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Monetary Transmission: Are Emerging Market and Low-Income Countries Different?

Aleš Bulíř and Jan Vlček *

Abstract

We use two representations of the yield curve, by Litterman and Scheinkman (1991) and by Diebold and Li (2006), to test the functioning of the interest rate transmission mechanism along the yield curve based on government paper in a sample of emerging market and low-income countries. We find a robust link from short-term policy and interbank rates to longer-term bond yields. Two policy implications emerge. First, the presence of well-developed secondary financial markets does not seem to affect transmission of short term rates along the yield curve. Second, the strength of the transmission mechanism seems to be affected by the choice of monetary regime: advanced countries with a credible IT regime seem to have "better behaved" yield curves than those with other monetary regimes.

Abstrakt

Článek testuje transmisi úrokových sazeb na výnosových křivkách vládních dluhopisů v rozvíjejících se a rozvojových zemích. K tomu využívá dvě reprezentace výnosových křivek, jejichž autory jsou Litterman and Scheinkman (1991) a Diebold and Li (2006). Výsledky ukazují na robustní přenos krátkodobých měnověpolitických a mezibankovních sazeb do výnosů dluhopisů s dlouhodobou splatností. Jejich implikace pro měnovou politiku jsou dvojího druhu. Zaprvé, přítomnost rozvinutého sekundárního trhu zřejmě neovlivňuje transmisi krátkodobých sazeb do výnosové křivky. Zadruhé, sílu transmisního mechanismu zřejmě ovlivňuje výběr měnověpolitického režimu, protože v rozvinutých zemích s kredibilním inflačním cílením pozorujeme „lépe se chovající" výnosové křivky ve srovnání s ostatními měnovými režimy.

JEL Codes: E43, E52, G12.
Keywords: Monetary transmission, yield curve.

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Nontechnical Summary

After the recent financial crisis many central banks in emerging market and low-income countries began reviewing their monetary frameworks, adding financial stability and growth to their price stability objectives. At the same time, these central banks felt uncertain about the transmission mechanism, as there is little agreement on its efficiency. Relying mostly on VAR models, some economists claimed that the transmission mechanism in these countries is weak (Mishra et al. (2012); Davoodi et al. (2013)). Others found a well functioning transmission mechanism in the East Africa region using the "narrative approach" (Berg et al. (2013)).

We explore the functioning of the interest rate channel in a sample of 16 countries that encompasses emerging market, low-income, and advanced countries. Instead of inspecting the whole transmission mechanism, we focus only on a part of the interest rate channel, namely, the transmission from short-term policy rates to long-term rates. According to the Keynesian interest rate channel, a policy-induced increase in the short-term nominal interest rate leads to an increase in longer-term nominal interest rates in line with the term structure of interest rates.

Inspecting that part of the interest rate channel, we assess the behavior of yield curves of government securities. Specifically, we identify the three latent factors commonly used to describe the dynamics of the yield curve – the level, slope, and curvature. We use both the principal component analysis (PCA) applied by Litterman and Scheinkman (1991) and the Diebold and Li (2006) methodology. The three latent factors explain most of the yield curve variability, which means that the shape and dynamics of the yield curve are non-stochastic, following the term structure of interest rates. A dominant level factor indicates a positive and significant correlation between short-term and long-term yields, implying a functioning transmission mechanism from short-term to long-term rates. Furthermore, we inspect whether these two sets of estimated factors are correlated with monetary policy rates, as, according to the term structure of interest rates, there should be a positive correlation between the policy rate and the level factor. Economic theory also suggests that the slope of yield curves should be negatively correlated with the policy rate. If a yield curve exhibits all the above mentioned features, we label it as "well-behaved."

We find "well-behaved" yield curves in all sample countries, indicating that the first part of the interest rate transmission channel is working. The three latent factors – the level, slope, and curvature – explain the bulk of interest rate movements, and the vertical shift dominates. The link from policy/interbank rates to bond yields appears to be robust across estimation techniques and largely unaffected by the monetary policy regime or the stage of economic development. We find no evidence that the presence of developed secondary markets strongly facilitates the transmission mechanism. Furthermore, we find only weak evidence that the transmission mechanism operates more smoothly in advanced countries, all practicing inflation targeting, than in less developed countries with mixed regimes. These results are remarkably consistent across the sample countries, despite short sample periods, gaps in longer maturities, various monetary policy regimes, and so on. The findings of this paper have an important policy implication – the first leg of the monetary transmission appears to be broadly independent of the level of financial sophistication.

1. Introduction

We explore a part of the transmission mechanism in a sample of 16 countries that includes advanced, emerging market, and low-income countries, generally finding "well-behaved" yield curves and a functioning monetary transmission mechanism. By "well-behaved" we mean that policy or short-term interbank interest rates are transmitted to market-determined, longer-term bond rates in all countries. The nominal interest rate part of the transmission mechanism appears to be functional and largely identical in all sample countries, including low-income ones, suggesting that the importance of developed secondary markets for monetary transmission is overstated.

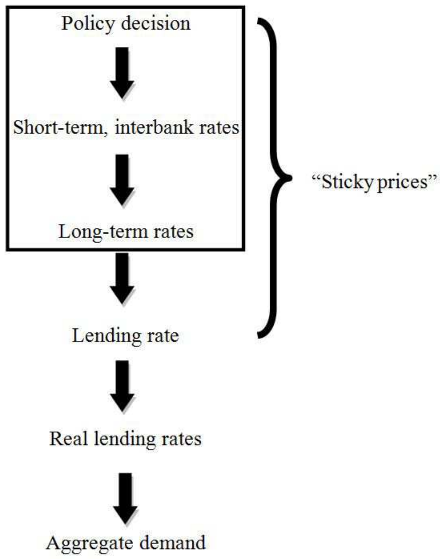
After the financial crises of the 1990s and 2000s, many emerging market and low-income country central banks began reviewing their monetary frameworks to make policy more forward-looking, in order to promote macroeconomic stability, growth, and financial development. At the same time, these central banks felt uncertain about how monetary policy would transmit to longer-term rates and, eventually, to output and prices. The task of identifying the transmission mechanism has been challenging in the environment of short, noisy time series plagued by policy-driven breaks and supply shocks. In general, there is little agreement on the efficiency of monetary transmission in low-income and emerging market countries, (see IMF (2015)).

Some economists, relying on reduced-form analysis capturing the transmission channels in a VAR model, have claimed that the transmission mechanism in these countries is weak (Mishra et al. (2012); Davoodi et al. (2013)). Christiano et al. (1999), however, documented theoretical and empirical difficulties in estimating the effects of monetary policy in the VARs of advanced countries with long series and a well-defined business cycle. Berg et al. (2013) argued that analyses based on VARs – requiring long time series without policy breaks – are unlikely to ever provide "statistically significant" results in low-income countries and instead used the "narrative approach" of Romer and Romer (1994) to identify textbook effects of the mechanism of transmission to output and prices.

Our approach is less ambitious in the sense that we focus only on the first part of the monetary transmission mechanism. Monetary policy actions are expected to move short-term market interest rates. While many central banks use a short-term rate as the policy instrument, others change short-term (money market) rates indirectly by setting money growth targets and managing liquidity in line with these targets. According to the Keynesian interest rate channel (Hicks (1937); Mishkin (1995)), a policy-induced increase in the short-term nominal interest rate leads to an increase in longer-term nominal interest rates in line with the term structure of interest rates as investors arbitrage away differences in risk-adjusted expected returns on debt instruments of various maturities (Figure 1). There are, of course, additional links between interest rates and the economy, such as intertemporal substitution and the impact of interest rate changes on the exchange rate, which in turn affect aggregate demand. Under sticky prices, the movements in nominal interest rates then translate into movements in real interest rates and agents find that their real cost of borrowing has increased over all horizons as a result of the initial short-term rate hike.

We explore the first leg of the interest rate transmission mechanism: from the short-term rate or policy rate to long-term bond rates. To this end, we identify the three latent factors commonly used to describe the dynamics of the yield curve – the level, slope, and curvature. We rely on two complementary empirical techniques to identify the yield curve latent factors and use them as a robustness check. The first is principal component analysis, PCA, initially applied by Litterman and Scheinkman (1991) to the U.S. data and then replicated for a number of advanced and emerging market countries, such as Mexico (Cortés et al. (2009)). Second, we corroborate the PCA results by explicitly estimating the three latent factors using the Diebold and Li (2006) methodology. We

Figure 1: The Interest Rate Transmission Mechanism



refer to these two methodologies as LS and DL, respectively. The latent factors should explain most of the yield curve variability. We then inspect whether these two sets of estimated factors are correlated and whether they co-move with monetary policy and interbank rates. In other words, policy hikes/cuts would result in level and slope shifts of the yield curve, minimizing arbitrage opportunities. Why do we stop at long-term bond rates and not continue to nominal lending rates? Unfortunately, the relevant lending rate series are only available for some industrial countries, although a few emerging market and low-income countries began to collect such series recently.

Our approach is a viable alternative to the VAR and other approaches in assessing the interest rate channel. Similar to other approaches, it is hampered by short and noisy data and structural breaks. However, as we focus only on the first leg of the interest rate channel and we employ market yields, our results are fairly robust .

In the remainder of the paper we proceed as follows. First, we outline the modeling techniques used to derive the three factors. Second, we describe our sample and discuss the various empirical tradeoffs. Third, we present our results and sketch policy implications. The final section concludes.

