-denominated bonds. The number of long-term bonds are greater than that of short-term bonds.

16It might be argued that swap rates may not be a preferable choice of risk-free rates in a framework of risk neutral probabilities, since they contain a level of counterparty risk. Therefore, we conduct a robustness test on treasury rates vs. swap rates, and found results to be unaltered.
The Borrowing Market. The second dataset, obtained from Data Explorers, provides the most extensive coverage on security lending and borrowing currently available. It includes detailed information on total amount lent out, total available lending supply, loan transactions, loan fees (cost of borrowing), and active loan utilizations of both euro- and usd-denominated bonds across the three EM countries, provided on a weekly basis by the major prime brokers, custodians, and the lending desks of large firms that actually lend/borrow these securities.\textsuperscript{17} It captures loan trading information from over 100 participants and covers approximately 85\% of the OTC securities lending market. The dataset contains information on both actual transactions and the available inventory security which is aggregated at the security level. When combining loan information from both the lender and borrower, double counting of the same loan can occur. The total “Balance Value” excludes double counting from fields which use both lender and borrower sourced data. “Loan Fee” is the value weighted average of all applicable transaction-level securities lending fees weighted by loan value. “Supply” is the active inventory of lendable securities. The total inventory stock is divided in active and inactive. This is motivated by the fact that sometimes there is a difference between the total amount that could be lent and the actual amount on offer. For instance, when securities are held in too small parcels or have been restricted by the beneficial owner. The active inventory looks at the depth of the security borrow market. The filters applied are as follows: (i) If a security has a fee of less than 100bp then all lendable will be considered active; (ii) If a given fund has lendable in a security but has no current trades, then all lendable of that security in that fund will be considered inactive; (iii) If a given fund has trades in a security but none of them started within the last 30 calendar days, then only the quantity/value that is currently out on loan will be considered active; (iv) If the fund has trades in a security and some of them start within the last 30 days, and there is less than £500,000 lendable that is NOT currently out on loan, only the quantity/value that is currently out on loan will be considered active; (v) If the fund has trades in a security, and some of them start within the last 30 days, and there is more than £500,000 lendable that is NOT currently out on loan, then all lendable will be considered active.

Learning about the Dynamics of the Crisis

The weekly data set covers the period July 2005 - April 2010, and is divided into three main sub-samples (and two further sub-samples for the crisis period). In our paper, the “Pre-crisis” period starts on 1 July 2005 and ends on 8 August 2007; the “Crisis” period starts on 9 August 2007 and ends on 31 March 2009; the “Post-crisis” period begins with 1 April 2009 and ends on 30 April 2010. Bernanke (2009) discusses that during the 2007-2009 financial crisis, both liquidity and credit risks have been quite important, but at different stages and to different degrees.\textsuperscript{18} Longstaff (2010) and Afonso et al. (2011) argue that Lehman’s collapse changed the nature of the crisis. While before the major concern was lack of market liquidity, after Lehman’s collapse the crisis became more affected by solvency risk.\textsuperscript{19} Accordingly, we divide the crisis period further into two additional subsamples: the “Liquidity Crisis” (9 August 2007 - 29 August 2008) and the “Credit Crisis” (1 September 2008

\textsuperscript{17}The dataset provides the average representative postings from multiple agents.

\textsuperscript{18}As an explanation to the Federal Reserve’s response to the crisis, Bernanke (2009) also argues that during the first stage of the crisis, the Federal Reserve provided liquidity to solvent institutions with minimal credit risk. However, during the second stage of the crisis, the Federal Reserve accepted credit risk exposure by providing capital to some impaired borrowers and to the market in order to directly address counterparty credit risk.

\textsuperscript{19}We follow Taylor and Williams (2009) and Longstaff (2010) and assume that the beginning of the liquidity crisis coincides
- 31 March 2009). This allows us to investigate in further details the effects of sub-prime crisis and the collapse of Lehman Brothers. While our definition of sub-sample periods is motivated by a naturally chosen important economic event (Fannie Mae and Lehman bankruptcies, which occurred on September 6th and 15th, respectively), we run Chow Breakpoint Tests to identify the timing of the potential structural breaks. Our tests indeed reveal the existence of these turning points.\textsuperscript{20}

Summary Statistics

Table 1 summarizes the sample statistics of the Eurobond credit spreads across USD and euro. In all three sample periods, Turkey on average pays the highest credit spread in USD, followed by Brazil and Mexico.\textsuperscript{21} Interestingly, Turkey credit spreads are on average higher and more volatile for USD denominated bonds than for euro denominated ones; the opposite holds for Brazil and Mexico that pay higher and more volatile credit spreads in euro. Average credit spreads tend to rise with time-to-maturity. The same monotonic relation does not hold for the term structure of bond spread volatilities. Credit spreads are highest between 1 September 2008 and 31 March 2009 (the Credit Crisis period). Table 1 reveals that both the average and volatility of credit spreads increases monotonically from the Pre-Crisis to the Credit Crisis period. During the Credit Crisis period, credit spreads trade at levels more than four times than their Pre-Crisis levels, highlighting the far-reaching impact of the financial conditions even for the sovereign markets of countries that were not directly linked to the U.S. sub-prime crisis. The Lehman Brothers bankruptcy severely dislocated periphery bonds markets. It is interesting to observe that in the Post-Crisis period, spread levels start to converge back not to their Pre-Crisis levels, but to their Liquidity Crisis levels. A similar pattern can be found for their volatilities. Table 1 also reveals that the exact same pattern holds for the euro credit spreads.

Insert Table 1 here

Limit to Arbitrage - \(LtA\)

The dynamics of \(LtA_{bond}\) highlight several important features (see Table 2). First, during the Pre-Crisis period, \(LtA_{bond}\) is not significantly different from zero, implying that the cross-asset arbitrage holds to a great extent, and the arbitrageurs can enforce equilibrium relationships. Second, during the Crisis period, \(LtA_{bond}\) values are large and highly volatile, suggesting that arbitrage relationship no longer holds empirically. The increase is by more than ten times their Pre-Crisis levels, reaching up to an average of 68 bps on an annualized basis for 9-15 maturity bonds (Turkey). Note that one of the most striking elements of the \(LtA_{bond}\) anomaly is that it is based on assets issued by countries that are supposed to be “remote” to the Credit Crisis; still, the dynamics of \(LtA_{bond}\) during the

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\textsuperscript{20}Results are available from authors upon request.

\textsuperscript{21}This ranking is consistent with Moody’s credit ratings during the majority of the period when Turkey had the lowest bond quality, and Mexico had the highest. In December 2009, however, Standard & Poor’s downgraded Mexico’s credit rating from BBB+ to BBB.
Credit Crisis is “close” to the evolution of the fundamentals of the U.S. markets. In this period, the Eurobond market enters its most distressed phase: either arbitrageurs are seriously constrained to access capital necessary to absorb arbitrage opportunities, or behavioral biases are preventing them to close the gap in fundamentals. Violations are considerably higher during the Credit than during the Liquidity Crisis. Until the collapse of Fannie Mae and Lehman, the size of the anomaly has not reached the climax levels that we can observe later: average \textit{LtA\textsubscript{bond}} deviations range between 3-5 bps, with some maturities giving negative (i.e. no-arbitrage) values, suggesting that during this period EM bond markets indeed managed to stay relatively “remote” to the unfolding of the U.S. crisis. \textit{LtA\textsubscript{bond}} deviations change quite dramatically, however, in the following seven months, increasing more than 10 times from the Liquidity Crisis. During the Post-Crisis period, \textit{LtA\textsubscript{bond}} gradually converge back to the levels prevailing in the Liquidity Crisis, but still not to the levels prevailing Pre-Crisis. This implies that markets have converged quite gradually, at a speed which is hardly consistent with text-book models. While markets started to stabilize, with arbitrageurs being relatively more capable of participating in financial markets, the effects of the market dislocation are still persistent. This highlights a substantial element of inertia in the limits to arbitrage, which holds consistently for all countries and all maturities.

Three questions emerge. First, can these wide \textit{LtA\textsubscript{bond}} levels be explained by a widening in the liquidity costs? To address this question, we run a separate comparative analysis with the bond-specific bid-ask spreads, which too are expected to widen during unstable periods, due to bond illiquidity. The average bid-ask spreads and the \textit{LtA\textsubscript{bond}} (without bid-ask adjustment) for each period and maturity bracket are reported in Table 2. We find that although the average bid-ask spreads indeed widen during the market distress, the increase in the \textit{LtA\textsubscript{bond}} far outstrips the bounds during the Credit Crisis. In the Credit Crisis period, \textit{LtA\textsubscript{bond}} (without bid-ask adjustment) exceeds transaction (liquidity) costs by up to 68 bps for 9-15 years Turkish bonds, whereas in Mexico and Brazil, the excess is up to 50 bps and 40 bps for 9-15 years bonds, respectively. These values, which we report on an annualized basis, are indeed very large: hence, something other than pure transaction costs must be at play to disallow arbitrageurs from providing liquidity to the market and enforcing the Law of One Price. We need to wait more than seven months to see a significant recompression.

Second, is the deviation due to frictions in the FX market or in the sovereign bond market? It is known that after Lehman’s collapse deteriorating usd funding costs generate deviations from the basic CIRP no-arbitrage restriction (Griffoli and Ranaldo, 2011). These deviations, however, are smaller than what one finds in the bond markets. During the Credit Crisis period, maximum of \textit{Basis\textsubscript{bond}} is on average three times greater than the maximum of covered interest rate parity violations. It is possible that this was due to the exceptional liquidity measures implemented by the Fed which helped the euro/usd FX market. This is economically important as one can use the dynamics of the deviations to search for clues about the economic drivers of limits to arbitrage at different economic states.

Third, is the sign of the deviations homogeneous across currency denomination? Figure 1 reveals that this is not the case. While covered interest rate parity violations are currency-specific (Griffoli
and Ranaldo, 2011), $Basis_{bond}$ is country-specific. For Turkey $Basis_{bond}$ is positive, whereas for Mexico and Brazil it is negative. This implies that an arbitrageur in Turkey would have made profits by shorting the usd spread (longing the usd bond) and longing the euro spread (shorting the euro bond), whereas he would have made the opposite trade in Mexico and Brazil. This is consistent with the previous finding that Turkey pays higher credit spreads in usd compared to euro. The opposite holds true for Mexico and Brazil. This result is of great interest and it can provides clues as of the type of frictions that could be at the source of these dynamics.

5 Determinants of LtA

5.1 The Role of Financial Frictions

Institutional impediments, or a severe supply/demand imbalance, affects the ability of an arbitrageur to either short a bond or to leverage a long position. This may limit arbitrage and impact market efficiency. Similarly, we hypothesize that high loan-supply and low lending fees help market efficiency, reducing deviations from the Law of One Price, captured by $LtA$. We use two main frictional factors: (i) total lendable quantity adjusted to include the active availability for lending; (ii) seven-day value weighted average loan fees for all new trades. While the former, called Supply, captures the tightening in the loan supply and short-sale constraints, the latter, called Loan Fee, captures the cost of borrowing in the bond market.22

5.2 Economic Risk Factors

While financial frictions might be important in explaining deviations from LOP, they might be endogenous to current economic conditions. Short-selling constraints might be tighter in states of the world when risk premia are higher. The recent asset pricing literature argues about the importance of two separate channels of asset price dynamics (a cash-flow and a discount rate channel).23 Thus, we study the separate role and interaction of frictions and the following risk factors: (i) Liquidity Risk Factors; (ii) Funding Risk Factors; (iii) Global Cash-Flow Factors; (iv) Local Risk Factors; (v) Global Discount Rate Risks; and (vi) Global Uncertainty. Details and a discussion of each of the explanatory variables follow.

Liquidity Risk Factors

Bond traders know that liquidity can have a profound impact on asset prices. Brunnermeier and Pedersen (2009) examine two components of liquidity: asset’s market liquidity (the ease with which the asset is traded) and traders’ funding liquidity (the ease with which traders can access funding). The argument is that traders do influence, and are greatly influenced by market liquidity conditions.24

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22 We standardize the supply series prior to estimations. To control for the time of borrowing cost, we account for the initiation of the arbitrage trade.


24 Amihud and Mendelson (1986), and a vast literature thereafter, argue that bond-specific market liquidity is a significant factor in the pricing of corporate bonds. Longstaff et al. (2005) point out the fact that a large portion of corporate spreads is due to default risk, but the time-varying nature of the non-default component is strongly related to bond-specific illiquidity.
• FX Liquidity: The no-arbitrage condition requires the conversion of usd to euro (or vice versa) via the spot and forward markets. This naturally urges us to control for the potential role played by Forex liquidity. Grifolli and Ranaldo (2011) argue that foreign exchange latent liquidity can be captured by the first principle component of the spot and forward usd-euro bid-ask spreads. We follow their approach and generate the same proxy with weekly forward rates, which we label FX-Liq.

• Repo Specialness: A second measure of liquidity has been suggested by Buraschi and Menini (2002) and Fontaine and Garcia (2009). This measure captures global bond market liquidity from the repo specialness of U.S. Treasury on-the-run bonds. Repo markets play a key funding role and can affect the balance sheet adjustments of intermediaries (see Adrian and Shin, 2010). Fontaine and Garcia (2009) measure the value of funding liquidity from the cross-section of on-the-run premia by adding a liquidity factor to an arbitrage-free term structure model. We use the weekly-adjusted monthly Fontaine and Garcia (2009) proxy of liquidity, which we label FG-Liq, to capture the effect generated by a global U.S. liquidity factor.

