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DOES THE EXPECTATIONS HYPOTHESIS OF THE TERM STRUCTURE HOLD IN KOREA AFTER THE ASIAN FINANCIAL CRISIS? SOME EMPIRICAL EVIDENCE (1999-2017)

ABSTRACT

This paper explores the validity of the Expectations Hypothesis of the Term Structure (EHTS) in Korea after the 1997-1998 Asian financial crisis. In line with the EHTS, one common stochastic trend is found in the term structure of interest rates, although the validity of the "symmetry" restriction is rejected. Moreover, significant liquidity *premia* and a causal relationship from long to short-term interest rates are documented. The main policy implications are that monetary policy should be implemented in a gradual manner, and putting greater emphasis on the expectations channel through which agents anticipate its future path.

Keywords: Term Structure of Interest Rates, Expectations Hypothesis, Asian Emerging Markets, South Korea, Cointegration, Monetary Policy
JEL Classification: C1, E43, E52

RIASSUNTO

La validità della "Expectations Hypothesis" sulla struttura a termine dei tassi di interesse in Corea dopo la crisi finanziaria asiatica. Alcune evidenze empiriche (1999-2017)

L'articolo analizza la validità della "Expectations Hypothesis" sulla struttura a termine dei tassi di interesse in Corea dopo la crisi finanziaria asiatica del 1997-1998. In linea con la "Expectations Hypothesis", l'analisi empirica documenta l'esistenza di un trend stocastico comune nella struttura a termine dei tassi di interesse, anche se la restrizione di "simmetria" viene respinta. Inoltre, si riscontrano significative componenti di premio per la liquidità ed una relazione di causalità dai tassi di interesse a lungo termine ai tassi di interesse a breve termine. Le più rilevanti implicazioni di politica economica sono che la politica monetaria dovrebbe essere

implementata in modo graduale, e ponendo una maggiore enfasi sul canale delle aspettative attraverso il quale gli agenti economici cercano di prevederne l'evoluzione futura.

1. Introduction

According to the Expectations Hypothesis of the Term Structure (EHTS), the return on a long-term financial asset is an average of current and expected short-term returns on this asset across the time to maturity. The arbitrage condition underlying this equilibrium relationship assumes perfect assets homogeneity (except in the term to maturity), rational expectations, and the absence of relevant transaction costs or taxes.

The earlier formulation of this theoretical framework, known as the "Pure Expectations" theory, relied on risk neutrality and emphasized the exclusive role of short-term expectations in driving long-term interest rates (see, e.g. Fisher, 1930). Subsequent extensions highlighted further important factors influencing long-term interest rates dynamics. The "Liquidity Premium" theory assumes the existence of risk-averse investors, thus positing that agents require an additional term premium component to compensate for the greater risk associated with investments in long-term financial instruments. This risk premium component is assumed to be constant, although increasing in the time to maturity. Complementary theoretical approaches emphasize either the role of supply and demand forces in determining yields at different maturities (i.e. the "Segmented Markets" theory, see Culbertson, 1957), or take a more eclectic view incorporating in a unified framework all factors emphasized in previous theories (i.e. the "Preferred Habitat" theory, see Modigliani and Sutch, 1966).

The EHTS has far-reaching implications, involving both finance and economics (see Gürkaynak and Wright, 2012 for a comprehensive discussion).

At the macroeconomic level, one important implication is related to the transmission mechanism of monetary policy. The modern approach to monetary policy assumes that the Central Bank controls a short-term policy rate and that monetary impulses are transmitted to the real sector through the yield curve (see, e.g. Clarida *et al.*, 1999). Assessing the empirical support for the EHTS and the causal relationships between interest rates at various maturities is therefore of great importance in this regard.

Focusing on emerging markets, applied research received a major impetus in recent years, mainly as a consequence of financial markets liberalizations occurred during the last two decades. A quite common result in this literature is that, notwithstanding the existence of an equilibrium relationship, the "Pure Expectations" theory is rejected (see, among others, Tabak, 2009 for Brazil; Buigut and Rao, 2010 for Hong Kong; Tronzano, 2015a, 2015b for India).
This paper contributes to the applied literature on the EHTS in Asian economies focusing on South Korea's experience during the last two decades. This country represents an interesting case study for various reasons.

First, South Korea plays a key economic role in the East Asian region since it belongs to the group of the so called Four Asian Tigers (together with Hong Kong, Singapore and Taiwan), which experienced exceptionally high growth rates between the early 1960's and the 1990's through rapid industrialization, strong technological innovation, heavy investments in infrastructures and human capital, and the creation of stable macroeconomic environments. South Korea's economy ranks 11th in terms of GDP nominal in 2016 (IMF, 2017) and 14th in terms of GDP(PPP) (forecasted estimates for 2017, see IMF, 2017), and thus belongs to the G-20 group of major world economies.

A second set of reasons which make this country an attractive case study is related to important structural features of the Korean economy, namely a long lasting process of financial markets liberalization and the switch to a monetary policy based on an interest rate rule in the late 1990's. The former feature is crucial for the validity of the no arbitrage equilibrium condition underlying the EHTS; the latter feature becomes instead relevant when assessing the effectiveness of the transmission mechanism of monetary policy.