2. Methodology

We apply the LS and DL methodologies to detrended short and long yields to identify the latent factors that govern the movements in yield curves, following the Diebold et al. (2006) approach to explore the first leg of the transmission mechanism (Appendix A). LS finds these factors with the help of the sample covariance matrix of the data, sequentially identifying mutually uncorrelated principal components (PCs). DL employs the Nelson and Siegel dynamic representation of the yield curve, defining a state-space model of the yield curve, and applying the Kalman filter to identify the three latent factors: the level, slope, and curvature, labeled β_1, β_2, and β_3. DL is free of the PCA restriction of zero correlation of the factors.[1]

We assess the interest rate channel as follows:

1. Compute the share of the variability in the interest rates explained by the latent factors derived using the LS and DL methodologies.
2. Assess whether the yield curve is "well-behaved" using the following criteria:[2]
   (a) The first two latent factors explain most of the variability in the observed yield curves. Hence, the shape and dynamics of the yield curve are non-stochastic, reflecting the term structure of interest rates (see Appendix B for a discussion);
   (b) The level factor is dominant, implying a positive and significant correlation between the short and long-term yields;
   (c) The level factor is positively correlated with the policy-driven short-term rates, ensuring that policy rate moves result in vertical shifts of the yield curve;
   (d) Providing inflation expectations are anchored and long rates reflect country fundamentals, the policy rate and the second factor are negatively correlated, implying that tighter monetary policy flattens the yield curve and looser policy makes it steeper.

3. Data

Extending yield curve analysis to emerging market and low-income countries proved to be challenging. Data are available for only a handful of countries, securities are rarely traded on secondary markets, and primary issue data often contain gaps. Periods of disinflation (or increasing inflation) have left the series with unit roots, which are not trivial to remove. To rectify this problem, we detrend interest rates and bond yields using the policy rate trend based on the Hodrick-Prescott filter. Detrending is particularly important for the LS approach, as calculations based on non-adjusted series overestimate the explanatory power of the level factor (see Appendix B). After detrending, all interest rates and yields are therefore expressed as term premiums. Furthermore, central banks that follow monetary targets or inflation targeters in low-income countries tend to provide liquidity to the banking sector at rates that differ from their declared policy rates.

3.1 Sample Countries

We explore the functioning of the interest rate channel in a sample of 16 countries, that is further divided into emerging market countries (EMCs), low-income countries (LICs), and advanced countries (ACs, see Table 1). The selection process for EMCs and LICs was based on data availability and the country making efforts to modernize its monetary framework (see IMF (2015)). The seven

[1] For a primer on both methodologies, see Appendix A. The principal components algorithm (Abdi and Williams (2010)) identifies a PC that accounts for as much of the variance in all the underlying data as possible. Then the second PC is identified with the objective of explaining as much as possible of the remaining variance under the constraint that this PC is uncorrelated with the preceding PC (and so on). The PCA zero correlation restriction imposes a signification economic restriction – the level and slope shifts are de-linked by construction. Forzani and Tolmasky (2003) demonstrate that the correlation matrices of yields are very similar across asset classes and countries and the PCs indeed capture the three latent factors.

[2] Our definition of "well-behaved" differs from that commonly used by financial market practitioners, where such term typically denotes a smooth yield curve.

Table 1: Sample Stylized Facts, 2000-2013

Country	MP regime	Inflation, in percent	Interbank rate, in percent	Per capita GDP, PPP US$
Czech Republic (CZE)	Inflation targeting	2.4	3.4	25,389
Egypt, Arab. Rep. (EGY)	Multiple objectives	8.0	7.0	5,893
Georgia (GEO)	Inflation targeting	5.3	10.4	4,932
Ghana (GHA)	Inflation targeting	14.8	11.6	2,679
Indonesia (IDN)	Inflation targeting	7.5	8.5	4,149
Israel (ISR)	Inflation targeting	2.0	4.1	30,535
Kenya (KEN)	Monetary aggregate targeting	9.6	13.9	1,582
Morocco (MAR)	Monetary aggregate targeting	1.6	6.3	4,554
Malaysia (MYS)	Multiple objectives	2.2	4.4	14,699
Nigeria (NGA)	Monetary aggregate targeting	11.7	15.5	2,293
Rwanda (RWA)	Monetary aggregate targeting	6.9	9.0	1,200
South Africa (ZAF)	Inflation targeting	5.7	3.9	10,105
Sweden (SWE)	Inflation targeting	1.4	2.9	37,498
Turkey (TUR)	Inflation targeting	14.6	10.3	13,110
Tanzania (TZA)	Monetary aggregate targeting	7.6	8.5	1,384
Uganda (UGA)	Monetary aggregate targeting	7.3	10.7	1,275

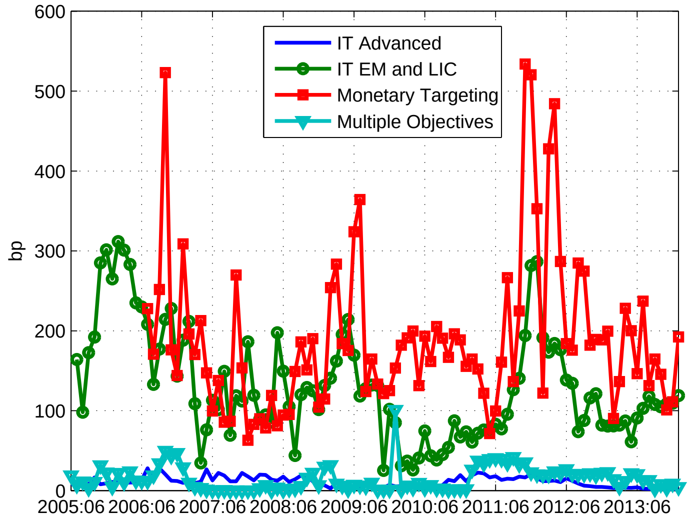
Source: IMF (2012), IFS database.

EMCs are Egypt (EGY), Georgia (GEO), Indonesia (IDN), Malaysia (MYS), Morocco (MAR), South Africa (ZAF), and Turkey (TUR). The six LICs are Ghana (GHA), Kenya (KEN), Nigeria (NGA), Rwanda (RWA), Tanzania (TZA), and Uganda (UGA). The control group of three ACs comprises the Czech Republic (CZE), Israel (ISR), and Sweden (SWE), all countries practicing inflation forecast targeting (IT) as defined by Svensson (1997). According to the IMF (2012) de facto classification, five out of the 13 countries in the EMC/LIC group are also IT countries. The sample is macro-economically diverse: average inflation ranged from 1.4 percent in Sweden to almost 15 percent in Ghana, with inflation being higher and more volatile in the EMC/LIC group. The average ex post short-term real interest rate was mostly positive, with a few negative-rate outliers among African countries. The poorest sample country is Uganda and the richest is Sweden. With the exception of Sweden and South Africa, the interest rate series start in the 2000s (Table 2).

3.2 Central Bank and Interbank Rates and Yields

All the sample countries have treasury bills and bonds of various maturities and interbank money market rates, and most have also a central bank interest rate. The latter rate is used differently across the sample, however. While all advanced and some emerging market countries use the central bank rate as a target rate for liquidity operations, most LICs occasionally provide liquidity at rates different from their central bank rates (Berg et al. (2013)). As a result, the ACs and some EMCs exhibit average spreads between the central bank and interbank interest rates to the tune of tens of basis points, whereas in LICs the spreads are in hundreds of basis points (see Figure 2 and also Table C1 in Appendix C). Hence, we use the rate only if the bank has used it consistently as a policy instrument and the interbank rates have been close to the central bank rate. Such conditions are satisfied only among the more advanced IT countries (the Czech Republic, Israel, and Sweden). Hence, we define the monetary policy stance either as the central bank rate or as the shortest maturity, typically overnight, interbank rate.

Figure 2: Spreads Between Interbank and Policy Rates



Note: In basis points. The groups are: Advanced IT – Czech Republic, Israel, and Sweden; EMC and LIC IT – Georgia, Ghana, Indonesia, South Africa, and Turkey; Monetary Targeting – Kenya, Morocco, Nigeria, Rwanda, Tanzania, and Uganda; and Multiple Objectives – Egypt and Malaysia.
Source: Authors' calculations.

The monetary policy rate should ultimately affect lending rates. However, this nexus is difficult to demonstrate empirically as the published lending rates in the EMC/LIC group are riddled with problems. First, some countries report as lending rates the so-called prime rate, at which little or no retail lending is done. Second, the published data sometimes contain an average rate for all immature loans with a given maturity.[3] Only ACs and some EMCs (Morocco) collect and publish usable series on current-period lending rates, classified by sector, firm size, and maturity, although some LICs (Uganda) has started collecting such data. Even for those countries, however, the series are difficult to obtain.

Finally, the EMC/LIC lending rates contain sizable credit and inflation premiums. Regarding the former, in Ghana the spread between the prime lending rate and the three-month interbank rate averaged about 2,000 basis points between 2004 and 2013, while in the Czech Republic the spread was only 200-300 basis points. The lending rates reflect the functioning of the domestic asset recovery system: lenders in countries with poor creditor protection charge higher loan-to-deposit spreads than those in countries with good protection, to build a buffer against nonperforming loans. Regarding the latter, the inflation premium tends to be sizable in countries with high and volatile inflation, dampening the pass-through from policy-induced changes in the (nominal) policy rate to the lending rate.

We therefore assess the transmission mechanism using yield curves that are based on government security market rates, following past literature (Litterman and Scheinkman (1991); Diebold et al. (2006); Aguiar-Conraria et al. (2012)). Ideally , we would have liked to estimate zero-coupon yield equivalents for bonds with coupons, but unfortunately these are regularly available only for

[3] For example, the 3-year lending rate is defined as the average of the current-month 3-year loan rate and rates on immature loans of this maturity issued during the preceding 35 months.