Funding Risk Factors

As discussed in Brunnermeier and Pedersen (2009), there are generally two types of traders involved in arbitrage opportunities: proprietary trading desks of investment banks and hedge funds. Although each of these traders chase similar arbitrage opportunities, they usually operate under different funding markets. While hedge funds borrow and lend against collateral on secured terms (secured arbitrage), investment bank prop desks participate in unsecured money market operations (unsecured arbitrage). For banks, commercial paper is a key source of financing (the “money market” financing channel). In our context, we want to investigate the separate roles of these three different funding markets. We divide the Funding factors into three components: (i) Unsecured Funding (OIS spread), (ii) Secured Funding (MBS spread) and (iii) Commercial Paper (CP issuance). Following the Lehman bankruptcy, there were large and persistent shocks to these factors. To replicate our weekly arbitrage strategy, we use weekly funding risk proxies.

• Unsecured Funding: The characteristics of the unsecured funding market are captured by the spread between weekly LIBOR and U.S. Overnight Index Swap (OIS) rates. This spread captures the relative cost of U.S dollar funding through private markets versus official liquidity facilities (see Goldberg et. al, 2010). A rise in the differential implies that financial institutions

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25 Figure 1 displays that the average and volatility of FX-Liq increase considerably during the Credit Crisis Period, giving approximately -10% correlation with the first principal of \( LtA_{bond} \).

26 They argue that the premium of on-the-run U.S. Treasury bonds should share a common component with risk premia in other markets, such as LIBOR loans, swap contracts and corporate bonds. Similarly, to investigate the determinants of CIRP deviations, Coffey et al. (2009) use 10-year off-the-run par bond minus the on-the-run 10-year Treasury yields, calling it the market liquidity risk measure.

27 The data does not cover the Post-Crisis, and hence, is not included in the panels for this specific period.

28 HSBC, Deutsche Bank and Thames River Capital discuss in their regular reports to their investors the relative value opportunities in usd and euro spreads in emerging markets (see Deutsche Banks Emerging Markets, Global Market Research, July 2005; Thames River Capital Global Emerging Markets, September 2006). Furthermore, Europe’s high-yield investors, such as BlueBay, have been exploiting the arbitrage opportunities by shorting the usd-denominated and longing the similar euro-denominated high-yield bonds (Wigglesworth, 2011).
become less willing to lend to each other due to problems in creditworthiness. We label this proxy as UNSECURED.29

- Secured Funding: The characteristics of the secured funding market is captured by the spread between the bond maturity-specific Agency MBS repo and the US Treasury repo rates (Coffey et al., 2009). Since both the MBS and the U.S. GC repo rates are collateralized, this spread captures the difference in value between high-quality vs. low-quality collateral securities.30 An increase in the MBS spread signals an increase in the risk premium related to collateral value, affecting the ability to leverage risky-arbitrage positions. This can be treated synonymously as the leverage constraints of Gromb and Vayanos (2010). Fleckenstein et al. (2010) and Musto et al. (2011) also argue that the frictions in the repo market may cause significant deterioration in the supply of the traded securities, which would lead to an imbalance in demand conditions. We label this proxy as SECURED.31

- Commercial Paper Issuance: The majority of commercial papers are issued by the financial sector in order to raise cheap capital at short-term interest rates; a low cost alternative to bank loans. Commercial papers, issued mainly by corporations, are made up of short-term promissory notes with maturities averaging 30 days, but ranging up to 270 days.32 Under normal market conditions, interest rates on commercial paper have been historically just slightly higher than those on Treasury bills and lower than LIBOR. We label the weekly outstanding volume of financial and non-financial commercial papers as CP.33

Global Cash-Flow Factors

- Macro-Activity Risk: Campbell and Vuolteenaho (2004) break the CAPM beta of a risky asset with the market portfolio into two components, one reflecting news about the market’s future cash flows and one reflecting news about the market’s discount rates. Bansal and Yaron (2005) argue that a substantial component of asset price variations can be explained by shocks to a small but persistent (long-run) cash flow component. To proxy for macro cash-flow factors, we follow Ludvigson and Ng (2009) who use dynamic factor analysis to estimate a set of common

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29The average and volatility of UNSECURED increase monotonically from the Pre-Crisis to the Credit Crisis periods, displaying a 29% correlation with the first principal of LtA\textsubscript{bond} during the latter period. The differential tends to close during the Post-Crisis, though still with higher volatility and correlation values compared to both the Pre-Crisis and the Liquidity Crisis periods.

30Gabaix et al. (2007) argue that the MBS markets play an important funding role, and may affect limits to arbitrage. Moreover, Garleanu and Pedersen (2011) discuss this channel by considering a model with heterogeneous-risk-aversion agents facing margin constraints, and showing that negative shocks to fundamentals make margin constraints bind, lowering risk-free rates and raising Sharpe ratios of risky securities, especially for high-margin securities. Such a funding-liquidity crisis gives rise to “basis” that is, the price gap between securities with identical cash-flows but different margins.

31Figure 1 reveals that SECURED also increases monotonically from the Pre-Crisis to the Credit Crisis in terms of average, volatility and correlation with LtA\textsubscript{bond}. The average correlation (across maturities) with the first principal of LtA\textsubscript{bond} is 56% during the credit turmoil.

32Every week, the Federal Reserve Board releases in its H.15 Statistical Release the 1, 2 and 3 month rates on AA financial and AA non-financial commercial papers. The Federal Reserve Board’s data is supplied by the Depository Trust and Clearing Corporation.

33Before the crisis, market players regarded most commercial papers of major financial institutions as a high-quality safe asset. But the outstanding volume of CPs started to decrease substantially already in January 2008, nine and half months before Lehman filed for bankruptcy protection. The correlation with the first principal of LtA\textsubscript{bond} is -9% during the Credit Crisis phase.
factors from a panel of 132 real, nominal, and monetary measures of economic activity. Unlike Ludvigson and Ng, however, we exclude price based information from the panel in order to interpret this variable as a pure macro-activity factor and allow for an easier distinction between macro-activity and other risk factors. After removing price based information from the panel, we end up with 102 cross-sectional economic series from which we extract a dynamic common component. The time series are based on Stock and Watson (2002), and are collected from Global Insights Basic Economics Database and The Conference Board’s Indicators Database. We label the weekly-adjusted factor as LN-Macro. The conjecture is that the dynamics of limits to arbitrage is explained by time variation in macroeconomic risk, as deteriorating global macroeconomic conditions can affect financial institutions. In this context, far from being a behavioral phenomenon, limits to arbitrage would be the rational result of an efficient market that limits access to capital in risky states of the world.

- Term Premia: Diebold and Li (2006) show that slope factor of the US yield curve is a forward looking proxy of macroeconomic activity. It has also been argued that arbitrageurs fund their activities using short maturity instruments, often rolling overnight positions. Vayanos and Vila (2009) study a theoretical model in which arbitrageurs can move along the term structure, and invest in maturities following a demand shock. Following this argument, the slope of the term structure should be informative about the relative cost of arbitrageurs to fund risky arbitrage. We define the US slope as the difference between 10 year Treasury and 3 month Libor yields. We label this factor as TP.

Local Risk Factors

- Local Equity and Credit Factors: To measure the impact of local EM factors, we control for two components: (a) the MSCI Emerging Market index and (b) the Markit CDX Emerging Markets Index, which is based on the average price of EM credit default swaps. We label the former as EM-MSCI, and the latter as EM-CDSI.

Global Discount Rate Factors

- Equity Risk Premium Factor: A vast macro-finance literature finds evidence of predictability in asset prices. Campbell and Cochrane (1999) motivate the findings in the context of a model with time-varying risk aversion due to habit persistence. Negative shocks to current consumption reduce the surplus consumption ratio (the distance of consumption to the habit stock) increasing risk aversion and the equilibrium level of dividend yields. In the context of their model, dividend yields increase in bad times and have predictive power for future

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34 They show that such a procedure to synthesize information from macroeconomic activity possesses strong predictive content for excess bond returns, explaining 26% of the one-year-ahead variation in returns, and importantly, contains information that is unspanned by bond yields. They argue that part of the success of using this procedure depends on cross-sectional averaging that irons out temporal instabilities that may be present in individual series.

35 Examples of price variables removed include: S&P dividend yield, the Federal Funds (FF) rate; 10 year T-bond; 10 year - FF term spread; Baa - FF default spread; and the Dollar-Yen exchange rate.

36 We control for inertia effect of the macroeconomic fundamentals.

37 The data does not cover the Post-Crisis, and hence, is not included in the panels for this specific period.
expected excess returns. This is potentially important also in the context of the dynamics of limits to arbitrage. Garleanu and Pedersen (2011) use dividend yields in the context of their heterogeneous risk-aversion model to proxy for states of the world in which “constraints are binding and deviations of the law of one price occur.” Accordingly, we use the weekly S&P500 dividend-price ratio (retrieved from Datastream) to control for hidden priced state variables that may affect market-wide expected excess returns. We label this proxy as DIVY.\textsuperscript{38}

- Closed End Fund Discount Risk: A large body of the literature investigates the persistence of the closed-end fund discount as an LOP anomaly under rational or behavioral models. Rational models tend to explain the anomaly with frictions as agency costs, managerial abilities or other fee-based neoclassical arguments (Malkiel, 1977; Spiegel, 1997; Ross, 2002; Berk and Stanton, 2007), whereas behavioral models argue that it is due to irrational investment decisions and market sentiments (De Long et al., 1990; Lee et al., 1991; Bodurtha et al., 1995; Baker and Wurgler, 2007). We build on this insight and compute the weighted average of closed-end funds discount of the four largest U.S. Emerging Market debt funds (EDD, TEI, ESD and MSD), and label it as Closed End.\textsuperscript{39} To label this proxy as either a rational or a behavioral component is out of the scope of this paper. Therefore, we treat the proxy under a more general categorization of a discount rate factor, since it is a market’s proxy of a discount valuation ratio.

- Perceived Tail Event Risk: A measure of market perception of tail event risk can be obtained from the VIX index. It summarizes the cost of protection against major market tail event risk. Pan and Singleton (2008) use VIX as a measure of tail event risk in credit markets, and argue that it is an important proxy of investors’ appetite against risky assets in emerging markets.\textsuperscript{40} Based on these arguments, we use the first difference of VIX as proxies of perceived tail event risk, labeling the the proxy as VIX. We argue that this proxy captures the objective uncertainty.\textsuperscript{41}

Global Uncertainty Factor


\textsuperscript{38}Indeed, DIVY increases substantially during the Crisis Period, reaching its maximum of 337 bps in November 2008, and starting to decline in the Post-Crisis period following 1 April 2009.

\textsuperscript{39}A closed-end fund premium (discount) is how much greater (smaller) the fund’s market price is compared to its net asset value (NAV). We generate the corresponding premiums (discounts) by dividing market prices to NAVs, and call it Closed End. The evidence in Figure 1 suggests that the proxy reaches its lowest average and highest volatility levels during the Credit Crisis, having a correlation of -53% with the first principal of $LtA_{bond}$.

\textsuperscript{40}Further examples include Campbell and Taksler (2003), who find significant co-movement between firm-implied volatility and credit risk premiums. Similarly, Landschoot (2008) highlights the significance of VIX (and VIX-squared to capture non-linearity effects) in corporate credit premiums across two currencies (i.e. usd and euro). Cremers et al. (2008) use option-implied volatility as a proxy for the jump risk premium and document its importance for credit spreads.

\textsuperscript{41}VIX level and volatility peaked during the credit crisis. What is of particular interest, given our focus, however, is that the correlation with first principal of $LtA_{bond}$ rise up to 65% in the Credit Crisis period.
a remarkable relationship between credit spreads and differences in beliefs. We incorporate subjective uncertainty via a Macro DiB factor, constructed by Buraschi and Whelan (2010). Then, we document the extent to which subjective belief heterogeneity is linked to changes in the $LTA_{bond}$. The disagreement in beliefs proxy is labeled as DiB.

### 6 Panel Regressions

We find that $LTA_{bond}$ is highly time-varying and state-dependent. During the Pre-Crisis, it is insignificantly different from zero, but becomes large and extremely volatile during the financial crisis, suggesting limited market participation by arbitrageurs. This is especially acute during the Credit sub-period, which follows Lehman’s collapse. The most striking feature of $LTA_{bond}$ during this period is its persistence. During the Post-Crisis phase, $LTA_{bond}$ gradually converges back to the levels observed during the Liquidity Crisis period. During the Post-Crisis period, however, the second moment of $LTA_{bond}$ remains considerably large.