Table 2: Government Paper and Data Sources

Country	Sample period	Yield type	Maturities
Czech Republic (CZE)	2000M4:2015M1	Yields at issue, primary market (pm), Bloomberg generic for long tenors	3M, 6M, 1Y, 2Y, 5Y, 10Y
Egypt, Arab. Rep. (EGY)	2006M7:2014M12	T-bills – yields at issue, T-bonds – Bloomberg generic	3M, 6M, 1Y, 2Y, 3Y, 5Y, 7Y, 10Y
Georgia (GEO)	2010M9:2014M11	Yields at issue, pm	1Y, 2Y, 5Y, 10Y
Ghana (GHA)	2007M1:2014M9	Yields at issue, pm	3M, 6M, 1Y, 2Y, 3Y
Indonesia (IDN)	2005M7:2015M1	Bloomberg generic	1Y, 2Y, 5Y, 10Y, 15Y
Israel (ISR)	2005M1:2015M1	Bloomberg generic	2Y, 3Y, 5Y, 10Y
Kenya (KEN)	2007M1:2014M9	Yields at issue, pm	3M, 6M, 5Y, 10Y, 15Y
Morocco (MAR)	2007M1:2015M1	Yields at issue, pm	3M, 1Y, 2Y, 5Y, 10Y, 15Y
Malaysia (MYS)	2005M1:2014M12	Yields at issue, pm	3M, 6M, 1Y, 2Y, 3Y, 4Y, 5Y, 10Y, 15Y
Nigeria (NGA)	2006M9:2014M10	Yields at issue and yield to maturity, pm and secondary markets	3M, 6M, 1Y, 3Y, 5Y, 10Y
Rwanda (RWA)	2008M1:2014M10	Yields at issue, pm	3M, 6M, 1Y, 3Y
South Africa (ZAF)	1999M12:2014M3	Bloomberg generic	2Y, 3Y, 5Y, 7Y, 10Y, 15Y
Sweden (SWE)	1994M6:2014M12	Bloomberg generic	3M, 6M, 1Y, 2Y, 3Y, 5Y, 10Y
Turkey (TUR)	2007M6:2015M1	Bloomberg generic	3M, 6M, 1Y, 2Y, 5Y, 10Y
Tanzania (TZA)	2003M1:2014M10	Yields at issue, pm	3M, 6M, 1Y, 2Y, 5Y, 7Y, 10Y
Uganda (UGA)	2005M1:2014M12	Yields at issue, pm	3M, 6M, 1Y, 2Y, 3Y, 5Y

Source: Various online databases.

advanced countries and estimation thereof for EMCs and LICs is hindered by a lack of benchmark issues. The next best option – monthly yields on generic bonds, obtained from the Bloomberg and public databases (Table 2) – has obvious drawbacks.

First, the time series for the EMCs and LICs are short, typically covering only the 2000s. Second, we frequently find the yields at issue only on the primary market, as secondary markets are either non-existent or illiquid. The primary market yields are often subject to non-market forces, as short maturities are used by the central bank for managing market liquidity and demand for longer tenors is affected by regulatory measures targeting the capital and liquidity ratios of various financial institutions. Third, the primary market data have missing observations, as not all maturities are auctioned at each point in time.[4]

The empirical work is further complicated by secular movements in inflation and the corresponding increases/declines in nominal interest rates. Such an underlying trend in inflation is likely to bias upward the importance of the level factor. The stationarity assessment is complicated by the fact that individual yields cannot be detrended separately, as the underlying inflation trend should be

[4] Missing observations are problematic only for the LS approach, however, and we intrapolate the missing monthly observations using the Hodrick-Prescott filter with $\lambda = 14,400$. No pre-filtering was needed for the DL approach.

common across all maturities. To this end, we detrend all yields using the trend of the country's monetary policy rate (Hodrick-Prescott filter with $\lambda = 14,400$), that is, all yields are expressed as term premiums. Still, even after such detrending we cannot reject nonstationarity in one fifth of all yields (Egypt, Georgia, Israel, Morocco, Turkey, Tanzania, and South Africa; Appendix B). This finding is hardly surprising, as our detrended yields are essentially measures of term premiums and these are generally nonstationary, as previously noted by Kim and Orphanides (2007) and Adrian et al. (2013) (Figure 3).

All yield-curve calculations are performed with monthly data and the correlations presented in the paper are sample Pearson product-moment correlation coefficients. For robustness checks we also calculate population correlations, computed from a first-order VAR model. These results are not materially different from the sample correlations and are posted at `http://ales-bulir.wbs.cz/Published-papers.html`.

4. Results and Policy Implications

A well-functioning transmission mechanism seamlessly transmits monetary policy innovations to longer-term rates.[5] We find evidence of such well-behaved yield curves in our sample countries, basing this conclusion on the latent factors explaining most of the variability across all maturities. Furthermore, the factors are correlated with policy interest rates. Regarding robustness, first, we check the explanatory power of the LS and DL estimates of the latent factors and compare the two techniques. Second, we discuss the links between the monetary policy rates and the first two factors. All the checks suggest that our results are methodology invariant.

4.1 LS and DL Estimates of the Latent Factors

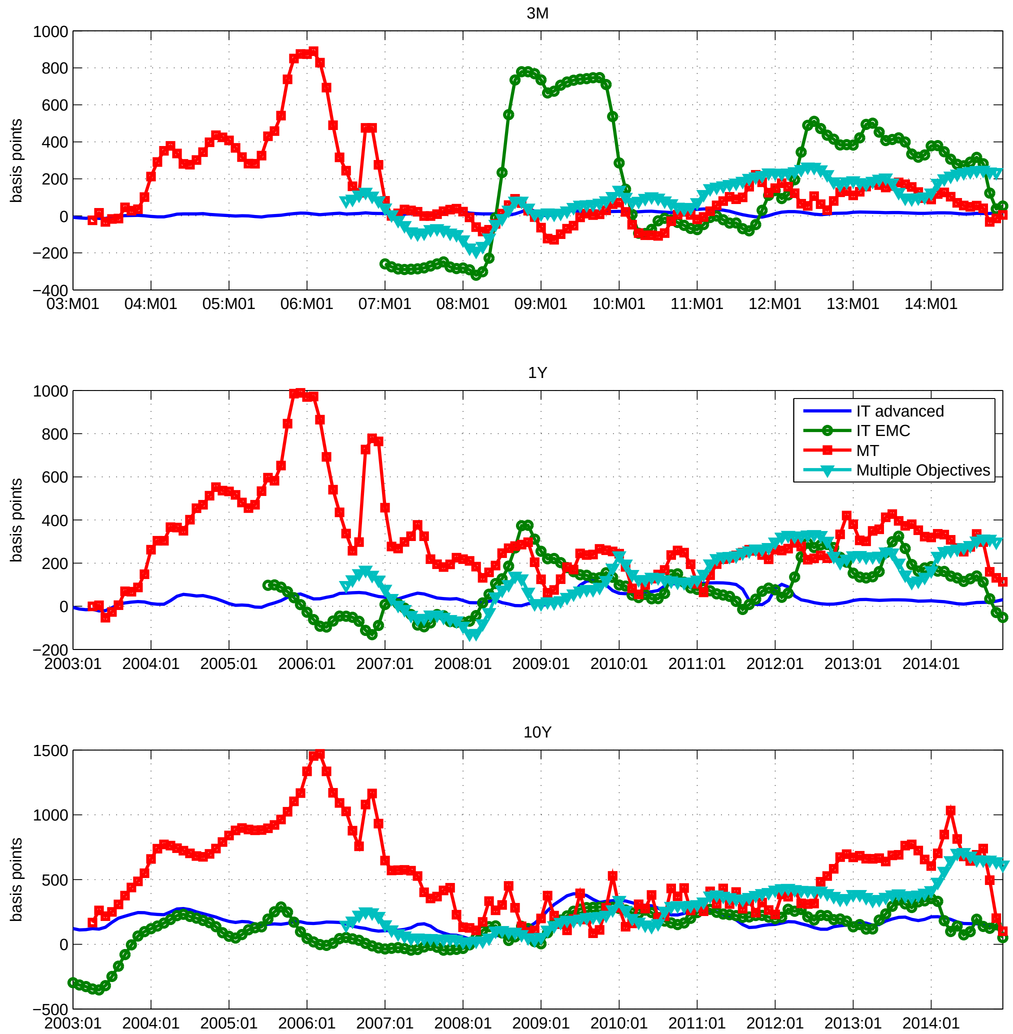
The LS and DL estimates of the latent factors are highly correlated in most of the sample countries despite the different identifying restrictions and we thus consider these estimates to be robust (Table 3). By extension, as the DL-based factors have a clear structural interpretation as the level, slope, and curvature, the LS-based estimates can be labeled in the same way.

Jointly, the three factors explain more than 95 percent of the interest rate variability in all countries except Nigeria, and the first two factors account for the most of yield variability (Figure 4). Assessing the *average* explanatory power of the level and slope factors jointly across different maturities does not suggest any material differences – the two factors explain 95 percent of the yield variance on average. The first latent factor, the level, is a crucial indicator of transmission, as it measures the vertical shifts of the yield curve and it clearly dominates in most countries.[6] The high contribution of this factor implies that the yields are correlated across maturities and, hence, innovations are quickly propagated. Of course, interest rate innovations may also be propagated through changes in the slope of the yield curve, especially if inflation expectations are anchored. We find that Sweden and South Africa, both inflation targeting countries, exhibit a comparatively low contribution of the level factor. The contribution of the noise and stochastic (unexplained) parts of the yield curve variability is estimated to be fairly small. From this perspective, we find the yield curves to be (i) well

[5] Of course, correlations are not evidence of causality. For example, a central bank can instantaneously map long-term rate developments into its policy rate and, indeed, there is some anecdotal evidence of such behavior in some non-IT emerging market central banks. We are indebted to Doug Laxton for bringing such behavior to our attention.

[6] The relatively high share of variability attributed to the first factor in some countries may be related to the presence of a trend in the data even after detrending (Egypt, Indonesia, and Morocco). The high explanatory power of the level factor in the case of Georgia might be partly caused by a very short series.

Figure 3: Average Term Premiums: Countries Grouped by Their Monetary Policy Regimes



Note: Premiums at 3-month, 1-year, and 10-year maturities: yield minus detrended policy rate ($\lambda = 14,400$). The policy rate is the central bank rate in ACs and the shortest maturity, typically overnight, interbank rate in the rest of the sample. The groups are: Advanced IT – Czech Republic, Israel, and Sweden; EMC and LIC IT – Georgia, Ghana, Indonesia, South Africa, and Turkey; Monetary Targeting – Kenya, Morocco, Nigeria, Rwanda, Tanzania, and Uganda; and Multiple Objectives – Egypt and Malaysia.
Source: Authors' calculations.

Table 3: Factor Comparison Between the LS and DL Methodologies

	First	Second	Third
CZE	0.5	1.0	0.0
EGY	0.9	1.0	0.7
GEO	1.0	0.6	0.6
GHA	0.6	0.8	0.8
IDN	1.0	0.9	0.7
ISR	0.4	0.7	−0.2
KEN	0.9	1.0	0.0
MAR	0.9	1.0	0.9
MYS	0.6	0.8	0.4
NGA	0.9	0.5	0.6
RWA	0.5	0.9	0.6
SWE	0.3	1.0	0.6
TUR	0.8	0.5	0.2
TZA	0.7	1.0	0.6
UGA	0.6	0.9	0.5
ZAF	0.9	0.7	0.3

Note: Sample correlation coefficients of the latent factors: the first, second, and third factors are labeled as the level, slope, and curvature. Statistically significant coefficients – at the 95 percent confidence level – are highlighted in gray. A correlation coefficient larger than 0.4 is considered to indicate strong correlation Doucouliagos (2011).
Source: Authors' calculations.

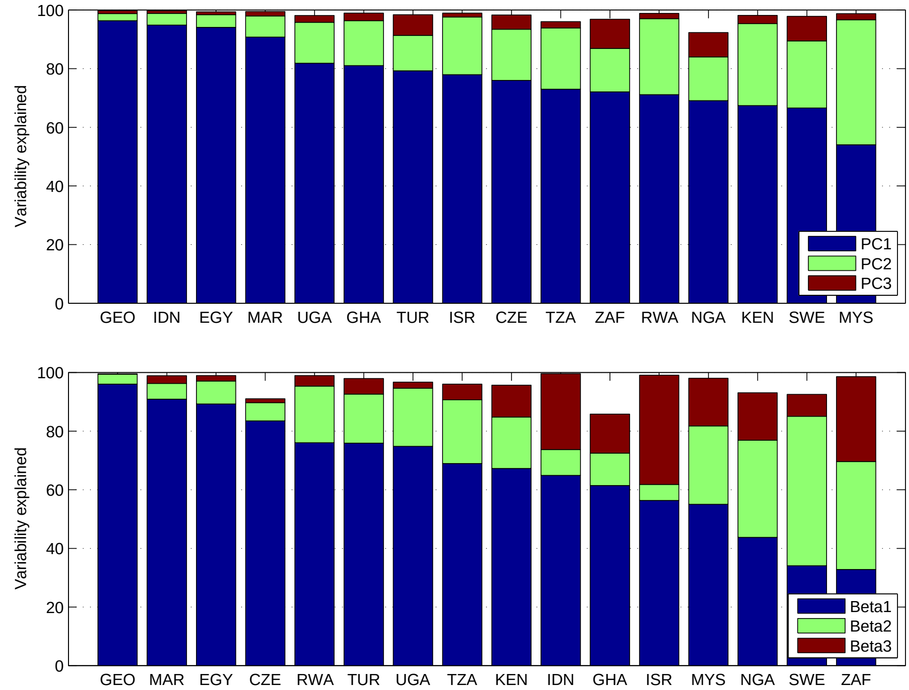
behaved in both developed and low-income countries and (ii) difficult to differentiate between the ACs and the EMCs and LICs, that is, regime invariant. In other words, our sample countries behave very much in line with the theory of the term structure of interest rates, with relatively small shocks to the term structure (see Appendix A for Monte Carlo simulations).

We find two major differences between the advanced IT countries and the rest of the sample. First, the contribution of the level factor declines at the 5-year and 10-year maturity in all three advanced countries, that is, the common innovations do not transmit to the longest maturities (see the full dark blue line in Figure 5). This finding indicates that the long maturities in AC inflation targeters are anchored by a credible inflation target and do not need to react to policy shocks.[7] Central banks in the rest of the sample lack such a credible anchor and the contribution of the level factor remains high at longer maturities. In other words, while in the ACs the yield curves move vertically and become flatter (pivot) at longer maturities after a policy shock, in the rest of the sample we observe mostly a vertical shift.

Second, the contribution of the level factor is small at short tenors in the sample of monetary targeters and countries following multiple objectives – the 3-month, 6-month, and 12-month interbank rates do not move with the rest of the yield curve (see the light blue line with triangle markers in Figure 5). Our interpretation is that the central banks in these countries do not have complete control over the short end of the yield curve and the level factor thus explains relatively little of the variability of short tenors. The lack of control can be attributed, first, to monetary targets that determine

[7] Advanced-country central banks regularly analyze the credibility of their inflation targets against financial market expectations of inflation. For analyses at the Czech National Bank and the Riksbank, respectively, see: `https://www.cnb.cz/miranda2/export/sites/www.cnb.cz/en/financial_markets/inflation_expectations_ft/inflation_expectations_ft_2015/A_inflocek_12_2015.pdf`; `http://www.prospera.se/media/1195/tns-sifo-prospera-inflation-expectations-tables-january-2016.pdf`.

Figure 4: Interest Rate Variability Explained by Three Factors Using the LS and DL Methodologies



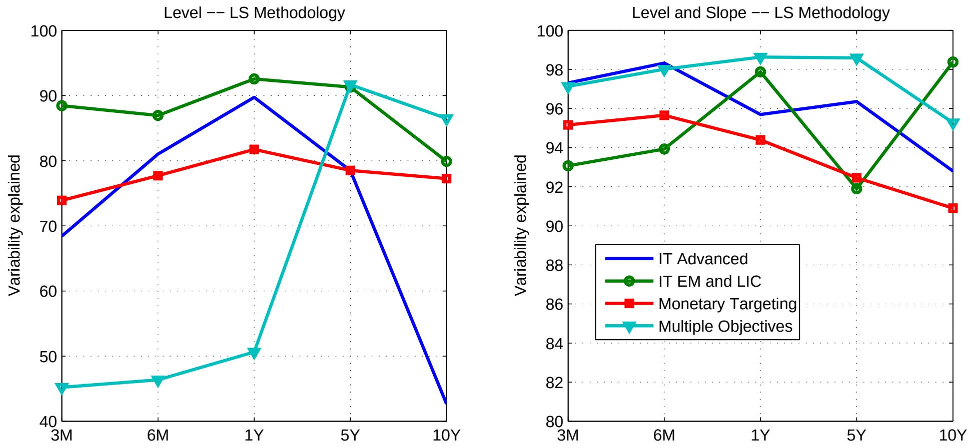
Note: The height of each bar in the upper chart indicates the proportion in percent of the total variance of the yields explained by the first, second, and third PCs (LS). The height of each bar in the bottom chart indicates the proportion of the total variance of the sample country interest rates explained by the estimates of the βs (DL). For example, the proportion of the variance explained by each PC (LS) for Uganda (UGA) is 81.8 percent, 14.0 percent, and 2.3 percent, respectively, cumulatively explaining 98.1 percent of the variance in Ugandan yields. The contribution of the βs are proxied by the relative contribution of their shocks to the variance of the observed yields.
Source: Authors' calculations.

the short-term rates residually and, second, to the earlier discussed unwillingness of some central banks to synchronize their policy rates with rates at which liquidity operations are executed.

Grouping countries into AC, EM, and LI suggests only small differences in explained variability (Figure 6). The first two factors explain on average 96 percent of the yield variance in ACs and EMCs, declining to 92 percent in LICs. Breaking the sample down by maturity points again to a credibility issue in EMCs and LICs, as long-term yields do not appear to be anchored by the inflation targets. We take these results as suggesting that advanced IT countries benefit from well-anchored long-term yields.

The summary differences in explained variability in countries with and without secondary markets are fairly small and fail to make a case for developing formal secondary financial markets in order to obtain a meaningful yield curve. We see several explanations for the yield correlations. The absence of secondary markets may limit instrument liquidity and agents' ability to hedge against future price movements. For example, if an agent desires an illiquid bond with 10-month maturity, she will demand the closest asset alternatives with, say, 9-month or 11-month maturities, thus instantaneously affecting the yields on assets with similar maturities. In other words, the high asset price correla-

Figure 5: LS Variability Attributed to the Level and Slope: Countries Grouped by Monetary Policy Regimes



Note: The variability explained by the slope and level factors is expressed in percent across different maturities. A country is excluded from the computation if the specific maturity is not observed. The groups are: Advanced IT – Czech Republic, Israel, and Sweden; EMC and LIC IT – Georgia, Ghana, Indonesia, South Africa, and Turkey; Monetary Targeting – Kenya, Morocco, Nigeria, Rwanda, Tanzania, and Uganda; and Multiple Objectives – Egypt and Malaysia.
Source: Authors' calculations.

tion could be the result of a missing hedge in an incomplete, but essentially unregulated market. Needless to say, the absence of a *formal* secondary market does not prevent the agents from trading. Commercial banks do most of the trading in government paper on the primary market in EMCs and LICs, developing the yield curve. Moreover, the absence of a formal secondary market could be a mirage as these assets can be traded on over-the-counter (OTC) markets. For example, during the 1990s in the Czech Republic, trading on OTC markets supplanted the then nonexistent secondary financial markets. Then there is the impact of so-called liquidity ratios, requiring commercial banks and pension funds to hold domestic paper with short and long maturities, respectively. Such ratios may affect both primary and secondary markets, in a direction that is difficult to predict.