#### The Role of Financial Frictions

The first set of results are based on fixed-effects panel regressions which we run for different bond maturities $m$, in different subsamples, and for each country. As explanatory variables we include both the total inventory of active lendable assets (Supply), and the value weighted average loan fees of all new trades. We run the regressions in differences (both left and right hand side variables): this has the advantage to avoid spurious results due to the potential persistence of some variables. In all regressions, we control for the potential existence of country fixed effects. For each country $j$ and maturity $m$, we run the following panel regressions:

$$
\Delta LTA(bond)^m_{j,t} = \alpha_j + B^m_1 [\Delta LoanFees_{j,i}] + B^m_2 [\Delta Supply_{j,i}] + e^m_{j,t}.
$$

We find that changes in the stocks of lendable securities and loan fees help to explain $LTA_{bond}$. Table 3 summarizes the results. Before Lehman’s default, there is no evidence of economic relevance: this is hardly surprising given that arbitrages were broadly within bid-ask bounds. After Lehman’s default, Supply turns significant at the 5% confidence level, while Loan Fees are significant at the 10% confidence level only for longer term bonds. The coefficients have the expected sign: an increase in Supply reduces $LTA$ while an increase in Loan Fees increases $LTA$. This channel alone explains approximately 13% of the dynamics in $LTA_{bond}$ and suggests that frictions affected the ability of arbitrageurs to either sell-short a bond or leverage long positions, eventually affecting the LOP.

To learn more about this link, we study in more details the dynamics of these variables. Table 4 summarizes their evolution. We find that during the Liquidity Crisis, there are 3,719, 2,030 and 3,294 million usd worth of total active lendable bonds in Brazil, Mexico and Turkey, of which 589, 332 and 726 usd million worth was actually lent out, respectively. This produces an average active bond market utilization (i.e. lent out amount divided by available amount to borrow) of approximately 17% for Brazil, 18% for Mexico and 22% for Turkey, respectively, for each country. However, during the Credit Crisis the situation changes. The total balance (i.e. amount lent out) decreases in value

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42Unit-root tests for $LTA_{bond}$ and risk proxies are available from the authors upon request.
by more than 60% for Brazil, 58% in Mexico and 75% for Turkey. Similarly, the average market utilization decreases by more than 38% for Brazil, 12% for Mexico and 46% for Turkey. Between September 2009 to April 2009, there are 3,441, 1,251 and 2,670 million usd worth of total active lendable bonds in Brazil, Mexico and Turkey, of which only 230, 140 and 179 usd million worth are lent out, respectively. The considerable drop in the total lendable bonds is striking, and indicative of a severe market dislocation. Figure 2 displays the evolution of the series.

The Law of One Price assumes a flat supply of contingent claim. We observe, instead, that the bond market shrinks dramatically for all three EM countries. This may have generated frictional impediments to arbitrageurs, who clearly find it increasingly difficult to short a bond on one leg of the trade and long the equivalent denominated in the other currency on the other leg of the trade. This is consistent with Duffie et al. (2002), who argue that short-sale constraints are more binding when there is a tighter level of supply, as arbitrageurs face higher searching costs to find a willing counterparty.

A confirmation is provided by Post-Crisis period. After April 2009, the total amount lent out to the investors starts to increase and grows by about 84% in Brazil, 48% in Mexico and 19% in Turkey. With an increasing number of loan transactions, this suggests less binding short-selling constraints. The Total Active Lendable Value increases for all countries but Mexico. However, in all countries both the number of transactions and the total balance value increase substantially (for Mexican bonds, for instance, the average active utilization increases by 83%). At the same time, LtA levels compress significantly.

Financial Frictions: Endogeneity. The effect of financial frictions, however, can be endogenous to current market conditions. Thus, we study what happens when we additionally control for time-varying risk premia:

$$\Delta LtA(bond)_{j,t} = \alpha_j + \beta_1^m [\Delta Liquidity Risks_t] + \beta_2^m [\Delta Funding Risks_t] + \beta_3^m [\Delta Local Risks_t] + \beta_4^m [\Delta Global Cash Flow Risks_t] + \beta_5^m [\Delta Global Discount Rate Risks_t] + \beta_6^m [\Delta Global Uncertainty_t] + \beta_7^m [\Delta Financial Frictions_{j,t}] + \gamma^m \times \Delta LtA(bond)_{j,t-1} + \epsilon_{j,t}. \quad (9)$$

Table 5 summarizes the results. Each regressor in Eq. (9) is a vector of explanatory variables. Liquidity risk includes the variables [FX-Liq; FG-Liq]; Funding Risk includes [Unsecured; Secured; CP]; Local Risk includes [EM-CDSI; EM-MSCI]; Global Cash-Flow Risk includes [LN-Macro; TP]; Global Discount Rate Risk includes [DIVY; Closed End; VIX]; Global Uncertainty includes [DiB]. Financial Frictions include [Supply; Loan Fee]. We report the results using White’s standard errors. As Phillips and Sul (2007) show, in dynamic panel regressions the finite sample autoregressive bias in time series models persists asymptotically in large panels as the cross section sample dimension goes to infinity. To correct this problem, we adopt the bias correction methodology proposed in Phillips and Sul (2007).

We find that the explanatory power of the frictions disappear and their effects are completely subsumed by the time variation in market risk premia. This is an important finding since it suggests
that frictions can be endogenous and dependent on market conditions. Moreover, it shows that
discount factor shocks (proxied from variables different from those used for calculating \( \text{LtA}_{\text{bond}} \)), can
have a first order impact on deviations from the LOP.

Insert Table 5 here

The Role of Time-Varying Price of Risk. Table 5 summarizes the results of the regressions on the
risk premia.\textsuperscript{43} We find that the nature of the violations of the law of one price evolves during the
three financial crisis subsamples (i.e. Pre-Crisis, Crisis, and Post-Crisis). We also find that longer
maturity bonds tend to be slightly more sensitive to traditional risk factors than shorter maturity
bonds. This is interesting and in accordance to economic intuition since, at maturity, bond cash
flows must converge. Thus, longer-term bonds are exposed to a longer resolution of uncertainty,
and therefore are riskier instruments to conduct relative value arbitrage. We also find that lagged
\( \text{LtA}_{\text{bond}} \) is statistically and highly significant with a negative slope coefficient for all sub-periods,
indicating that the process is persistent; the average size of the autocorrelation coefficient is \(-0.48\),
suggesting a mean reversion process. For maturities ranging from 3 to 15 years, the slope coefficient
is about -0.39 during the Pre-Crisis period, and becomes -0.50 and -0.55 in the Crisis and Post-
Crisis periods, respectively, indicating a stronger mean-reversion in the latter periods. The results
discussed below also provide strong evidence that the \( \text{LtA}_{\text{bond}} \) dynamics are driven to a great extent
by global (U.S.) risk factors, consistent with rational models of financial markets with frictions (see
evidence in Longstaff et al. (2010)).

1. Pre-Crisis Period: As shown in Table 5, \( R^2 \) values in the Pre-Crisis period range between
5% and 7%. \( \text{LtA}_{\text{bond}} \) values are very small and most of the explanatory power is due to
the lagged \( \text{LtA}_{\text{bond}} \). The majority of the explanatory variables, even when significant, have
low statistical powers, and none of the traditional risk factors are relevant. This is broadly
consistent with the basic assumption of no-arbitrage for frictionless markets.

2. Crisis Period: A completely different picture emerges during the Crisis Period (i.e. 9 August
2007 - 31 March 2009). The explanatory power of the model is considerably higher, and the
average value of \( \text{LtA}_{\text{bond}} \) widens. To learn more about the evolution of markets behavior during
the crisis, we decide to investigate two subperiods: the “Liquidity Crisis” (before Lehman’s
collapse, i.e. 9 August 2007 - 29 August 2008) and the “Credit Crisis” (after Lehman’s collapse,
i.e. 1 September 2008 - 1 March 2009). Several interesting results emerge. Table 5 reveals
that in the Liquidity Crisis period, \( R^2 \) values range between 27% and 34%, which is higher
than in the Pre-Crisis period, but still smaller than in the Credit Crisis sub-period. After
controlling for lagged values of \( \text{LtA}_{\text{bond}} \), none of the risk factors are statistically significant.\textsuperscript{44}
This is not completely surprising since the size of \( \text{LtA}_{\text{bond}} \) deviations during this period is still
rather limited.

During the “Credit Crisis” period (following Lehman’s collapse), however, the nature and
determinants of the violations change quite significantly. The \( R^2 \) values of the model increase

\textsuperscript{43} Our results are robust to the panel specifications without the Financial Frictions factors.

\textsuperscript{44} While FX-Liq and CP are significant when used in univariate regressions, they are insignificant in the multivariate
specification.
substantially, reaching up to 73% at the longer-ends of the term structure. When we rank different groups of explanatory variables in terms of their marginal contribution to the overall $R^2$ values (see Figure 3) for all maturities and subsamples, some important results emerge. The results for 9-15 years, as an example, are reported in Table 6. We find strong evidence that the Global Discount Rate group provides the greatest marginal contribution during the “Credit Crisis”, explaining on its own up to 25% of the total variation in $LtA_{bond}$ (see Figure 3). This makes Global Discount Rate the primary source of mispricing, especially at the long end of the term-structure. The negative sign is consistent with our expectation. The closed-end fund discount deteriorates further as it tends to larger negative values. The negativity of the loading hence implies that the $LtA_{bond}$ anomaly tends to increase with every additional discount rate deterioration. This is an important and surprising result since it shows that discount rate shocks (captured by Closed End Fund Discount risk) can play a significant role during periods of market stress, in conjunction with financial constraints, in explaining not only market-wide valuations but also violations of no-arbitrage relations. Our results also show that even large deviations in $LtA_{bond}$ can be persistent when access to capital is limited, and discount rates embed large risk premia.45

Global Cash-Flow risk factors are the second most important explanatory factor, accounting for more than 16% at the long end (i.e. 9-15 years). In fact, for 9-15 years bonds, Macro-Activity risk alone plays the most significant role (compared to Term Premia), explaining around 15% of the total $LtA_{bond}$ variation in that period.46 This is important, since it reveals that the longest-end of the term structure is indeed very sensitive to those risks that are directly related to economic fundamentals. It also highlights the economic importance of cash-flow risk for the relative pricing of asset prices with nearly identical cash flows and is consistent with De Long et al. (1990) argument that small deviations from fundamentals may not correct instantaneously in a context of uncertainty.

Funding Risk is the third most significant explanatory variable. Within this group, we find that the Unsecured Funding risk channel is insignificant, while the Secured Funding risk is highly significant statistically and economically, with an average t-statistics equal to 1.9 for maturities in the 3-15 years range. The positive loading implies that $LtA_{bond}$ tends to increase with tighter funding constraints. Figure 3 reveals that the average impact of Funding risk (in particular Secured Funding) tends to increase from 3-6 years to 9-15 years, explaining more than 10% of the total average variation. This finding is consistent with the argument in the model of Garleanu and Pedersen (2011), where demand shocks can generate violations of the Law of One Price by affecting the value of collateralized securities, and generating constraints that are significant for the implementation of arbitrage strategies.47 The most surprising

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45 Also note that the impact of Perceived Tail Event Risk (i.e. VIX) is statistically significant in the multivariate specification (see Table 5). However, this is not true in the univariate regressions (not reported). Nevertheless, when VIX is regressed against the maturity-specific credit spreads (as opposed to $LtA_{bond}$), separately across usd and euro, it is found to be highly and statistically significant, generating an average t-statistics of 6.2 for usd credit spreads, and 3.5 for their euro equivalents (not reported). This suggests that shocks to perceived tail event risk can still play an important role in explaining credit spreads alone, which is consistent with the findings of Pan and Singleton (2008).

46 We find that the Term Premium has a negligible impact. We also controlled for the changes in the 10-year U.S. Treasury rates separately, and found it insignificant as well.

47 See also Bernanke and Gertler (1989), who suggest that collateral values can be severely impaired by negative shocks to economic activity, and can play a role in the efficient allocation of capital.
result is that the Unsecured Funding risk factor is statistically insignificant. This is indeed very interesting given the extensive debate, before and during the Crisis, that focused on the conjectured importance of the unsecured interbank funding market. Greenspan (2008) argues that LIBOR/OIS differential captures how markets perceive the probability of bank insolvency and of extra capital needs; and uses this indicator to measure the policy effectiveness of FED interventions: “Lehman default [...] drove LIBOR/OIS up markedly. It reached a riveting 364 basis points on October 10th. The passage by Congress of the 700 billion dollar Troubled Assets Relief Programme (TARP) on October 3rd eased, but did not erase, the post-Lehman surge in LIBOR/OIS. The spread apparently stalled in mid-November and remains worryingly high.” A conjecture that convinced the Federal Reserve to intervene in the swap market in order to directly address the unusually wide LIBOR/OIS spreads in the initial stage of the crisis. This argument contrasts with our finding which suggest the important of the Secured Funding Risk factor, captured by the spread between the Mortgage-Backed Securities (MBS) and GC repo rates. Indeed, the Federal Reserve eventually recognized the stressed conditions in the secured funding markets, and at a later stage intervened with an ambitious program targeting the purchase of MBS securities.

The fourth most significant group is Liquidity risk, which explains around 8% - 9% of the total variation of the arbitrage deviation. The majority of the explanatory power is attributed to the FX-Liq factor, which highlights the importance of the tightening liquidity constraints in the foreign exchange rate markets. The role played by the Repo Specialness is not robust to different specifications. This suggests that no-arbitrage relations are not influenced by bond market liquidity as much as other risk factors; this finding was somewhat surprising to the authors, given that this explanation is often used to justify a variety of dynamics during this period.