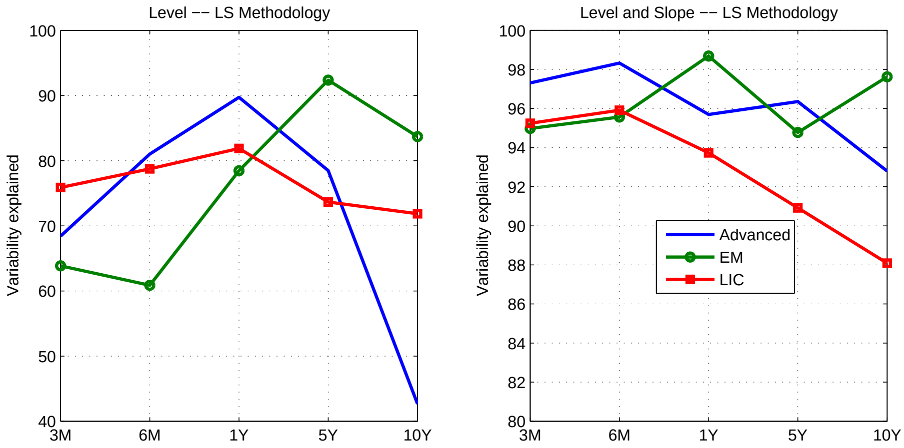
4.2 Short-term Rates and Factors

We proceed to explore how well policy rate hikes/cuts are reflected in longer-term rates by examining, first, the correlations between actual interest rates and the estimated latent factors and, second, the shape of the PCA loadings. While neither technique proves causality from policy to long-term rates, the alternative of the policy rate passively reflecting long-term bond rate movements is inconsistent with the forward-looking behavior of the sample central banks. Diebold et al. (2006) argued that these correlations are unlikely to be driven by a third variable. Our results strongly suggest that changes at the short end of the yield curve have a powerful impact on long-term yields.

First, we show how the monetary policy rates interact with the yield curves. All the correlations between the monetary policy rates and the shortest available maturity yield are positive (Table 4, first column). The correlations are particularly high among the IT countries.[8] Furthermore, monetary

[8] The low correlation coefficient in South Africa is driven by the fact that the shortest maturity available in our sample is 2 years.

Figure 6: LS Variability Attributed to the Level and Slope: Countries Grouped by the Level of Economic Development



Note: The variability explained by the slope and level factors is expressed in percent across different maturities. A country is excluded from the computation if the specific maturity is not observed. The groups are: AC – Czech Republic, Israel, and Sweden; EMC – Egypt, Georgia, Indonesia, Morocco, Malaysia, South Africa, and Turkey; and LIC – Ghana, Kenya, Nigeria, Rwanda, Tanzania, and Uganda.
Source: Authors' calculations.

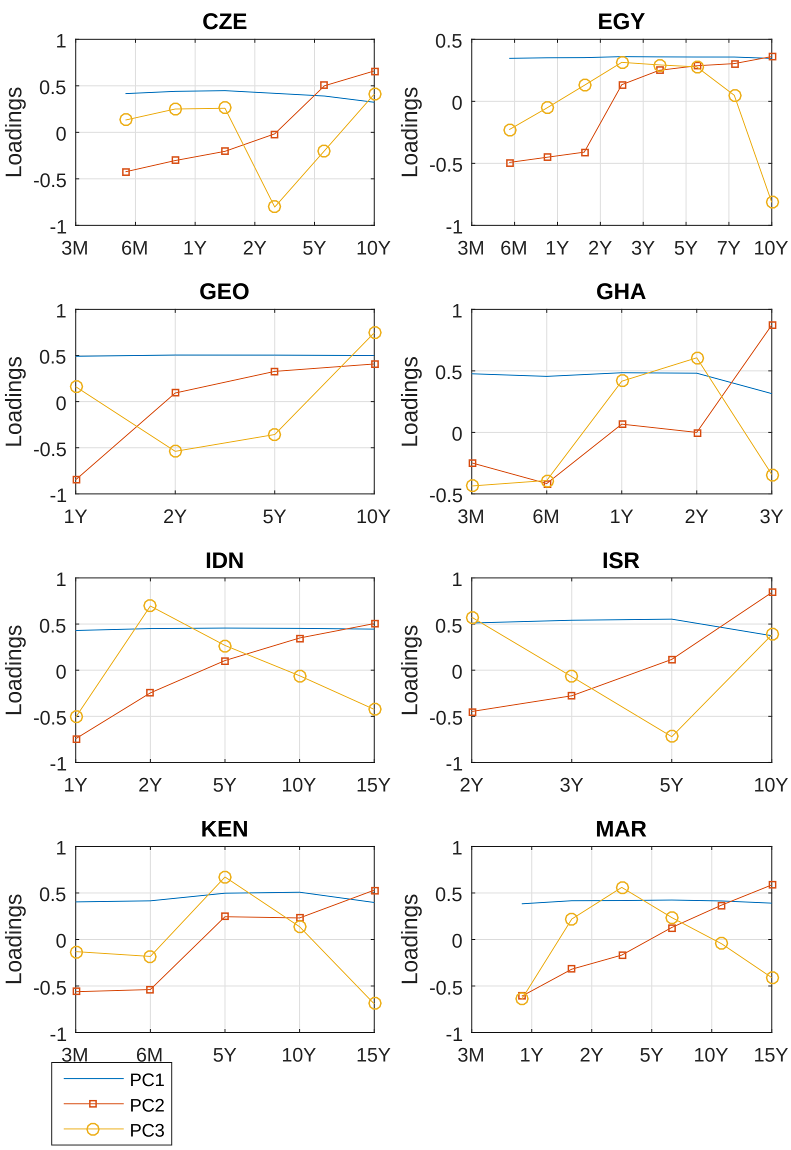
policy rates are positively correlated with the level factors identified using LS in most of the countries. However, for a few IT countries we found negative correlations using the DL methodology (Table 4, second column). We also find the expected negative correlation coefficients between the policy rates and the slope in all countries except Nigeria. Of course, not all the correlations between the policy rates and the later factors have to be statistically significant – in some countries policy moves are reflected mostly in vertical shifts of the yield curve, while in others the yield curve pivots (for example in multiple objective countries).

Second, we assess the loading factors. In all sample countries, the level loadings are essentially constant at about 0.4-0.6, suggesting that all observed maturities enter the first factor with similar weights (the full blue line labeled PC1 in Figures 7 and 8). The only exceptions are Rwanda, where the loadings level off at the 1-year maturity, and Malaysia, where the loading is close to zero for short maturities up to 2 years. The estimated second and third latent factors also have the expected properties (see the green and red lines, respectively). The loadings of the second principal component are either downward or upward sloping across maturities, proxying the slope of the yield curve, and the factor is correlated with the empirical measures of the slope.[9] The loadings for the third principal component approximate the convex/concave curvature of the yield curve.

Turning to individual countries, the first factor is positively correlated with both the empirical short-term and long-term yields in all 16 countries (Appendix B). As before, we find no material differences between the sample countries, for either short or long tenors, interpreting these findings as supporting our hypothesis that the interest rate transmission mechanism is present in all the sample countries.

[9] The empirical measures of the level, slope, and curvature are the yields on securities with the shortest and the longest maturity in the sample; the long-to-short difference between these maturity extremes; and double the yield on maturity in the middle of the extremes minus the sum of the yields on those extreme maturities, respectively.

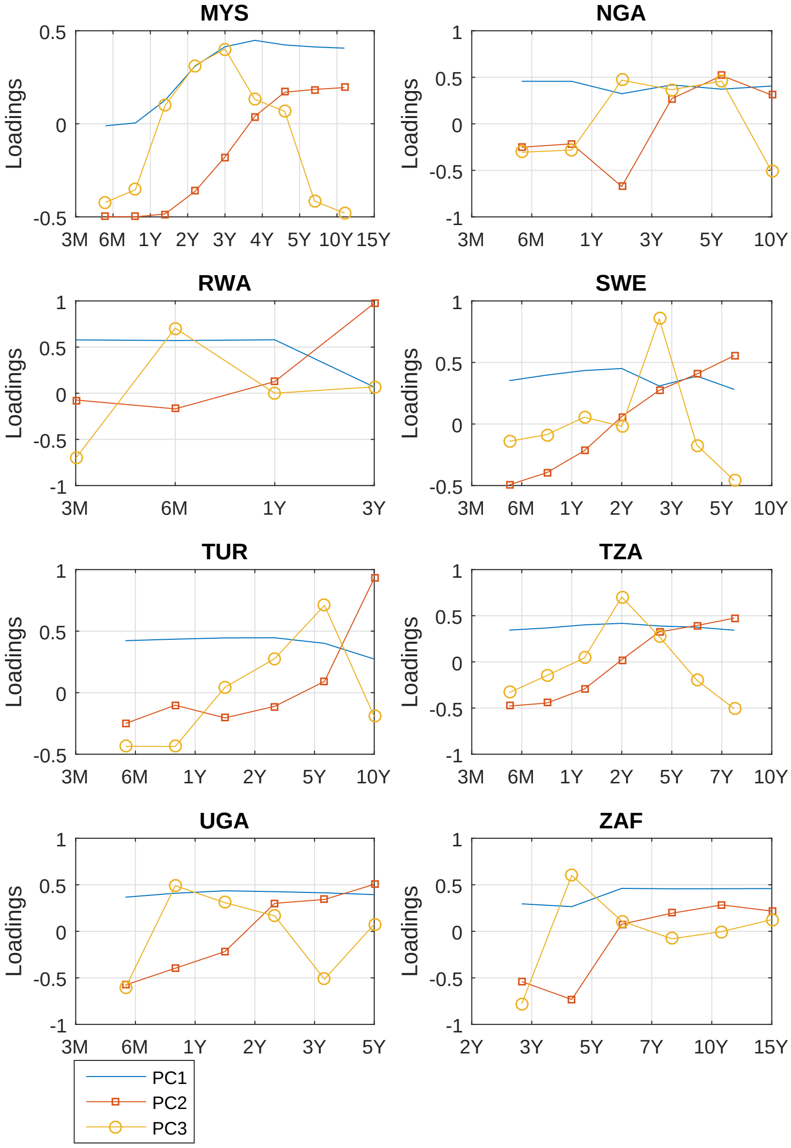
Figure 7: Principal Component Loadings



Note: The loadings for the first factor (level) are denoted by a solid blue line; the loadings for the second factor (slope) are denoted by green squares; and the loadings for the third factor (curvature) are denoted by red circles.

Source: Authors' calculations.

Figure 8: Principal Component Loadings



Note: The loadings for the first factor (level) are denoted by a solid blue line; the loadings for the second factor (slope) are denoted by green squares; and the loadings for the third factor (curvature) are denoted by red circles.

Source: Authors' calculations

.

Table 4: Correlations Between Monetary Policy Rates and Yields, and Factors

	Shortest Mat.		Level LS	Level DL		Slope LS	Slope DL
CZE	0.9	CZE	0.7	−0.0	CZE	−0.6	−0.6
EGY	0.5	EGY	0.3	0.2	EGY	−0.6	−0.6
GEO	0.3	GEO	0.5	0.6	GEO	0.4	0.7
GHA	0.8	GHA	0.8	0.2	GHA	−0.4	−0.6
IDN	0.8	IDN	0.7	0.6	IDN	−0.3	−0.5
ISR	0.7	ISR	0.5	−0.1	ISR	−0.5	−0.7
KEN	0.8	KEN	0.4	0.2	KEN	−0.7	−0.6
MAR	0.3	MAR	0.1	0.1	MAR	−0.2	−0.2
MYS	0.9	MYS	−0.2	−0.7	MYS	−0.9	−0.8
NGA	0.3	NGA	0.4	0.5	NGA	0.2	0.2
RWA	0.9	RWA	0.8	0.5	RWA	−0.1	−0.3
SWE	0.9	SWE	0.6	−0.3	SWE	−0.7	−0.8
TUR	0.4	TUR	0.4	0.1	TUR	−0.6	−0.4
TZA	0.4	TZA	0.3	−0.0	TZA	−0.4	−0.4
UGA	0.8	UGA	0.6	0.0	UGA	−0.6	−0.6
ZAF	0.2	ZAF	−0.0	−0.3	ZAF	−0.6	−0.6

Note: Sample correlation coefficients. Statistically significant coefficients – at the 95 percent confidence level – are highlighted in gray. The first block reports correlations between the monetary policy rate and the shortest maturity available. The “Level” block reports the correlations between the monetary policy rates and the level factor, using the LS and DL estimates of the factors, respectively. The “Slope” block reports the correlations between the monetary policy rates and the slope factor.
Source: Authors’ calculations.

Policy-induced interest rate movements are correlated with vertical shifts of the yield curve. However, such movements may also affect the slope of the yield curve. As expected, the first and second latent factors based on the DL methodology are positively correlated and most of these correlations are statistically significant (the LS-based latent factors are orthogonal by construction). In other words, monetary tightening/loosening pivots the yield curve in addition to shifting the level (see the first column in Table 5). As before, we fail to observe any systematic differences between the advanced and low-income countries. In contrast, the correlations between the first and third and between the second and third latent factors are small and change signs.

4.3 Policy Implications

Our sample findings have useful policy implications and we summarize them into five sets. First, we find strong co-movement between the policy rate and bond yields, suggesting well-behaved yield curves without arbitrage opportunities. Such a yield curve is a necessary, if not sufficient, condition for monetary transmission. Second, for countries that use their policy rate as a monetary policy instrument, we find a strong link between that rate and short-term interbank or treasury bill rates. Third, we find a number of intuitive results linked to the credibility of the policy regime and the level of development. Only in advanced countries – all practicing inflation forecast targeting – are inflation expectations anchored, and their long rates thus react less to the first (level) factor than in the other countries. Conversely, the level shift matters equally for all maturities in the EMC/LIC sample. Furthermore, monetary targeters and EMC/LIC inflation targeters have incomplete control over the short end of the yield curve and the level factor explains less of the variability of short tenors as compared to AC inflation targeters.

Table 5: Correlations Among the Latent Factors (DL)

	First&Second	First&Third	Second&Third
CZE	0.7	−0.2	−0.4
EGY	0.2	0.1	0.3
GEO	0.9	0.6	0.6
GHA	0.5	−0.5	−0.5
IDN	0.1	−0.2	0.0
ISR	0.4	−0.6	0.1
KEN	0.5	−0.2	−0.4
MAR	0.4	−0.0	−0.2
MYS	1.0	−0.6	−0.6
NGA	−0.1	0.2	0.5
RWA	0.6	−0.1	−0.2
SWE	0.8	−0.1	−0.2
TUR	0.6	−0.5	−0.3
TZA	0.7	0.1	−0.1
UGA	0.7	−0.1	−0.1
ZAF	0.5	0.2	0.8

Note: Pairwise correlation coefficients among the three latent factors (the level, slope, and curvature) obtained from the DL methodology. Statistically significant coefficients – at the 95 percent confidence level – are highlighted in gray.
Source: Authors' calculations.

Fourth, the transmission gains from deeper secondary markets in ACs appear to be surprisingly small. Deep secondary markets do not seem to be necessary for a well-behaved yield curve, either because the absence of a liquid market forces agents to buy assets of similar maturities or because commercial banks are the main buyers and sellers across all maturities on primary and OTC markets. Finally, the link between short rates and lending rates in EMCs and LICs remains a topic for future research, as series on meaningful loan rates are unavailable except for a few advanced countries. Such rates would allow the transmission mechanism to be extended to include the "lending nexus."

5. Conclusions

We find a well-behaved yield curve for bond yields in advanced, emerging, and low-income countries, indicating a working interest rate transmission channel in all of our sample countries. The three latent factors – the level, slope, and curvature – explain the bulk of interest rate movements, and the vertical shift dominates. The link from policy/interbank rates to bond yields appears to be robust across estimation techniques and largely unaffected by the monetary policy regime or the stage of economic development. We find no evidence that well-developed secondary markets supercharge the transmission mechanism. Furthermore, we find only weak evidence that the transmission mechanism operates more smoothly in more developed countries practicing inflation targeting than in less developed countries. These results are broadly invariant to the methodologies used and they are also remarkably consistent across the sample countries, despite short samples, gaps in longer maturities, monetary policy regimes, and so on.

The findings of this paper have a strong policy implication – the presence of the first leg of the monetary transmission is broadly independent of the level of financial sophistication. To the extent that advanced inflation targeting countries appear to have marginally better-behaved yield curves than countries that follow other objectives, the functioning of the transmission mechanism seems partly a matter of domestic choice and credibility thereof. These results are relevant, as the sample central banks continue to gauge their ability to steer the economy with indirect instruments. The overall message is clear – central bank actions do matter even in low income countries.

References

ABBRITTI, M., S. DELL'ERBA, A. MORENO, AND S. SOLA (2013): "Global Factors in the Term Structure of Interest Rates." IMF Working Papers 13/223, International Monetary Fund.

ABDI, H. AND L. J. WILLIAMS (2010): "Principal Component Analysis." *Wiley Interdisciplinary Reviews: Computational Statistics,* Vol. 2:433–459.

ADRIAN, T., R. K. CRUMP, AND E. MOENCH (2013): "Pricing the Term Structure with Linear Regressions." *Journal of Financial Economics,* Vol. 110(1):110–138.

AGUIAR-CONRARIA, L., M. M. F. MARTINS, AND M. J. SOARES (2012): "The Yield Curve and the Macro-economy Across Time and Frequencies." *Journal of Economic Dynamics and Control,* 36(12):1950–1970.

BERG, A., P. D. KARAM, AND D. LAXTON (2006): "A Practical Model-Based Approach to Monetary Policy Analysis-Overview." IMF Working Papers 06/80, International Monetary Fund.

BERG, A., L. CHARRY, R. A. PORTILLO, AND J. VLCEK (2013): "The Monetary Transmission Mechanism in the Tropics; A Narrative Approach." IMF Working Papers 13/197, International Monetary Fund.

CHRISTIANO, L. J., M. EICHENBAUMAND, AND C. L. EVANS (1999): *Monetary Policy Shocks: What Have We Learned and to What End.In Handbook of Macroeconomics Vol. 1A.*, North Holland edition.

CORTÉS, E., J. FERNANDO, C. CAPISTRÁN, M. RAMOS-FRANCIA, AND A. T. GARCÍA (2009): "An Empirical Analysis of the Mexican Term Structure of Interest Rates." *Economics Bulletin,* 29(3):2310–2323.

DAVOODI, H. R., S. V. S. DIXIT, AND G. PINTER (2013): "Monetary Transmission Mechanism in the East African Community." IMF Working Papers 13/39, International Monetary Fund.

DIEBOLD, F., G. D. RUDEBUSCH, AND S. B. ARUOBA (2006): "The Macroeconomy and the Yield Curve: A Dynamic Latent Factor Approach." *Journal of Econometrics,* 131(1-2): 309–338.

DIEBOLD, F. X. AND C. LI (2006): "Forecasting the Term Structure of Government Bond Yields." *Journal of Econometrics,* 130(2):337–364.

DOUCOULIAGOS, H. (2011): "How Large is Large? Preliminary and Relative Guidelines for Interpreting Partial Correlations in Economics." Deakin University Working Paper 2011/5, Deaking University.

FORZANI, L. AND C. TOLMASKY (2003): "A Family of Models Explaining the Level-Slope-Curvature Effct." *International Journal of Theoretical and Applied Finance,* 6(3):239–255.

HICKS, J. (1937): "Mr. Keynes and the 'Classics'; A Suggested Interpretation." *Econometrica,* 5: 147–159.

IMF (2012): *Annual Report on Exchange Arrangements and Exchange Restrictions.* International Monetary Fund.

IMF (2015): *Evolving Monetary Policy Frameworks in Low-Income and Other Developing Countries.* International Monetary Fund.

KIM, D. H. AND A. ORPHANIDES (2007): "The Bond Market Term Premium: What Is It, and How Can We Measure It?" *BIS Quarterly Review,* 27–40.

LITTERMAN, R. AND J. SCHEINKMAN (1991): "Common Factors Affecting Bond Returns." *Journal of Fixed Income,* 1:54 – 61.

MISHKIN, F. S. (1995): "Symposium on the Monetary Transmission Mechanism." *The Journal of Economic Perspectives,* 9(4):3–10.