Insert Figure 3 and Table 6 here

3. Post-Crisis Period: As for the Post-Crisis period, the $R^2$ drops compared to the previous period, ranging between 36% and 43%, which is still higher than the Liquidity Crisis. The contribution is mostly due to Local Risk factors (i.e. EM-CDSI), which is statistically significant for all maturities. Figure 3 reveals that the marginal contribution of the Local Risk factors is around 4% on average. The explanatory power of other shocks is much more limited, if not negligible.

6.1 Term Structure Analysis

Our findings provide evidence that $LtA_{bond}$ tends to rise with bond maturity. This leads us to the investigation of the potential determinants that explain the changes in the difference between the

48Sarkar and Shrader (2010) also study the behavior of the Secured funding factor (as a proxy for funding illiquidity), and the impact of the FED asset-purchase programs.

49Note that the impact of CDSI is not as significant as expected. This is interesting, as it implies that there might be more to the story than just the default probability of the corresponding bonds.
short-term $LTA_{bond}$ and their long-term equivalents. Our results are based on the fixed-effects panel regressions which we run for $[LTA(bond)_{m1}^{j,t} - LTA(bond)_{m2}^{j,t}]$ for each country $j$, for $m_1 = 10$ and $m_2 = 5$, respectively, across the term structure, in different subsamples and for each country. The panel structure follows Eq. (8). Our results (not reported) confirm that the major explanation is attributed to Closed End Fund Discount Risk and Secured Funding Risk during the Credit Crisis period. The same factors are significant in explaining both the time-series and the cross-sectional variation (over the maturity structure) of no-arbitrage deviations, thus providing robust evidence that a significant component of arbitrage deviations are consistent with a risk-based explanation.

6.2 Currency Dependence

A potentially important result is that while covered interest rate parity deviations are currency-specific (Griffoli and Ranaldo, 2011), $Basis_{bond}$ is country-specific: while for Turkey $Basis_{bond}$ is positive, for Mexico and Brazil it is negative (Figure 1 reports Turkish $Basis_{bond}$ on an inverted scale). This implies that an arbitrageur in Turkey would have made profits by shorting the usd spread (longing the usd bond) and longing the euro spread (shorting the euro bond), whereas he would have made the opposite trade in Mexico and Brazil. This result is of great interest and it provides clues as to the type of frictions that are at the source of these dynamics.

Using data on the lendable inventory of bonds, we measure the dynamics of the difference in the lendable inventory in the two currency denominations for each country. We find that in Brazil the lendable inventory of usd denominated bond drops much more rapidly than the inventory of euro denominated bonds. The differential between the total usd lendable assets minus the total euro lendable assets as of the week of Lehman collapse dropped by 231 million usd (from 3.1 billion usd to an approximate 2.8 billion usd). Similarly, in Mexico the differential drops by 450 million usd (from 1.2 billion usd to 701 million usd). In both cases usd denominated bonds become more scarce to borrow. The opposite is true for Turkey, where the differential instead increases by an amount of about 71 million usd during the same period. This is consistent with the different dynamics of the $LTA$ for the three countries. Usd bonds are on average priced relatively more expensively than their euro equivalents in Mexico and Brazil; while the opposite is true for Turkey.

This result is also consistent with the relative differences in the international reserve positions of the three countries and the different degree of participation of these countries to the Federal Reserve emergency funding policies. To this end, Figure 4 summarizes (a) the total deposit distributions, (b) the foreign deposit rates, and (c) the 5-year cross-currency basis swap spreads of Turkey during the 2007-2010 period. One can notice that the total usd bank deposit volume falls from 60 billion usd in mid-2008 to 48 billion in November 2008, whereas the euro bank deposit rises from 25 billion to about 30 billion euros in the same period, consistent with a substantial deleverage in usd and a substantial increase in euro deposits. In 2008, the proportion of usd (euro) reserve assets to total foreign assets in Turkey is 51% (46%). The situation is the exactly the opposite for Brazil and Mexico: both countries, especially Mexico, are major trade partners for the U.S., and their

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50 This analysis draws links with Vayanos and Vila (2009), who argue that, because of frictions, arbitrageurs may have preferred arbitrage habitats on the term structure.

51 The cross-currency basis swap market does not exist for Brazil due to currency inconvertibility.

52 We thank HSBC Bank Turkey and HSBC Bank Brazil for providing us with the data.
international reserves consist of at least 70% USD assets. Table 7 illustrates that the weight of USD reserve assets rises from 50% in 2004 to 90% in 2008 for Brazil, whereas the weight of the euro assets, during the same period, falls from 35% to 9%.

This is helped by the fact that both Brazil and Mexico have access to the special dollar swap facilities established by the Federal Reserve. In addition, the bottom-left Figure 4 also focuses on the dynamics of the spread between the 3-month average USD and euro bank deposit rate (in Turkey) during the last quarter of 2008 and first quarter of 2009 (Credit Crisis). One may notice a substantial jump in the deposit spread (from -20 bps to 80 bps) after the Lehman collapse: in Turkey USD deposit rates increased well above their euro equivalents. The acceleration of this phenomenon suggests that USD funding of Turkish banks rapidly became costlier than euro funding, most possibly due to the country specific demand/supply imbalances. Finally, the Turkish (Tribor vs. USD Libor) 5-year cross-currency swap spreads decrease from -50 bps in mid-2008 to a record -250 bps in January 2009 (see Figure 4, bottom-right panel).\(^{53}\) Turkey, which did not have access to the Fed emergency credit swap lines, is in short supply of USD funding; this affected the relative USD vs. euro rollover costs and risks (see Table 7). Both Brazil and Mexico, on the other hand, are relatively poorer in euro than in USD during the Credit Crisis, thus affecting the euro funding risks compared to Turkey. The evidence is supportive of a notion of limits to arbitrage in which limited risky capital, triggered by a large systemic event, allows segmentation to occur across related markets, and asset prices to reflect country-specific institutional constraints. As arbitrageurs become unwilling to integrate related markets, demand shocks remained local and country-specific (for a theoretical discussion, see Vayanos and Vila, 2009; Gromb and Vayanos, 2010).\(^{54}\)

Accordingly, we turn to study the functioning of the price discovery mechanism when no-arbitrage conditions are impaired. Since the order flow of the Eurobonds might be fragmented, the price discovery may be different depending either on the institutional characteristics of the markets, in which most trades occurs, or the currency habitat of the traders, or the funding currency of the trading operations. If credit spreads are not identical and reflect risk factors that are not entirely a function of the characteristics of the issuer, some important questions emerge. Does a bond in one currency provide more timely information than its equivalent in the other currency? Which bond retains a greater contribution to price discovery? Being able to answer these questions is important since they are related to which credit spread should be used in modeling sovereign default risk. For

\(^{53}\)Cross currency basis swap is quoted as USD Libor against an EM currency (plus a spread). It typically generates a negative spread in EM countries since the credit risk in the EM Libor is greater than in the USD Libor. The chart displays the amount of spread that is subtracted from the 3-month TRIBOR in exchange for the 3-month USD LIBOR. Therefore, if the spread becomes more negative, the USD borrower is willing to receive a lower TRIBOR rate in exchange for the given level of USD LIBOR, indicating the existence of an increasing demand for USD.

\(^{54}\)The Barclays Capital Credit Research (2010) presents related evidence consistent with this interpretation. The report identifies potential trading opportunities in the corporate bond market, for dual currency Eurobonds issued by the same European corporate issuers. They report that, before the crisis, euro-denominated corporate bonds have historically traded more expensive than their equivalent bonds denominated in USD (of the same issuer) due to European corporates’ heavy reliance on bank loans. However, in the last few years, the relative pricing reversed, with a substantial increase in the issuance of the euro-based assets and reduction of USD funding, causing euro credits to trade cheaper to their USD equivalents (of the same company) for the first time. Similar to our findings, this indicates a link between country specific demand-supply imbalances and the direction of limits to arbitrage.
the detailed discussions of Price Discovery analysis, refer to Appendix 2 and Table 8.

Insert Table 8 here

7 The FED Interventions and the Law of One Price

It is hard to think of a more significant period in which the regular functioning and price discovery in financial markets were challenged as severely as in the 2008 Credit Crisis. The Federal Reserve intervened with a host of different policy measures. It is of great interest, therefore, to investigate how these different policies affected the dynamics of the limits to arbitrage.

In the first phase of its interventions, which we labeled the “Liquidity phase”, the Federal Reserve became increasingly concerned about market liquidity. On December 12, 2007, the Federal Reserve introduced a Term Auction Facility (TAF), designed to lend funds directly to depository institutions for a fixed term (28 or 84 days). Two auctions of term loans were held in December, two were held in January 2008, and two more were held in February 2008. The TAF offered an anonymous source of term funds and was hoped to address the potential stigma attached to discount window borrowing. Two important restrictions applied: (a) the funds available were fixed and limited in supply; (b) foreign banks could bid through their U.S. branches or agencies if they maintained reserves with a Federal Reserve Bank, otherwise they need to borrow in their own jurisdictions. To facilitate the provision of U.S.-dollar liquidity to other central banks, the Fed arranged currency swap lines with the ECB and the SNB in amounts of $20 billion and $4 billion, respectively. On September 18th 2008, the Fed expanded the cap on these swap lines and eventually on October 13th the caps were completely removed. It should be noted that these swaps lines were available only to some central banks. For instance, while the Banco Central do Brasil and the Banco de Mexico gained access to these facilities on October 29th, 2008, the Turkish central bank never had access.

In the third quarter 2008, this program was extended when the FED started the purchase of commercial papers from money market mutual funds. In the second phase of its interventions, which we labeled the “Credit phase”, the Federal Reserve developed new policies and shifted the nature of its interventions to directly address credit risk concerns. Three “unconventional” policy interventions followed: (1) Troubled Asset Relief Program (TARP) aimed at compensating for the lost capital of U.S. banks and restart their lending activities; (2) Term Asset-Backed Securities Loan Facility (TALF) aimed at increasing credit availability and support economic activity by facilitating renewed issuance of consumer and business ABS at more normal interest rate spreads; (3) The Commercial Paper Funding Facility (CPFF) was created in October 2008 to improve liquidity in short-term

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55 For example, at its auction on December 17, 2007, the Federal Reserve offered $20 billion with a 28-day term and received bids totaling $61.553 billion. Bids offering the highest interest rates were accepted until the full $20 billion had been allocated, though all successful bids were funded at the lowest accepted bid rate (4.65 percent).

56 The program was launched on 3 October 2008, and involved the mass purchasing of capital and equity (approximately 700 billion USD) of US commercial banks.

57 The program was announced on 25 November 2008, and involved the lending of 200 billion USD repo loans for the collaterals of newly issued asset-backed securities.
funding markets and thereby contribute to greater availability of credit for businesses and households. Under the CPFF, the Federal Reserve Bank financed the purchase of highly rated unsecured and asset-backed commercial paper.

The final phase, which we labeled the “Uncertainty phase”, is quite different compared to the first and second phases or any previous historical experience. In 2009, the Federal Reserve addressed more directly market uncertainty and tail risk perception by implementing explicit economic assessments and “stress tests” on a broad set of banks and financial institutions. The Federal Reserve Chairman Bernanke made a public announcement on 25 February 2009 and later signed the release of a set of stress test results (5 May 2009). The goal of this exercise was to reduce uncertainty about the true fundamental value of major financial institutions and regain the trust of market participants. Europe also conducted stress tests both in 2010 and in 2011 periods.

It is of great interest to explore the dynamics of $LTA_{mod}$ around these events. Which (if any) of these policy announcements, economic news, and/or policy actions have been the most significant in re-compressing $LTA_{mod}$ deviations? What was the relative role of U.S. vs. European policy interventions with regard to the dynamics of $LTA_{mod}$? To address rigorously these questions we run a comprehensive regression event study. We collect an extensive database of 174 financial and political news originating from the U.S., Euro and the rest of the world (i.e. China) from 2007 to early 2010. Similar to Dooley and Hutchison (2009), the crisis timeline is based on two data sources: one being the official source (the Federal Reserve Bank of Saint Louis) and the other being a market source (Bloomberg). Then, we aggregate and classify the most important financial and political news into 9 types of events: (i) Write-down announcements on U.S. financial institutions (WRD), (ii) News on European finance (NEWS-EU), (iii) News on UK finance (NEWS-UK), (iv) News on Rest of the World finance (NEWS-ROW), (v) FED USD-Swap Lines to developed and emerging markets (SWAP), (vi) Policy announcements on FED’s balance sheet (PAF), (vii) Policy announcements on the US Treasury’s balance sheet (PAT), (viii) Policy announcements on U.S. housing market (FF), and (ix) Stress Tests on U.S. financial institutions (STRESS). Table 8 provides a detailed explanation of these policy events, with the respective timing during the three phases of the crisis. For each of the 10 category, Table 8 provides an example of a news or announcement. For instance, on September 29th, 2008, at the FOMC meeting the Federal Reserve decided to extend $330 billion of swap lines to nine central banks; later, on October 29th, 2008, the FED decided to expand this program by an additional $120 billion of swap lines also to four peripheral central banks (including the Central Banks of Mexico and Brazil). We classify them in the same SWAP indicator group. We also include 46 economic policy announcements originating from Europe, UK and China (which included a two-year 586 billion usd stimulus plan), as well as news of liquidity interventions by the European Central Bank and the Bank of England and other announcements supporting the financial system. Furthermore, given that the event of Lehman collapse has a dominating impact, we remove it from the panels to see which other news and events follow it in terms of explanatory power. Then, we run the ordinary panel regression for country $j$ at maturity $m$ during 17 November

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58To highlight the positive assessment results, Bernanke pointed out to the Joint Economic Committee: “I’ve looked at many of the banks and I believe that many of them will be able to meet their capital needs without further government capital.” (Reuters News Agency on May 5, 2009).