MISHRA, P., P. J. MONTIEL, AND A. SPILIMBERGO (2012): "Monetary Transmission in Low-Income Countries: Effectiveness and Policy Implications." *IMF Economic Review,* 60(2): 270–302.

ROGER, L. AND A. PELSSER (2007): "Level-Slope-Curvature - Fact or Artefact?" *Applied Mathematical Finance,* 14:105–130.

ROMER, C. D. AND D. H. ROMER (1994): "Monetary Policy Matters." *Journal of Monetary Economics,* 34(1):75–88.

SVENSSON, L. E. (1997): "Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets." *European Economic Review,* 41:1111–1146.

Appendix A: A Primer on Yield Curve Methodologies

The paper replicates the LS principal component analysis and DL methodologies to capture the dynamics of the sample-country yield curves. Both approaches characterize the movements of the yield curves by identifying three latent factors labeled as the level, slope, and curvature. We briefly describe both methodologies and list the relevant references.

Principal Component Analysis

Principal component analysis (PCA) is a well established method for reducing data dimensionality. It transforms multiple observed series into a set of uncorrelated principal components. As the interest rate series are correlated, one should be able to capture their variability with fewer principal components than the count of the observed series.

Let us assume that the data are collected in an $X(m \times n)$ matrix, where the n columns are the observations and the m rows are the variables (yields). PCA finds a transformation matrix $W(m \times m)$ such that it projects X into principal components $P^C(m \times n)$:

$$P^C = WX, \tag{A1}$$

choosing W such that the rows of P^C are uncorrelated with each other and hold the same information as the original matrix X. The rows of P^C are ordered in descending order of importance, as there are a total of m principal components. It can be shown that in order to fulfill the objectives above, the rows of W are the eigenvectors of the covariance matrix, XX^T, and W is called the matrix of factor loadings.

We follow Litterman and Scheinkman (1991), who applied PCA to observed yields. The data are normalized by dividing each maturity yield by its sample standard deviation, interpolating missing data with the Hodrick-Prescott filter. The principal components are ordered in descending order by the total variance explained, and the first, second, and third principal components are labeled as the level, slope and curvature factors of the yield curve. Roger and Pelsser (2007) derive sufficient conditions for a correlation matrix under which the level, slope, and curvature are jointly present.

The Diebold and Li Framework

Diebold and Li (2006) suggested a modification to the Nelson and Siegel exponential component framework to fit yield curves. The DL framework uses three time-varying parameters, which can be also interpreted as the level, slope, and curvature. These unobserved parameters are identified based on the data and mean square error optimization, after imposing simple structural restrictions. The state-space representation along with Kalman filtration allows for missing observations.

In our version the yield curve follows:

$$y_t(\tau) = \beta_{1t} + \beta_{2t}\left(\frac{1-\exp^{-\lambda\tau}}{\lambda\tau}\right) + \beta_{3t}\left(\frac{1-\exp^{-\lambda\tau}}{\lambda\tau} - \exp^{-\lambda_t\tau}\right), \tag{A2}$$

where $y_t(\tau)$ is the yield at time t of a bond with maturity τ. β_{1t}, β_{2t}, and β_{3t} are the time-varying parameters (or factors) and λ are country-specific parameters driving the exponential decay rate. Following Diebold and Li (2006), we set λ based on countries' average maturity of government paper.

DL show that the parameter β_1 can be interpreted as a level shift, as it increases all maturity yields equally. The parameter β_2 is closely related to the slope of the yield curve. The loading on this parameter, $\frac{1-\exp^{-\lambda\tau}}{\lambda\tau}$, is between 0 and 1. The parameter β_3 describes the curvature: its loading, $\frac{1-\exp^{-\lambda\tau}}{\lambda\tau} - \exp^{-\lambda_t\tau}$, starts at 0, increases up to a certain maturity, and gradually decays afterward.

In order to identify unobserved time-varying parameters, we transformed the model to a state-space form following Diebold et al. (2006). The transition equations driving the dynamics of yields are:

$$\begin{bmatrix} y_t(\tau_1) \\ y_t(\tau_2) \\ \vdots \\ y_t(\tau_N) \end{bmatrix} = \begin{bmatrix} 1 & \frac{1-\exp^{-\lambda\tau_1}}{\lambda\tau_1} & \frac{1-\exp^{-\lambda\tau_1}}{\lambda\tau_1} - \exp^{-\lambda\tau_1} \\ 1 & \frac{1-\exp^{-\lambda\tau_2}}{\lambda\tau_2} & \frac{1-\exp^{-\lambda\tau_2}}{\lambda\tau_2} - \exp^{-\lambda\tau_2} \\ \vdots & \vdots & \vdots \\ 1 & \frac{1-\exp^{-\lambda\tau_N}}{\lambda\tau_N} & \frac{1-\exp^{-\lambda\tau_N}}{\lambda\tau_N} - \exp^{-\lambda\tau_N} \end{bmatrix} \begin{bmatrix} \beta_{1t} \\ \beta_{2t} \\ \beta_{3t} \end{bmatrix} + \begin{bmatrix} \varepsilon_t(\tau_1) \\ \varepsilon_t(\tau_2) \\ \vdots \\ \varepsilon_t(\tau_N) \end{bmatrix}. \tag{A3}$$

The factors, β_i, are assumed to be random-walk processes:

$$\begin{bmatrix} \beta_{1t} \\ \beta_{2t} \\ \beta_{3t} \end{bmatrix} = \begin{bmatrix} \beta_{1t-1} \\ \beta_{2t-1} \\ \beta_{3t-1} \end{bmatrix} + \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ \eta_{3t} \end{bmatrix}, \tag{A4}$$

where ε and η are white noise shocks with zero means and covariance matrices Q and H:

$$\begin{pmatrix} \varepsilon_t \\ \eta_t \end{pmatrix} \sim WN\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} Q & 0 \\ 0 & H \end{pmatrix}\right]$$

The measurement equations then link the observed yields with state variables assuming no measurement errors:

$$\begin{bmatrix} y_t(\tau_1) \\ y_t(\tau_2) \\ \vdots \\ y_t(\tau_N) \end{bmatrix} = \begin{bmatrix} y_t^{obs}(\tau_1) \\ y_t^{obs}(\tau_2) \\ \vdots \\ y_t^{obs}(\tau_N) \end{bmatrix}. \tag{A5}$$

We match the state-space model with the data using the Kalman filter. For each country we estimate matrices Q and H using Bayesian estimation techniques with inverse gamma distribution of priors.

We simplify the original DL framework in three respects, without losing any of its structural advantages. First, we reduce the number of estimated parameters by filtering the noise in the data via the error terms, ε, rather than by treating measurement errors explicitly. Second, we impose random walk processes for the latent factors. Third, we do not allow for cross-factor dynamics and correlations. The last two simplifications follow Diebold et al. (2006), who found the factors to be highly persistent with insignificant cross-factor dynamics.

Assessing Yield Curves Using the LS and DL Methodologies

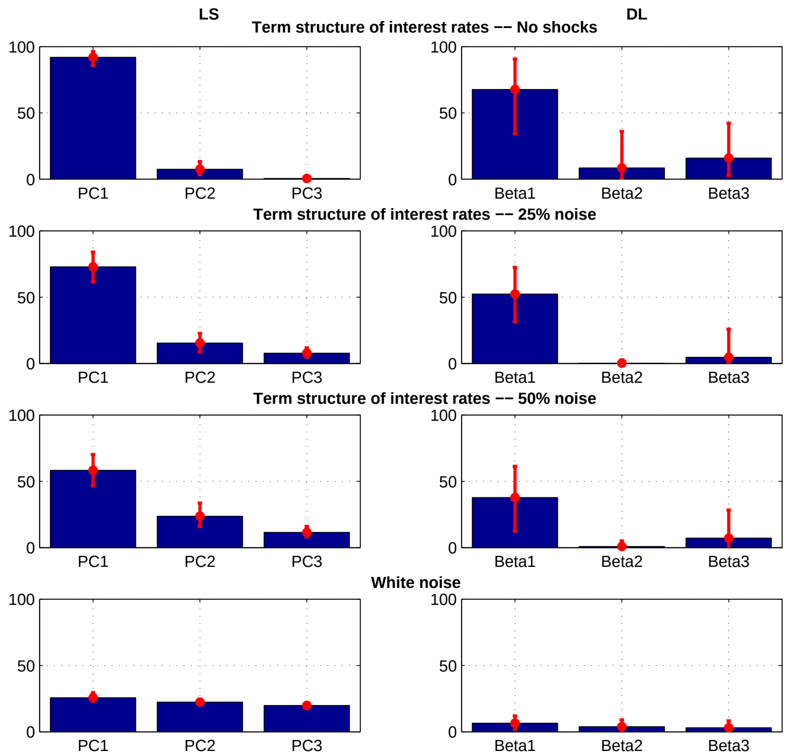
The LS and DL methodologies are commonly used to fit yield curves and we argue that they can be used to assess the transmission of short-term to long-term rates along the yield curves. In general, we consider a yield curve to be "well behaved" if short-term interest rates transmit to long tenors in line with the expectation theory of the term structure, which implies that a long-term yield adjusted for a term premium has to be equal to expected short-term yields compounded to the same maturity.

The LS and DL methodologies by construction do not ensure arbitrage-free conditions and the expectation term structure of interest rates. Hence, it might not be clear how the term structure of interest rates would be reflected in latent factors and their structure. However, as the term structure of interest rates determines the correlation of yields, the latent factors' effects are derived from the covariance matrices. In order to demonstrate how the LS and DL methodologies can be used for assessing yield curves, we generated artificial yield curve data using Monte Carlo simulations of the term structure of interest rates in a structural macroeconomic model. The data were generated by a workhorse gap model similar to Berg et al. (2006) augmented with the expectation theory of interest rates.[10] Using the model, we generated yield samples and conducted our analysis. First, we generated artificial yields by assuming a common set of business cycle shocks (short-term demand, supply, exchange rate, and policy shocks; long-term inflation target and country risk premium shocks) without any shocks to the term structure of interest rates. Second, we did the same exercise with the term structure shocks explaining about 25 percent and 50 percent of the yield variability. Finally, we generate yields as white noise.

The results suggest that the interest rate variability in our Monte Carlo simulations – for a plausible setup of term structure shocks being equivalent to 25 to 50 percent of the yield variability – is mostly explained by the first factor, much as in the actual sample (Figure A1).[11] As expected, the contribution of the first factor declines with the magnitude of the term structure shocks. The first two factors explain more than 90 percent of the observed interest rate variability in the case of the pure term structure (both LS and DL) and in the case of a 25-50 percent noise contribution in addition to the term structure (LS) – see the top three left-hand-side charts. The explained share, especially for the first factor, is somewhat lower for the DL methodology. In the extreme case of white noise data, the variability explained by any factor is very low (bottom row). Based on these results, we conclude that well-behaved yield curves, following the term structure of interest rates, are mirrored in the LS and DL methodologies: first, level is the leading factor as measured by its explanatory power and, second, level and slope together explain most of the variability in the data.

[10] We used a generic calibration for a small open economy with a floating currency and an explicit inflation target. The yield curve simulations are robust to parameter changes.
[11] Abbritti et al. (2013) decomposed yield curve variability in a FAVAR framework and their results make us believe that the above contribution to the yield variability is a good rule of thumb for small open economies.

Figure A1: Variability Explained Using LS and DL Methodologies (Monte Carlo Simulations)



Note: The LS and DL methodologies, shown in the left and right columns, respectively, are applied to artificial data generated by a structural model of the business cycle augmented with the term structure of interest rates using a 1,000-draw sample. In the first row we show results for the model with a standard set of business cycle shocks without any white noise shocks to the term structure of interest rates. In the second and third rows we add term structure shocks, calibrating their standard deviations to be equivalent to about 25 percent and 50 percent of the yield variability, respectively. In the final row we generate an artificial sample of white noise yields. The variability explained by each factor is reported on the horizontal axis in percent, with the red line indicating the 95 percent confidence

Source: Authors' calculations.

Appendix B: Series Properties and Robustness Checks

ADF Tests

Most countries in our sample contain a trend in inflation, typically as a result of past disinflation and, hence, we also find a trend in the central bank rate series. Therefore, the data have to be detrended, otherwise the presence of a unit root would imply unrealistically high correlation of yields and, as a result, the LS approach would grossly overestimate the contribution of the first factor.

We detrend the data using the trend in the domestic monetary policy rate (either the central bank rate or the interbank rate), in effect re-defining all series as term premiums. The trend in the monetary policy rate is identified using the HP filter. Augmented Dickey-Fuller tests show that we can reject the null hypothesis of stationary series for most but not all of the detrended yields (Table B1).

Table B1: Augmented Dickey-Fuller Tests for Detrended Series

	3M	6M	1Y	2Y	3Y	4Y	5Y	7Y	10Y	15Y
CZE	**	**	**	***			***		**	
EGY	*	*	*	N.Rej.	N.Rej.		N.Rej.	N.Rej.	N.Rej.	
GEO			***	**			**		N.Rej.	
GHA	**	**	**	**	*					
IDN			***	***			***		***	**
ISR				***	***		**		N.Rej.	
KEN	***	***					**		***	***
MAR	*		N.Rej.	N.Rej.			N.Rej.		N.Rej.	N.Rej.
MYS	***	***	***	***	***	**	**		**	**
NGA	**	**	*		**		**		**	
RWA	***	***	**		***					
SWE	***	***	***	***	***		***		***	
TUR	**	**	**	**			**		N.Rej.	
TZA	***	***	***	**			N.Rej.	N.Rej.	N.Rej.	
UGA	***	**	**	*	**		**			
ZAF				***	***		*	*	N.Rej.	*

Note: Rows denote countries and columns maturities. Three, two, and one star mean stationarity can be rejected at the 99 percent, 95 percent, and 90 percent confidence level, respectively. "N.Rej." means that the null hypothesis of a unit root cannot be rejected. Empty spaces indicate that the maturity is not available for this country.
Source: Authors' calculations.

Latent Factor Correlations

The LS and DL factor estimates are highly correlated in most sample countries despite different identification techniques. The first factor estimates are strongly correlated in all countries, except in Rwanda. The same holds for the second factor, except for Israel, Nigeria, South Africa, and Turkey. The evidence is mixed for the third factor: the correlations are high mostly in low-income countries which exhibit unit roots even after detrending (Egypt, Morocco, and Malaysia).

Factors and Their Empirical Counterparts

In order to check the robustness of the latent factors, we compared them with the commonly used empirical measures of level, slope, and curvature. The first factor is positively correlated with both

Table B2: Factor Correlations with Empirical Yields

	Shortest Maturity		Longest Maturity		Slope (Long−Short Maturities)	
	LS	DL	LS	DL	LS	DL
CZE	0.9	0.2	0.7	0.9	0.1	0.7
EGY	1.0	0.9	1.0	1.0	0.4	0.1
GEO	1.0	0.9	1.0	1.0	0.2	0.9
GHA	1.0	0.5	0.6	0.7	−0.6	0.2
IDN	0.9	0.8	1.0	1.0	−0.2	0.2
ISR	0.9	0.0	0.7	0.9	−0.2	0.9
KEN	0.7	0.5	0.9	1.0	−0.0	0.6
MAR	0.9	0.7	0.9	1.0	0.7	0.3
MYS	−0.0	−0.8	0.9	0.6	0.7	0.9
NGA	0.9	0.7	1.0	1.0	−0.8	0.1
RWA	1.0	0.5	0.6	1.0	−0.5	1.0
SWE	0.8	−0.2	0.6	0.9	−0.1	0.8
TUR	0.9	0.6	0.9	1.0	−0.4	0.6
TZA	0.8	0.2	0.8	1.0	−0.0	0.6
UGA	0.8	0.3	0.8	0.9	−0.4	0.5
ZAF	0.7	0.4	1.0	1.0	0.7	0.6

Note: Sample correlation coefficients of the first two latent factors with the empirical measures of the level and slope. The first two columns contain the correlations between the level factor and the empirical yields, both short-term and long-term, while the third column contains the correlations between the slope factor and the empirical slope measure.
Source: Authors' calculations.

the short and long-term yields in all 16 countries, suggesting that the first factor is a good proxy for the level shift and that it affects all maturities along the yield curve (Table B2).

Appendix C: Central Bank and Interbank Rates

All the sample countries have interbank money markets and most also have a policy interest rate. However, the latter instrument is used differently across the sample (Table C1). All advanced and some emerging market countries use the policy rate as a target rate for liquidity operations. As a result, these countries exhibit very high correlation between policy and interbank interest rates (see Table C1). For example, in the Czech Republic the one-day interbank rate has on average been only 14 basis points higher than the policy rate of the Czech National Bank (the two-week repo rate). Only at the height of the 2008 financial crisis did the spread temporarily widen to 100 basis points.

In contrast, most LICs periodically provided liquidity at rates very different from their policy rates. For example, in Ghana the policy rate and the main liquidity instrument, approximated by the 30-day Bank of Ghana bill, were periodically far apart: between mid-2005 and end-2007 liquidity was made available to commercial banks 270 basis points *below* the policy rate on average, while during 2013 it was made available some 600 basis points *above* the policy rate. As the effective liquidity rate differed from the policy rate in these countries, the correlation between policy and interbank rates was low.

Table C1: Central Bank and Interbank Rates

Country	Policy rate and liquidity operations	Root mean square difference (basis points)	Range
Czech Republic (CZE)	Liquidity operations conducted at central bank rate (**2W repo rate**). Interbank rate (**1D PRIBOR**) close to central bank rate.	14	2002M1–2015M1
Egypt, Arab. Rep. (EGY)	Corridor between overnight deposit and lending facility since June 2005 and **repo rate** at center of corridor since March 2013. However, **overnight interbank rate** close to overnight deposit rate.	33	2005M6–2014M11
Georgia (GEO)	**Refinancing rate** introduced as central bank rate in 2008. **Overnight interbank rate** close to refinancing rate since second half of 2010.	134	2008M2–2014M12
Ghana (GHA)	Liquidity operations and **central bank rate** periodically disconnected. As a result, **interbank rate** differed from central bank rate.	266	2004M2–2014M9
Indonesia (IDN)	**Interbank JIBOR rate** deviates from central bank rate – **interbank rate**.	183	2005M7–2015M1
Israel (ISR)	**Bank of Israel interest rate** is used for liquidity operations and is closely followed by **interbank rate**.	20	2001M1–2014M12
Kenya (KEN)	Central bank rate was used as from July 2006, but remained disconnected from liquidity operations. As a result, **interbank rate** deviates significantly from **central bank rate**.	401	2006M7–2015M1
Morocco (MAR)	**Interbank rate** deviates occasionally from **central bank rate**.	47	2002M1–2015M1
Malaysia (MYS)	**Interbank rate** managed closed to **overnight policy rate**.	20	2004M4–2014M1
Nigeria (NGA)	**Interbank rate** deviates substantially from **central bank rate**.	323	2006M12–2014M10
Rwanda (RWA)	**Repo rate** and **interbank rate** differ.	164	2008M1–2014M10
South Africa (ZAF)	**Repo rate** is central bank rate and it is closely followed by **interbank rate**.	104	1997M1–2014M5
Sweden (SWE)	**Repo rate** is central bank rate and is closely followed by **interbank rate**.	12	1998M6–2015M1
Turkey (TUR)	**Interbank rate** stays close to the overnight deposit rate and is disconnected from **repo rate**.	213	2010M5–2014M11
Tanzania (TZA)	No official central bank rate. **Overnight interbank rate** frequently out of sync with **repo rate**.	385	2002M4–2014M9
Uganda (UGA)	**Central bank rate** used since July 2011. Liquidity operations are conducted at **7D interbank rate** close to central bank rate.	161	2011M7–2014M12

Source: Central banks' web pages and reports and authors' computations.

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