59We retrieve the world news data from Bloomberg’s credit crisis timeline. In Bloomberg, these news can be found under CCRT Index.
2006 to 26 March 2010 as follows:

\[
\Delta LtA_{(bond)}^m_{j,t+1} = \alpha_j + \beta_1 WRD_t + \beta_2 NEWSEU,t + \beta_3 NEWSSUK,t + \beta_4 NEWSSROW,t \\
+ \beta_5 SWAP_t + \beta_6 PAF_t + \beta_7 PAT_t + \beta_8 FF_t + \beta_9 STRESS_t \\
+ \beta_{10} \Delta LtA_{(bond)}^m_{j,t},
\]

where each event is treated as a dummy variable that equals 1 on the days of the announcements. The expected arbitrage return is taken this time between times \(t + 1\) and \(t\), in order to capture the extent of which the future returns respond to the current news. We also control for the lagged dependent variable for residual autocorrelations. Table 9 summarizes the results.

We find evidence that the news originating from EU Zone, UK and the Rest of World have strong impact on the dynamics of \(LtA_{(bond)}\). This is indicative of the level of integration of emerging markets with global economies, and the extent to which they respond closely to global news. The impacts tend to increase monotonically from short-term to long-term bonds. The bad news regarding large write-downs and downgrades (WRD) of U.S. banks, on the other hand, are found statistically insignificant. However, the housing market developments in the U.S. (FF) are found to have significant impact, with an average positive loading of 0.38. This is hardly surprising, given the high media coverage. As expected, the adverse mortgage news have a worsening impact on the expansion of \(LtA_{(bond)}\), since the variable captures the core essence of the Credit Crisis, which is linked directly to the bad developments regarding the U.S. housing system.

A very topical discussion among monetary economists focused around the effectiveness of the first round of policy interventions by the Federal Reserve. By extending swap lines, the Federal Reserve tried to address the liquidity problem by lending dollars to financial intermediaries as well as foreign central banks (including Mexico and Brazil). The extension of swap lines (SWAP) is found highly and statistically significant for \(LtA_{(bond)}\) across all maturities with an average negative loading of -0.34. Its impact increases with the maturity of the bond, and is pronounced for Turkey as well, even though Turkey did not participate in the agreement. A possible explanation is that SWAP extensions had a positive signaling effect across other emerging markets beyond a direct liquidity impact. The negative loading suggests that the prospect of higher liquidity relieved market friction and helped \(LtA_{(bond)}\) to converge back to its fundamentals. However, even though the explanatory power is relatively high during the post-Lehman period, \(LtA_{(bond)}\) still fails to converge fully back to its Pre-Crisis levels, suggesting that the early liquidity interventions have not been as effective as expected in restoring the link between price and fundamentals. On the one hand, this suggests that funding risks are priced and affect expected returns, on the other hand it indicates that \(LtA_{(bond)}\) were driven by other factors beyond and above funding risks.

In the second phase of its policy interventions, the Treasury and the Fed started to use directly their balance sheet to launch various lending facilities and asset purchasing programs. The most important are the Term Securities Lending Facility (TSLF), which is included in the variable “PAF”; and the Troubled Asset Relief Program (TARP)\(^{60}\), which is included in the variable “PAT”. These

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\(^{60}\)In 12 November 2008, the Treasury Secretary Paulson announced that they had decided not to use TARP funds to buy
programs tried to compensate for the U.S. bank capital losses, and restart their lending activities, by means of a substantial MBS purchases program which was officially launched on October 3rd, 2008 and continued during the first half of 2009. The key difference between the Treasury and the FED programs is that while the Treasury’s balance sheet interventions mainly address secured markets via purchasing mortgage-related securities and taking on credit risk exposure (by providing capital to the troubled borrowers), FED interventions affect unsecured markets (i.e. interbank funding markets via new term auction facilities). Our results reveal that these programs did not improve the funding conditions. The slope coefficients of the variable PAT and PAF are statistically insignificant.

Our results suggest that while SWAP extensions helped unlock the funding conditions to a significant extent, even this measure did not prove sufficient. In February 2009, the annualized \(LtA_{bond}\) levels were still around 30 bps on average across the emerging markets. Closed End Fund Discount Risk was still highly and economically significant at the beginning of the second phase of the FED program. Therefore, although vast amount of government resources have been used to help the financial sector, not all these measures, especially the early ones, have been as successful as hoped. We had to wait until the announcement of the stress tests to see the most significant compression of \(LtA_{bond}\) levels. Our results reveal that the stress tests (STRESS) are economically and statistically significant across all maturities, as shown in Table 9, with an average negative loading of -0.61. The negative loading suggests that \(LtA_{bond}\) (i.e. the arbitrage anomaly) decreases with diminishing market uncertainty. This supports the argument in Acharya and Merrouche (2010, p. 6) that points out the importance of stress tests: “[...] regulatory attempts to thaw the money market stress and reduce variability of inter-bank rates [...] should involve addressing insolvency concerns (for example, early supervision and stress tests, and recapitalization of troubled banks) and not just provisions of emergency liquidity.” Interestingly, the impact of the Closed End Risk factor is almost completely eliminated after the stress test announcements. The magnitude of this result is of great interest and highlights the importance of the formation of expectations for the dynamics of \(LtA_{bond}\), and how these effects can be addressed via FED’s public signaling.

8 Robustness

In this section, we test the robustness of our findings along several dimensions. First, we compare actual transaction prices with quotes. Second, we include various additional explanatory variables to see if we omitted any crucial risk proxies.

Transaction Prices vs. Quotes: From HSBC Asset Management, we are provided with the actual traded data for bonds of Turkey denominated in usd and euro for maturities greater than two years.\(^{62}\) The average difference in the bid-ask prices between Bloomberg generic and actual transactions data for 2006 - 2010 is only 7 bps. Only 5% of the time the difference is greater than 15 bps. This implies that the Bloomberg Generic prices are representative of the actual transaction prices.

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\(^{61}\)See also Taylor and Williams (2009), who find no evidence of an effect of the Term Auction Facility (PAF event in our study) on LIBOR-OIS spreads. They argue that the Term Auction Facilities program did not effectively increase total liquidity in markets.

\(^{62}\)We thank HSBC Asset Management for kindly providing us with the data.
Bloomberg Generic (BGN) screen takes the weighted average of indicative, executable and traded quotes submitted by at least five brokers and dealers.

Additional Variables: While one can never completely mute a criticism based on an omitted-variables argument, we check the robustness of our previous findings by testing the relevance of other traditional risk proxies omitted from our panel regressions. We repeat the same fixed-effects panels using all the original variables, and also the new variables separately. Our results are unreported but available upon request. To capture the European measures of change, we re-run the fixed-effects regression on $\text{LtA}_{\text{bond}}$ for those risk factors that can be generated for euro (i.e. Unsecured Funding, Secured Funding, Term Premia and Perceived Tail Event Risk), subtracted from their usd equivalents. Our results reveal that the relative proxies have lower explanatory power than the usd factors alone. We also re-run the panels with (1) TED spread as a measure of general liquidity (see Brunnermeier, 2009; Griffoli and Ranaldo, 2011), (2) US-CDX as a measure of default risk, (3) CIVIUS and CIVIEM as two currency indices for U.S. and emerging markets, respectively. The impact of these additional variables are found negligible, if not insignificant during the market turmoil. Our main conclusion is still valid: the arbitrage in Eurobond markets are mainly driven by global discount rate factors, macro-economic fundamentals and funding constraints.

9 Conclusion

We contribute to the existing literature by introducing an empirical notion of limits to arbitrage ($\text{LtA}_{\text{bond}}$) in a large and liquid market: the sovereign bond market of EM economies. We use a simple no-arbitrage relation for Eurobonds issued in two currencies by the same sovereign to investigate the determinants of the limits to arbitrage. Under no-arbitrage condition, the $\text{LtA}_{\text{bond}}$ proxy should be zero, or within the bid-ask bounds. This is indeed the case, in our data, before and after the Credit Crisis. During the Credit Crisis, however, $\text{LtA}_{\text{bond}}$ becomes large, volatile, and persistent. It starts to converge back to initial levels only a full year after the initial widening. During this period, $\text{LtA}_{\text{bond}}$ is time-varying and state dependent. This suggests that while arbitrageurs were able (or willing) to take positions in the Pre-Crisis period, their risk-aversion or funding abilities during the Crisis prevented them from providing enough liquidity to the market, therefore preventing asset prices to fully reveal fundamentals. We focus on two main risk categories to explain the variations in $\text{LtA}_{\text{bond}}$: Financial Frictions and Economic Risk factors. The former is captured by total lending supply and average cost of borrowing at security level, whereas the latter is represented by different sub-groups of potential market risk factors that have been discussed in the asset pricing literature and in the press: Funding risk, Liquidity Risk, Global Cash-Flow risk, Local risks, Global Discount Rate risk, Global Uncertainty. The significance of risk factors depends on the subsample period, time-to-maturity, and prevailing market conditions. The impacts tend to be more pronounced for longer-term maturity bonds. Our findings provide evidence that the dislocations in the total lending

\textsuperscript{63}We use 3-month EUR Libor (EURIBOR) and EUR OIS (EONIA) for the Unsecured Funding matched with the 3-month usd equivalent. For the Secured Funding, we use maturity-specific EUR Treasury Repo and EUR Government Agency AAA rates matched with the usd equivalent.

\textsuperscript{64}CIVIUS and CIVIEM are the Citi Implied Volatility USD pair index and Citi Implied Volatility Emerging Markets index, respectively.

\textsuperscript{65}US-CDX is found significant only for 1-3 years bonds.
supply and average borrowing cost have considerable impact on the deviations of $LtA_{bond}$ during the Credit Crisis, with an explanatory power of 13%. Their impact is subsumed by global economic factors, which account for a large portion of the total $LtA_{bond}$ variations. While Closed End Fund Discount risk, Macro-Activity risk, Secured Funding, and FX Liquidity constraints have negligible impact before and after the Crisis periods, their impact becomes dramatic especially during the Credit Crisis phase, when panels generate $R^2$ of more than 60%. By order of impact, Closed End Fund Discount risk, Macro-Activity risk and Secured Funding risk account for the majority of the explanation. Our results, therefore, suggest that arbitrageurs are considerably affected by market discount risk factors, funding and liquidity costs, and also the economic fundamentals during market turmoils. The significance of both the Global Cash-Flow risk and Global Discount Rate risk factors suggests that no-arbitrage relations are affected both by the cash-flow and discount-rate factors. Repo Specialness and FX Liquidity are found to have lower impacts than was expected during the Liquidity crisis, whereas the latter has a higher impact during the Credit Crisis. This is almost counter-intuitive as one would have expected (traditional) liquidity factors to be most relevant during what was labeled the Liquidity Crisis. Finally, we conduct an Event Analysis to show how the FED’s and Treasury’s lending facilities, asset purchase programs and stress test announcements affected the anomalous asset prices, providing new insights on the monetary transmission mechanism during the Credit and Liquidity Crises. We find that the compression of $LtA_{bond}$ levels starts with the US Government intervention via MBS purchases, though most of the compression coincides with the stress tests announcements. This suggests that, on the one hand, the initial actions of U.S. Government have been relatively ineffective and that, on the other hand, the later rounds of interventions relieved the frictions between financial institutions and investors, helping markets to stabilize and become more informative about fundamentals. This obviously bears welfare and policy implications left for further research. Our findings also suggest that price discovery process tends to be regional in emerging markets: while usd-denominated bonds significantly lead their euro equivalents in Brazil and Mexico, the exact opposite relationship is observed in Turkey. This is linked to the evidence that the spread basis deviations (i.e. $Basis_{bond}$) are country-specific in terms of its direction. As another important finding, the existence of currency-dependence in Eurobonds suggests that the curve estimations and credit pricing models concerning the credit spreads (across two currencies) should be built independently for each corresponding currency, even though the maturity and the issuer of both bonds are the same.
Appendix 1

Let the price of a defaultable sovereign bond be \( P_d(t, T) \) and let the cash flow process of the defaultable bond be \( P^* = \delta_1(\tau \leq T) + (1 - \delta_1(\tau \leq T)) \) with \( \delta \) being an indicator function which takes the value of 1 if the bond defaults before \( T \).\(^{66}\) Let \( A(t) \) be the value of the money market account at time \( t \), accruing a risk-free spot rate \( r_d(t) \). No-arbitrage implies the existence of a risk-adjusted measure \( Q \) such that the relative price of any tradable security follows a martingale with respect to \( Q \). Thus the price of a riskless zero-coupon bond \( P_d(t, T) \), relative to the cash account, must satisfy:

\[
P_d(t, T)/A(t) = E_t^Q [P_d(\tau, T)/A(\tau)] \quad \forall t < \tau < T
\]

(11)

Let the quoted yield spread at time \( t \) of the defaultable bond be defined as \( s_d(t, T) \), so that \( P_d(t, T)/B_d(t, T) \equiv e^{-s_d(t,T)(T-t)} \). Then, since the value at maturity \( T \) of the defaultable bond is \( P_d(\tau^*, T) = P^* \), the following condition must hold: \( B_d(t, T)e^{-s_d(t,T)(T-t)} = E_t^Q \left[ \frac{A(t)}{A(T)} P^*_d \right] \).

If the default process of the issuing country is independent of the dollar interest rate, then:

\[
E_t^Q \left[ \frac{A(t)}{A(T)} P^*_d \right] = E_t^Q \left[ \frac{A(t)}{A(T)} \right] E_t^Q [P^*_d]
\]

(12)

which implies that by no arbitrage the following must hold:

\[
E_t^Q [P^*_d] = e^{-s_d(t,T)(T-t)}
\]

(13)

Consider now the second bond, which is denominated in euro, and use the same martingale restriction from the perspective of the domestic investor. If \( X(t) \) is the exchange rate, then the dollar value of the euro-denominated bond needs to be a martingale with respect to the same risk-adjusted probability measure \( Q \): \( X(t)P^*_e(t, T)/A(t) = E_t^Q [X(T)P^*_e(T, T)/A(T)] \). If the quoted yield spread at time \( t \) of the second defaultable bond is \( s_e(t, T) \) with respect to the euro risk-free yield, so that \( P^*_e(t, T)/B^*_e(t, T) \equiv e^{-s_e(t,T)(T-t)} \). Then, since the value at maturity \( T \) of the bond \( P^*_e(T, T) \) is \( P^* \) the following must hold: \( B^*_e(t, T)e^{-s_e(t,T)(T-t)} = E_t^Q \left[ \frac{X(T)}{X(t)} \frac{A(t)}{A(T)} P^*_e \right] \). If the exchange rate process \( X(t) \) is independent of the default process \( P^* \), then:

\[
E_t^Q \left[ \frac{X(T)}{X(t)} \frac{A(t)}{A(T)} P^*_e \right] = E_t^Q \left[ \frac{X(T)}{X(t)} \frac{A(t)}{A(T)} \right] E_t^Q [P^*_e]
\]

Moreover, since by no-arbitrage (covered interest rate parity), \( B^*_e(t, T) = E_t^Q \left[ \frac{X(T)}{X(t)} \frac{A(t)}{A(T)} \right] \), then:

\[
E_t^Q [P^*_e] = e^{-s_e(t,T)(T-t)}
\]

(14)

Since condition (13) and (14) must be satisfied at the same time, then:

\[
s_d(t, T) = s_e(t, T), \quad \text{for } \forall t, T
\]

(15)

Credit spreads of bonds denominated in different currencies must equate.

\(^{66}\)Refer to Jankowitsch and Pichler (2005) for a similar proof.
Appendix 2

Price Discovery: As defined by Lehmann (2002), price discovery can be described as timely incorporation of the trading activities into market prices. To this end, we set out to investigate the differences in the information contents of credit risks denominated in different currencies. There are two traditional ways to conduct price discovery analysis. The first one is based on the information share (IS) measure, as suggested by Hasbrouck (1995). The second one is based on the component share (CS) measure, as suggested by Gonzalo and Granger (1995). Following Blanco et al. (2005), we calculate the IS measures to find the contribution of usd credit spreads to their euro equivalents. We also follow Eun and Sabherwal (2003) in generating the spread series by using the midpoint of the bid and ask quotes in each market. We first test for the existence of cointegration across credit spreads of a single issuer, and estimate a VEC (Vector Error Correction) model. Given our objective, we conduct the analysis for the entire period without subdividing the sample. Then, we estimate the relative contribution to price discovery of each of the two bond spreads by computing Hasbrouck’s IS price discovery measures. Since the LOP in frictionless markets implies that $S^d_t - b_{1,t} \times S^e_t = 0$, with $b_{1,t} \equiv (1 + R^d_t)/(1 + R^e_t) \approx 1$, we estimate the following VECM specification:

\begin{align}
\Delta S^d_t &= A_1[S^d_{t-1} - b_1(S^e_{t-1})] + \sum_{n=1}^{N} \phi_{1n} \Delta S^d_{t-n} + \sum_{n=1}^{N} \gamma_{1n} \Delta S^e_{t-n} + u_{1t} \quad (16) \\
\Delta S^e_t &= A_2[S^d_{t-1} - b_1(S^e_{t-1})] + \sum_{n=1}^{N} \phi_{2n} \Delta S^d_{t-n} + \sum_{n=1}^{N} \gamma_{2n} \Delta S^e_{t-n} + u_{2t}, \quad (17)
\end{align}

where $c_1 = 1$, $b_1 = 1$, $S^d$ and $S^e$ are the usd and euro credit spreads, respectively, and $u_{1t}$ and $u_{2t}$ are the error terms. In our specification, the term $(S^d_{t-1} - b_{1,t}S^e_{t-1})$ captures the no-arbitrage relation that needs to be satisfied in a frictionless economy. In presence of frictions, if the euro credit spread contributes to price discovery, then $A_1$ should be statistically significant. On the other hand, if the usd credit spread contributes to price discovery, then $A_2$ should be statistically significant. If both coefficients are significant, then both credit markets are jointly important in the price discovery process.

Table 10 summarizes the results for the upper, lower and averages of the Hasbrouck bounds. If the average of the Hasbrouck bounds is greater (less) than 0.5 then usd (euro) risk premium leads euro (usd) risk premium. Our findings reveal that for Brazilian and Mexican bonds the $A_2$ coefficient in Eq. (17) is positive and statistically significant, implying that the usd-denominated bonds tend to lead their euro-denominated equivalents in terms of price discovery. For Turkey, however, the opposite pattern emerges: $A_1$ coefficient in Eq. (16) is negative and statistically significant, implying that euro-denominated bonds tend to contribute more than their usd-denominated equivalents. Taking into account the maturities with significant discoveries, we find that the contributions of usd denominated spreads are, on average, 68% and 65% for Brazil and Mexico, respectively, and 35% for Turkey. This result seems linked to two previous results that also suggest that the characteristics of

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67 Both measures rely on the estimation of a vector error-correction models (VECM) of market prices; but IS assumes that price volatility reflects new information, and allows for the correlation among multiple markets via the variance and covariance of price innovations.

68 Eun and Sabherwal (2003) prefer using quotes over transaction prices, since transaction prices may suffer from the autocorrelation problem arising due to infrequent trading.

69 We used Johansen cointegration test, and determined the number of lags according to the Akaike information criterion.

We find that the usd and euro credit spreads are cointegrated for each bond pair during the whole sample period.
$LtA_{bond}$ are country specific. In the case of Turkey, the large majority of the market-making activity is funded in euro and conducted by European banks. The opposite holds for Brazil and Mexico. This suggests that price discovery depends, to some extent, on the natural habitat of traders, the market structure of the funding institutions, and the regulatory role played by the respective central banks. This seems to have important implications for $LtA_{bond}$. For instance, a regional European bank may have a capital structure that would make the bank have euro as a preferred funding currency. Due to their natural habitat, regional banks may have limited access to usd during times of crisis, making the euro-denominated bond market more preferable in terms of price discovery, especially if European banks have a larger exposure to Turkish sovereign bonds. Gromb and Vayanos (2002) formalize this argument by showing that if the arbitrageurs lack sufficient capital to cover the variations in both margin accounts of the segmented asset markets, then they might not be able to eliminate price discrepancies.

These findings have another important implication. Most data suppliers (i.e. Reuters and Bloomberg) and rating agencies (i.e. Moody’s and Standard Poors) use usd-denominated bonds as inputs in modeling the euro-denominated credit spread curves of the same issuer. The market convention is to use usd as de-facto currency in the valuation of foreign denominated credit products. The widening discrepancy between the usd and euro bond spreads suggest that this approach might be incorrect. Not only do the investors seem to require different compensations for the variations in usd- and euro-denominated bonds, but the price discovery process differs across different bonds. This seems related to their specific funding markets. The assumption of currency-independence for bonds of the same issuer may lead to seriously mispriced credit products. Risk models for credit products denominated in different currencies than usd may require assumptions that are specific to the currency of denomination.\(^7\)

\(^7\)Barra (2003) decomposes the bond excess returns of the same issuer (denominated in different currencies) into four elements, and highlights that credit risk models for these bonds must be built independently. Their model is as follows

$$r_{excess} = (r_{IR} + r_{curr} + r_{spread} + r_{specific})$$

where $r_{IR}$ denotes the changes in interest rates, $r_{curr}$ denotes the changes in currency exchange rates, $r_{spread}$ denotes the changes in credit spreads and $r_{specific}$ denotes the specific factors not explained by common factors.
References


Table 1
Credit spread summary statistics
This table summarizes the average USD and euro credit spreads generated from mid-prices, and their differentials (in percentages) by country and bond maturity. Standard deviations (in percentages) are given immediately below average values. The data set is divided into Pre-Crisis (1 July 2005 - 8 August 2007), Liquidity Crisis (9 August 2007 - 29 August 2008), Credit Crisis (1 September 2008 - 31 March 2009) and Post-Crisis (1 April 2009 - 30 April 2010) periods.

<table>
<thead>
<tr>
<th>Year</th>
<th>Maturity</th>
<th>USD Credit Spread</th>
<th>EUR Credit Spread</th>
<th>Credit Spread Differentials</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Turkey</td>
<td>Brazil</td>
<td>Mexico</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-9 Years</td>
<td></td>
<td>1.41</td>
<td>1.18</td>
<td>0.33</td>
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<td></td>
<td></td>
<td>0.36</td>
<td>0.79</td>
<td>0.17</td>
</tr>
<tr>
<td>9-15 Years</td>
<td></td>
<td>1.66</td>
<td>1.46</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.37</td>
<td>0.92</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Liquidity Crisis Period</strong></td>
<td></td>
<td>(9 August 2007 - 29 August 2008)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-6 Years</td>
<td></td>
<td>1.82</td>
<td>0.88</td>
<td>0.61</td>
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<td></td>
<td></td>
<td>0.49</td>
<td>0.34</td>
<td>0.27</td>
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<tr>
<td>6-9 Years</td>
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<td>0.66</td>
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<td></td>
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<td>0.35</td>
<td>0.27</td>
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<td>9-15 Years</td>
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<td>2.11</td>
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<tr>
<td><strong>Credit Crisis Period</strong></td>
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<td>(1 September 2008 - 31 March 2009)</td>
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<td></td>
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<tr>
<td>3-6 Years</td>
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<tr>
<td>6-9 Years</td>
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<td>0.99</td>
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<td>2.66</td>
<td>1.84</td>
<td>1.81</td>
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This table summarizes average values of \( L_t A_{bond} \) (in percentages) generated from mid-prices [Mean(Mid)], generated with transaction (liquidity) adjustment [Mean(Adj)], and the average bond-specific relative bid-ask spreads [Bid-Ask] by country and bond maturity, derived from the no-arbitrage equilibrium function. The average bid-ask spreads for euro-denominated bonds are displayed immediately below those for usd-denominated bonds. The data set is divided into Pre-Crisis (1 July 2005 - 8 August 2007), Liquidity Crisis (9 August 2007 - 29 August 2008), Credit Crisis (1 September 2008 - 31 March 2009) and Post-Crisis (1 April 2009 - 30 April 2010) periods.

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<th>Year</th>
<th>Maturity</th>
<th>Turkey Mean (Mid)</th>
<th>Turkey Mean (Adj)</th>
<th>Turkey Bid-Ask</th>
<th>Brazil Mean (Mid)</th>
<th>Brazil Mean (Adj)</th>
<th>Brazil Bid-Ask</th>
<th>Mexico Mean (Mid)</th>
<th>Mexico Mean (Adj)</th>
<th>Mexico Bid-Ask</th>
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<td>0.08</td>
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<td>0.04</td>
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<tr>
<td></td>
<td>6-9 Years</td>
<td>0.06</td>
<td>-0.11</td>
<td>0.08</td>
<td>0.08</td>
<td>-0.07</td>
<td>0.06</td>
<td>0.05</td>
<td>-0.16</td>
<td>0.09</td>
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<tr>
<td></td>
<td>9-15 Years</td>
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<td>-0.12</td>
<td>0.09</td>
<td>0.07</td>
<td>-0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>-0.17</td>
<td>0.10</td>
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<tr>
<td>Liquidity Crisis</td>
<td>3-6 Years</td>
<td>0.15</td>
<td>-0.01</td>
<td>0.07</td>
<td>0.15</td>
<td>-0.01</td>
<td>0.10</td>
<td>0.13</td>
<td>-0.06</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>6-9 Years</td>
<td>0.14</td>
<td>-0.04</td>
<td>0.09</td>
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<td>0.07</td>
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<td>-0.05</td>
<td>0.09</td>
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<tr>
<td></td>
<td>9-15 Years</td>
<td>0.13</td>
<td>-0.05</td>
<td>0.09</td>
<td>0.13</td>
<td>0.00</td>
<td>0.08</td>
<td>0.11</td>
<td>-0.10</td>
<td>0.09</td>
</tr>
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<td>Credit Crisis</td>
<td>3-6 Years</td>
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<td>0.61</td>
<td>0.08</td>
<td>0.50</td>
<td>0.30</td>
<td>0.10</td>
<td>0.63</td>
<td>0.48</td>
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<td>6-9 Years</td>
<td>0.85</td>
<td>0.66</td>
<td>0.11</td>
<td>0.54</td>
<td>0.41</td>
<td>0.05</td>
<td>0.70</td>
<td>0.50</td>
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<tr>
<td></td>
<td>9-15 Years</td>
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<td>0.69</td>
<td>0.11</td>
<td>0.58</td>
<td>0.43</td>
<td>0.09</td>
<td>0.76</td>
<td>0.53</td>
<td>0.15</td>
</tr>
<tr>
<td>Post-Crisis</td>
<td>3-6 Years</td>
<td>0.16</td>
<td>-0.03</td>
<td>0.08</td>
<td>0.14</td>
<td>-0.05</td>
<td>0.09</td>
<td>0.18</td>
<td>0.04</td>
<td>0.04</td>
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<tr>
<td></td>
<td>6-9 Years</td>
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<td>-0.03</td>
<td>0.10</td>
<td>0.16</td>
<td>0.01</td>
<td>0.06</td>
<td>0.17</td>
<td>-0.02</td>
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<tr>
<td></td>
<td>9-15 Years</td>
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<td>0.10</td>
<td>0.22</td>
<td>0.06</td>
<td>0.10</td>
<td>0.17</td>
<td>-0.06</td>
<td>0.12</td>
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Table 3
Summary regressions of weekly changes in $LtA_{bond}$ for Turkey, Brazil and Mexico. Variables are made stationary by taking first-differences. The explanatory variables are [Loan Fees] and [Supply]. The former is captured by the value weighted average loan fees for all new trades in seven calendar days. The latter is captured by the total country-specific loan quantity available to lend at each time $t$. Sample is divided into Liquidity, Credit and Post Crisis periods. We report the parameter estimates, and the associated t-statistics are displayed immediately beneath (based on White’s standard errors). Intercepts are not reported. (**) shows 95% and (*) shows 90% confidence interval. For each bond of country $j$ at maturity period $m$, the following fixed-effects panel is estimated:

$$
\Delta LtA_{bond, t}^{j, m} = a_j + B_{1, j}^m \Delta Loan\ Fees_{j, t} + B_{2, j}^m \Delta Supply_{j, t} + e_{j, t}
$$

<table>
<thead>
<tr>
<th>Categories</th>
<th>Coefficients</th>
<th>Liquidity Crisis Period</th>
<th>Credit Crisis Period</th>
<th>Post-Crisis Period</th>
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</thead>
<tbody>
<tr>
<td>Financial Loan Fees</td>
<td>0.01 0.01 0.02</td>
<td>0.41 0.71 0.73</td>
<td>0.01 0.03 0.09</td>
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</tr>
<tr>
<td></td>
<td>0.21 0.28 0.52</td>
<td>1.33 1.83* 1.74*</td>
<td>0.18 0.46 1.10</td>
<td></td>
</tr>
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<td>-0.63 -0.72 -0.77</td>
<td>0.07 0.08 0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.10 0.51 0.17</td>
<td>-3.60** -3.14** -2.79**</td>
<td>1.37 2.15** 0.50</td>
<td></td>
</tr>
<tr>
<td>Supply</td>
<td>0% 0% 0%</td>
<td>13% 15% 13%</td>
<td>1% 1% 1%</td>
<td></td>
</tr>
</tbody>
</table>

R-squared
Table 4
Financial Frictions summary statistics
This table summarizes the total active lendable values (usd millions), total balance values (usd millions), average active utilizations (percentage) and the number of loan transactions (integer) for Brazil, Mexico and Turkey during Liquidity Crisis (9 August 2007 - 29 August 2008), Credit Crisis (1 September 2008 - 31 March 2009) and Post-Crisis (1 April 2009 - 30 April 2010) periods. Mean values are given immediately above the volatility values in columns Statistics. The columns named Change display the percentage change between the current period and the previous period.

<table>
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<td>Statistics</td>
<td>Change (%)</td>
<td>Statistics</td>
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<td>Brazil</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>-7%</td>
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<tr>
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<td>257.76</td>
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<td>395.48</td>
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<tr>
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<td>-61%</td>
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<tr>
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<td>235.01</td>
<td></td>
<td>56.06</td>
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<td>17.24</td>
<td>-38%</td>
<td>10.66</td>
</tr>
<tr>
<td></td>
<td>5.96</td>
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<td>3.36</td>
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<tr>
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<td>173.45</td>
<td></td>
<td>34.79</td>
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<tr>
<td>Mexico</td>
<td></td>
<td></td>
<td></td>
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<td>2030.21</td>
<td>-38%</td>
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<td>258.79</td>
</tr>
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<td><strong>Total Balance Value (millions)</strong></td>
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<td>-58%</td>
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<td></td>
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<tr>
<td><strong>Average Active Utilisation (percentage)</strong></td>
<td>17.79</td>
<td>-12%</td>
<td>15.70</td>
</tr>
<tr>
<td></td>
<td>4.39</td>
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<td>4.55</td>
</tr>
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<td><strong>Number of Transactions (integer)</strong></td>
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<td>-36%</td>
<td>102.68</td>
</tr>
<tr>
<td></td>
<td>33.47</td>
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<td>21.96</td>
</tr>
<tr>
<td>Turkey</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Active Lendable Value (millions)</strong></td>
<td>3293.57</td>
<td>-19%</td>
<td>2670.60</td>
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<tr>
<td></td>
<td>426.31</td>
<td></td>
<td>403.54</td>
</tr>
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<td><strong>Total Balance Value (millions)</strong></td>
<td>725.64</td>
<td>-75%</td>
<td>178.85</td>
</tr>
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<td>258.24</td>
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<td>94.45</td>
</tr>
<tr>
<td><strong>Average Active Utilisation (percentage)</strong></td>
<td>22.16</td>
<td>-46%</td>
<td>11.94</td>
</tr>
<tr>
<td></td>
<td>9.23</td>
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<td>4.25</td>
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<td><strong>Number of Transactions (integer)</strong></td>
<td>358.09</td>
<td>-72%</td>
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<tr>
<td></td>
<td>114.63</td>
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<td>42.59</td>
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Table 5

**LtA** bond panel regressions on financial factors - entire period

Summary regressions of weekly changes in **LtA** bond for Turkey, Brazil and Mexico. Variables are made stationary by taking first-differences. The explanatory variables are the following: Liquidity Risk includes the variables [FX-Liq; FG-Liq]; Funding Risk includes [Unsecured; Secured; CP]; Global Cash-Flow Risk includes [LN-Macro; TP]; Local Risk includes [EM-CDSI; EM-MSCI]; Global Discount Rate factors include [DIVY; Closed End; VIX]; Global Uncertainty includes [DiB]; Financial Frictions include [Supply; Loan Fee]. Sample is divided in Pre-Crisis, Liquidity and Credit Crisis, and Post-Crisis periods. We report Phillips-Sul (2006) bias-corrected parameter estimates and the associated t-statistics are displayed immediately beneath (based on White's standard errors). Intercepts are not reported. (***) shows 95% and (*) shows 90% confidence interval. For each bond of country \( j \) at maturity period \( m \), the following fixed-effects panel is estimated:

\[
\Delta \text{LtA}(\text{bond})_{mj,t} = \alpha_j + \beta_m [\Delta \text{Liquidity Risks}]_{j,t} + \beta_m [\Delta \text{Funding Risks}]_{j,t} + \beta_m [\Delta \text{Global Cash-Flow Risk}]_{j,t} + \beta_m [\Delta \text{Local Risk}]_{j,t} + \beta_m [\Delta \text{Global Discount Rate Risk}]_{j,t} + \beta_m [\Delta \text{Global Uncertainty}]_{j,t} + \beta^m \times \Delta \text{LtA(bond)}_{j,t-1} + \epsilon_{mj,t}
\]

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<th>Categories</th>
<th>Coefficients</th>
<th>Pre-Crisis Period</th>
<th>Liquidity Crisis Period</th>
<th>Credit Crisis Period</th>
<th>Post-Crisis Period</th>
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<td></td>
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<td>(3-6 Years)</td>
<td>(6-9 Years)</td>
<td>(9-15 Years)</td>
<td>(3-6 Years)</td>
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<td>-0.16</td>
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<td>0.74</td>
<td>0.08</td>
<td>-0.04</td>
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<td>0.83</td>
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<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
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<tr>
<td>TP</td>
<td>1.82**</td>
<td>1.27</td>
<td>0.41</td>
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<td>Local Risk</td>
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<td></td>
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<td>EM-MSCI</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>Global Discount Rate Risk</td>
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<tr>
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<td>0.38</td>
<td>0.05</td>
<td>0.31</td>
<td>1.16</td>
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<tr>
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<td>0.15</td>
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<td>-0.17</td>
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<tr>
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<td>0.05</td>
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<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
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<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
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<tr>
<td>R-squared</td>
<td>6%</td>
<td>7%</td>
<td>5%</td>
<td>33%</td>
<td>27%</td>
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</table>
Summary regressions of weekly changes in $L_t A_{bond}$ for Turkey, Brazil and Mexico for 9-15 years bonds. Variables are made stationary by taking first-differences. The explanatory variables are the following: Liquidity Risk includes the variables [FX-Liq; FG-Liq]; Funding Risk includes [Unsecured; Secured; CP]; Global Cash-Flow Risk includes [LN-Macro; TP]; Local Risk includes [EM-CDSI; EM- MSCI]; Global Discount Rate factors include [DIVY; Closed End; VIX]; Global Uncertainty includes [DiB]. Each risk category is regressed separately. Sample is for the Credit Crisis period. We report the average parameter estimates, and the associated t-statistics are displayed immediately beneath (based on White’s standard errors). Intercepts are not reported. (**) shows 95% and (*) shows 90% confidence interval.

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<tr>
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<td>Unsecured</td>
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<tr>
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<td></td>
<td>3.48** 3.02** 3.70** 3.82** 3.38** 3.38**</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
<td>0.39 0.78 0.50 -0.72 0.37 0.40</td>
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<tr>
<td>FG-Liq</td>
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<td>LN-Macro</td>
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<td>-0.06 -0.17</td>
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<tr>
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<td>EM-MSCI</td>
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<td>1.30 0.20</td>
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<tr>
<td>Closed End</td>
<td>-12.73 -11.48</td>
</tr>
<tr>
<td></td>
<td>-4.06** -4.40**</td>
</tr>
<tr>
<td>VIX</td>
<td>-0.05 -0.04</td>
</tr>
<tr>
<td></td>
<td>-2.06** -1.10</td>
</tr>
<tr>
<td>Global Uncertainty Risk</td>
<td></td>
</tr>
<tr>
<td>DiB</td>
<td>-2.94 -1.66</td>
</tr>
<tr>
<td></td>
<td>-0.65 -0.33</td>
</tr>
<tr>
<td>R-squared</td>
<td>15% 25% 28% 20% 37% 16% 0% 25% 4% 15% 6%</td>
</tr>
</tbody>
</table>
Table 7
Brazil and Turkey international reserve asset distribution
This table displays the time evolution of the distribution of foreign asset values to total foreign assets in the Central Bank of Brazil (Banco Central do Brazil) and Central Bank of Turkey for the sample 2002 to 2010. The data preceding 2008 is not available for Turkey. The foreign assets include the following currencies: U.S. dollars (USD), Euro (EUR), Japanese Yen (JPY), British Pound (BGP), Canadian dollars (CAD), Australian dollars (AUD) and Others.

| Period | Brazil |          |          |          |          |          | Others |          |          |          | Others |          |          | Others |          |          | Others |          | Others | Others | Others | Others | Others | Others | Others |
|--------|--------|----------|----------|----------|----------|----------|--------|----------|----------|----------|--------|----------|----------|--------|----------|----------|--------|----------|----------|--------|----------|----------|--------|----------|----------|--------|
|        | USD    | EUR      | JPY      | GBP      | CAD      | AUD      | Others | USD      | EUR      | JPY      | GBP      | CAD      | AUD      | Others | USD      | EUR      | JPY      | GBP      | CAD      | AUD      | Others | USD      | EUR      | JPY      | GBP      | CAD      | AUD      | Others |
| 2002   | 63.1%  | 22.3%    | 13.5%    | 0.0%     | 0.0%     | 0.0%     | 1.1%   | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2003   | 58.3%  | 32.9%    | 7.8%     | 0.0%     | 0.0%     | 0.0%     | 1.0%   | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2004   | 54.6%  | 35.1%    | 9.3%     | 0.0%     | 0.0%     | 0.0%     | 1.0%   | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2005   | 73.2%  | 21.3%    | 4.4%     | 0.0%     | 0.0%     | 0.0%     | 1.1%   | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2006   | 88.3%  | 10.3%    | 0.7%     | 0.0%     | 0.0%     | 0.0%     | 0.7%   | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2007   | 90.0%  | 9.5%     | 0.0%     | 0.0%     | 0.0%     | 0.0%     | 0.5%   | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2008   | 89.1%  | 9.4%     | 1.0%     | 0.0%     | 0.0%     | 0.0%     | 0.5%   | 51.0%    | 46.0%    | 1.3%     | 1.5%     | 0.2%     | 0.0%    | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2009   | 81.9%  | 7.0%     | 0.8%     | 3.7%     | 3.5%     | 1.9%     | 1.2%   | 52.6%    | 44.6%    | 1.6%     | 1.1%     | 0.1%     | 0.0%    | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
| 2010   | 81.8%  | 4.5%     | 0.9%     | 2.7%     | 6.1%     | 3.1%     | 0.9%   | 51.3%    | 46.5%    | 0.7%     | 1.3%     | 0.2%     | 0.0%    | -      | -        | -        | -        | -        | -        | -        | -      | -        | -        | -        | -        | -        | -      | -      |
Table 8
Policy events and announcements summary
This table summarizes the classification and sample characteristics of the 9 groups of policy events and/or announcements that occurred during the sample period. An example of policy event and/or announcement is provided for each category. The table displays the number of events corresponding to each category during the Liquidity, Credit and Post-Crisis periods. The event categories are: Write-down announcements on US financial institutions (WRD), News on European finance (NEWS-EU), News on UK finance (NEWS-UK), News on Rest of the World finance (NEWS-ROW), FED Swap Lines to developed and emerging markets (SWAP), Policy announcements on FED’s balance sheet (PAF), Policy announcements on the US Treasury’s balance sheet (PAT), Policy announcements on US housing market (FF) and Stress Tests on US financial institutions (STRESS). The events are generalized and reported in chronological order, starting from the liquidity crisis and ending at the post-crisis periods. The entries are left undefined (-) for the events that had no occurrence in the given subsample periods.

<table>
<thead>
<tr>
<th>Event</th>
<th>Definition</th>
<th>Example</th>
<th>Date</th>
<th>Number of Events</th>
<th>Liquidity</th>
<th>Credit</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRD</td>
<td>Write-down announcements on US financial institutions</td>
<td>$18 Billion Write-down of Citi and Infusion of Merill Lynch</td>
<td>15.01.2008</td>
<td>29</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NEWS-EU</td>
<td>News on European finance</td>
<td>Liquidity funding by ECB, BoE and Swiss</td>
<td>21.01.2008</td>
<td>10</td>
<td>8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NEWS-UK</td>
<td>News on UK finance</td>
<td>Nationalization of Northern Rock</td>
<td>22.02.2008</td>
<td>14</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PAF</td>
<td>Policy announcements on the Federal Reserve’s balance sheet</td>
<td>The Fed announced the TSLF, which offers Treasury collateral to primary dealers in exchange for mortgage bonds and investment grade securities</td>
<td>11.03.2008</td>
<td>5</td>
<td>16</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>SWAP</td>
<td>FED Swap Lines to developed and emerging markets</td>
<td>The FOMC expands a $330 billion of swap lines to nine central banks of developed markets</td>
<td>29.09.2008</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The FOMC expands a $120 billion of swap lines to four central banks of emerging markets</td>
<td>29.10.2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAT</td>
<td>Policy announcements on the US Treasury’s balance sheet</td>
<td>U.S. Treasury launched the Troubled Asset Relief Program (TARP), which involves the mass purchasing of 700 billion usd worth of capital and equity of US commercial banks</td>
<td>03.10.2008</td>
<td></td>
<td>-</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>NEWS-ROW</td>
<td>News on Rest of the World finance</td>
<td>A two-year $586 billion stimulus plan is announced by China</td>
<td>09.11.2008</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>FF</td>
<td>Policy announcements on US housing market</td>
<td>A new program to purchase housing-related government-sponsored enterprises is announced by the Federal Reserve Board</td>
<td>25.11.2008</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>STRESS</td>
<td>Stress Tests on US financial institutions</td>
<td>For U.S. bank holding companies with assets over $100 billion, the Federal Reserve Board announces that it will make stress tests or economic assessments</td>
<td>25.02.2009</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Table 9
Event analysis regressions
Average parameter estimates of the event analysis panel regressions on Brazil, Turkey and Mexico are reported below for each maturity bucket (i.e. 1-3 years, 3-6 years, 6-9 years and 9-15 years). The dependent variable is the changes in the one-way \( \Delta \text{LtA}(\text{bond}) \), and the independent variables are the 9 news categories each treated as a dummy variable. We also control for the lagged dependent variable. The event categories are: Write-down announcements on US financial institutions (WRD), News on European finance (NEWS-EU), News on UK finance (NEWS-UK), News on Rest of the World finance (NEWS-ROW), FED Swap Lines to developed and emerging markets (SWAP), Policy announcements on FED’s balance sheet (PAF), Policy announcements on the US Treasury’s balance sheet (PAT), Policy announcements on US housing market (FF) and Stress Tests on US financial institutions (STRESS). Sample includes the time series between 17 November 2006 to 26 March 2010. Coefficient of determinations are displayed, and the t-statistic are given immediately below. Intercepts are not reported. (*) shows 90% and (**) shows 95% confidence intervals. For each country \( j \) at maturity \( m \), the following ordinary panel regression is estimated:

\[
\Delta \text{LtA}(\text{bond})_{jt}^{m+1} = \alpha_j + \beta_1 \text{WRD}_t + \beta_2 \text{NEWS-EU}_t + \beta_3 \text{NEWS-UK}_t + \beta_4 \text{NEWS-ROW}_t + \\
\beta_5 \text{SWAP}_t + \beta_6 \text{PAF}_t + \beta_7 \text{PAT}_t + \beta_8 \text{FF}_t + \beta_9 \text{STRESS}_t + \\
\beta_{10} \Delta \text{LtA}(\text{bond})_{jt}^{m} + \epsilon_{jt}
\]

<table>
<thead>
<tr>
<th>News</th>
<th>3-6 Years</th>
<th>6-9 Years</th>
<th>9-15 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEWS-EU</td>
<td>0.31</td>
<td>0.38</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>4.24**</td>
<td>4.66**</td>
<td>4.58**</td>
</tr>
<tr>
<td>NEWS-UK</td>
<td>-0.31</td>
<td>-0.33</td>
<td>-0.33</td>
</tr>
<tr>
<td></td>
<td>-4.69**</td>
<td>-4.50**</td>
<td>-4.11**</td>
</tr>
<tr>
<td>NEWS-ROW</td>
<td>0.31</td>
<td>0.47</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>2.37**</td>
<td>3.22**</td>
<td>3.86**</td>
</tr>
<tr>
<td>PAF</td>
<td>-0.04</td>
<td>0.00</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>-0.52</td>
<td>0.06</td>
<td>0.76</td>
</tr>
<tr>
<td>PAT</td>
<td>0.09</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>1.51</td>
<td>1.21</td>
<td>0.75</td>
</tr>
<tr>
<td>FF</td>
<td>0.42</td>
<td>0.37</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>4.79**</td>
<td>3.85**</td>
<td>2.90**</td>
</tr>
<tr>
<td>SWAP</td>
<td>-0.25</td>
<td>-0.35</td>
<td>-0.43</td>
</tr>
<tr>
<td></td>
<td>-2.94**</td>
<td>-3.64**</td>
<td>-4.08**</td>
</tr>
<tr>
<td>WRD</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>0.96</td>
<td>0.78</td>
<td>0.57</td>
</tr>
<tr>
<td>STRESS</td>
<td>-0.77</td>
<td>-0.63</td>
<td>-0.46</td>
</tr>
<tr>
<td></td>
<td>-4.40**</td>
<td>-3.26**</td>
<td>-2.15**</td>
</tr>
<tr>
<td>Mean Reversion</td>
<td>-0.46</td>
<td>-0.51</td>
<td>-0.55</td>
</tr>
<tr>
<td></td>
<td>-12.48**</td>
<td>-14.31**</td>
<td>-15.99**</td>
</tr>
<tr>
<td>R-Squared</td>
<td>34%</td>
<td>40%</td>
<td>45%</td>
</tr>
</tbody>
</table>
Table 10
Price discovery analysis
This table summarizes the results of the price discovery regressions between the USD and euro bond spreads of country j, for the entire time period. The tests are based on VECM specification, where \( S_{\text{USD}} \) and \( S_{\text{EUR}} \) are the USD and euro credit spreads, respectively, and \( u_{1t} \) and \( u_{2t} \) are the error terms. We impose the restrictions that \( b_1 = 1 \approx (1 + R_t^{d})/(1 + R_t^{f}) \), and \( c_1 = 1 \). The regressions are run using an optimal number of lags determined by AIC. Only the coefficients A1 and A2 are displayed in the table with t-statistics shown immediately below. \( H_x \) and \( H_y \) are the Hasbrouck bounds, and \( \sigma_1, \sigma_2, \sigma_{12} \) are the standard deviations and covariance of the residual series, respectively. HM is the arithmetic mean of two Hasbrouck measures, which captures the contribution of USD credit spreads to euro credit spreads. The VECM is specified as follows:

\[
\begin{align*}
\Delta S^d_t &= A_1[S^d_{t-1} - b_1(S^f_{t-1})] + \sum_{n=1}^{N} \phi_{1n} \Delta S^d_{t-n} + \sum_{n=1}^{N} \gamma_{1n} \Delta S^f_{t-n} + u_{1t} \\
\Delta S^f_t &= A_2[S^d_{t-1} - b_1(S^f_{t-1})] + \sum_{n=1}^{N} \phi_{2n} \Delta S^d_{t-n} + \sum_{n=1}^{N} \gamma_{2n} \Delta S^f_{t-n} + u_{2t} 
\end{align*}
\]

<table>
<thead>
<tr>
<th>Country</th>
<th>A1</th>
<th>A2</th>
<th>( H_x )</th>
<th>( H_y )</th>
<th>HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-6 Years</td>
<td>-0.06</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.68</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>[-1.95]</td>
<td>[-0.19]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-9 Years</td>
<td>-0.06</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.65</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>[-1.54]</td>
<td>[-0.25]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-15 Years</td>
<td>-0.08</td>
<td>-0.04</td>
<td>0.23</td>
<td>0.29</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>[-1.44]</td>
<td>[-0.82]</td>
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<tr>
<td>Brazil</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>3-6 Years</td>
<td>0.02</td>
<td>0.15</td>
<td>0.37</td>
<td>0.99</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>[0.26]</td>
<td>[1.74]</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6-9 Years</td>
<td>-0.03</td>
<td>0.14</td>
<td>0.19</td>
<td>0.99</td>
<td>0.59</td>
</tr>
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<td></td>
<td>[-0.33]</td>
<td>[1.38]</td>
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<td>9-15 Years</td>
<td>-0.09</td>
<td>0.13</td>
<td>0.14</td>
<td>0.93</td>
<td>0.54</td>
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<td></td>
<td>[-0.93]</td>
<td>[1.34]</td>
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<td>Mexico</td>
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<tr>
<td>3-6 Years</td>
<td>-0.16</td>
<td>0.11</td>
<td>0.13</td>
<td>0.84</td>
<td>0.49</td>
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<td>[-1.55]</td>
<td>[1.41]</td>
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<tr>
<td>6-9 Years</td>
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<td>0.09</td>
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<tr>
<td>9-15 Years</td>
<td>-0.04</td>
<td>0.12</td>
<td>0.31</td>
<td>0.99</td>
<td>0.65</td>
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<tr>
<td></td>
<td>[-0.45]</td>
<td>[2.28]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. LTA dynamics: the three panels above show the Basis\textsubscript{bond} proxy of Brazil, Mexico, and Turkey (inverted scale), respectively, in percentages. The three panels below show the co-movement between the first principal component of the LTA\textsubscript{bond} proxy (left axis, blue line), constructed from all countries and maturity buckets, and three risk factors (right axis, red line): FX Liquidity [FX-Liq], first principal component of Secured [PCA Secured] and Closed End Fund Discount Risk [Closed End] (on an inverted scale). The vertical lines in graphs denote the three sub-periods: Pre-Crisis, Crisis and Post-Crisis, accordingly.
Figure 2. LTA dynamics: the three panels above show the Total Active Lendable Value (i.e. amount available for borrowing) for Brazil, Mexico, and Turkey, respectively, in usd millions. The three panels below show the Total Balance Value (i.e. amount lent out) for Brazil, Mexico, and Turkey, respectively, in usd millions. The sample includes the Credit Crisis period, where the vertical lines denote the start of Credit Crisis (1 September 2008).
Figure 3. *Individual impacts:* the panels display the total $R^2$ of each risk category regressed separately against the $LtA_{bond}$ proxy for each maturity group (3-6 years, 6-9 years, 9-15) and each sub-period (Pre-Crisis, Liquidity Crisis, Credit Crisis and Post-Crisis). The explanatory variables are the following: Liquidity risk includes the variables [FX-Liq; FG-Liq]; Funding Risks includes [Unsecured; Secured; CP]; Global Cash-Flow Risk includes [LN-Macro; TP]; Local Risk includes [EM-CDSI; EM-MSCI]; Global Discount Rate factors includes [DIVY; Closed End; VIX]; Global Uncertainty includes [DiB]. Values are in percentages.
Figure 4. *Macro Fundamentals - Turkey:* the chart above displays the total Bank Deposit Distribution (millions) in USD (left axis) and euro (right axis) in Turkey during 2007-2010. The left hand of the two charts below illustrates the difference (spread) between the 3-month average USD minus euro deposit rates (bps) of Turkey during 2008-2009. The right hand of the two charts below displays the 5-years cross-currency basis swap spreads (bps) for Turkey during 2007-2010. The chart displays the amount of spread that is subtracted from the 3-month TRIBOR in exchange for the 3-month USD LIBOR. The vertical lines in graphs denote the period of July 2008 to March 2009.