A gradual process of interest rates liberalization started in the early 1980s when all commercial banks were privatized; this process intensified in the next decade, when the government implemented a multi-year plan to liberalize interest rates at all maturities. Turning to monetary policy, the Bank of Korea formally adopted an inflation targeting regime in 1999, in the context of a highly liberalized financial and economic environment. Since the end of the 1990s, therefore, monetary policy switched from a traditional approach based on the control of monetary aggregates to an interest rate rule relying on a short-term policy instrument.

A third reason motivating the selection of South Korea is related to some shortcomings in the existing literature. To the best of my knowledge, although applied work on the Korean term structure has addressed various research issues, no contribution has explicitly focused on the degree of empirical support for the EHTS.

Yoo and Oh (2005) analyze the forecasting power of the Korean term structure under alternative monetary policy frameworks. They find that this term structure has forecasting power on the direction of future interest rates during the inflation targeting regime, whereas an opposite conclusion holds during the monetary targeting regime. Lim (2005) explores the information content of the term structure for monetary policy purposes. He finds that implied forward rates derived from the term structure provide information about market expectations of future spot rates, and documents that imbalances between supply and demand play a crucial role in determining risk premiums on the Korean Treasury bonds market.

Although these papers provide useful information for monetary policy, they do not assess neither the degree of empirical support for the EHTS nor the causal relationships between yields at different maturities.
The present paper fills these two relevant gaps in the literature.

The outline of the paper is as follows. The next section describes the data set and performs a preliminary data inspection. Section three contains the main empirical evidence which includes standard cointegration tests, an extension of cointegration analysis inside a multivariate framework and some causality tests between yields at different maturities. On the whole, this empirical evidence raises some implications for monetary policy, which are discussed at the end of this section. Section four performs some robustness tests. Section five concludes and outlines some directions for future research.

2. DATA SET AND PRELIMINARY DATA INSPECTION

The Asian financial crisis of 1997-1998 had strong destabilizing effects on the Korean economy. In South Korea, the crisis was triggered in early 1997 by a series of bankruptcies of large and heavily indebted financial institutions (the so called "chaebols"); the crisis was then amplified by a massive speculative attack on the Won/U$ exchange rate which, at the end of 1997, experienced a nominal depreciation of more than 90%. The Won collapse induced domestic authorities to implement a huge monetary tightening in order to stabilize the domestic currency, and short-term interest rates more than doubled in December 1997, rising from 12 to 30%. Short-term interest rates displayed a high volatility in 1998, particularly during the first half of this year (see Cho and West, 2003, Figure 1.5, p. 21). Harvie and Pahlavani (2009) highlight the extreme instability of Korea's economy during this period documenting, for all key macrovariables, the existence of significant structural breaks[1].

Given the strong instability associated with the Asian financial crisis and a structural break in interest rates at the end of 1998, I exclude the above period and select 1999 as a starting point. The sample includes therefore monthly data from 1999.1 to 2017.1, yielding a total of about 200 observations for each series.

I use the 3-month commercial paper rate as a proxy for the policy rate, and government bond yields for maturities of one-year, three-years and five years[2]. The selection of these variables is mainly dictated by data availability and the results from a preliminary data inspection[3].
As a prerequisite for cointegration analysis, it is important to ascertain that interest rates series are integrated of order one (I(1)).

It is well known that, although nominal interest rates dynamics is usually extremely persistent, the I(1) property of interest rates has been controversially discussed in the literature[4]. One relevant theoretical argument supporting the absence of a stochastic trend in nominal interest rates is that, if they were truly I(1) processes, they would have wandered off long ago, which is not the case. On the other hand, interest rates non-stationarity is often regarded as a widespread sample property by many applied econometricians, and the I(1) property has not been rejected in seminal work exploiting a cointegration-based approach to test the validity of the EHTS (Campbell and Shiller, 1987)[5].

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[1] More specifically, as far as short-term interest rates are concerned, the estimated structural break date is the fourth quarter of 1998.
[2] All interest rates are obtained from Thomson Reuters - Datastream and are expressed in percentage per annum. The definitions and codes for the series are the following: Korea Commercial Paper 91-days [KOCP91D]; Korea Monetary Stabilization Bond 1-Year [KOMSBD1]; Korea Treasury Bond 3-Year [KOBDY3Y]; Korea Treasury Bond 5-Year [KOBDY5Y].
[3] Data for longer maturities, such as the 10-year government bond yield, could not be used since they are not available for the whole period. Moreover, differently from all other interest rates, the null hypothesis of non stationarity is strongly rejected for the 10-year bond yield, thus precluding to use this series for cointegration analysis.
[4] I thank an anonymous referee for drawing my attention on this point.
[5] Note, finally, that also many applied studies analyzing exchange rate behavior and monetary policy shocks assume that nominal interest rates are I(1) variables (see, among others, Dickey *et al.*, 1991; Dees *et al.*, 2005).

In the light of the above considerations, a large set of unit root tests is applied to the data set analyzed in this paper. More specifically, besides the standard procedures proposed in the literature (Dickey and Fuller, 1979; Phillips and Perron, 1988), I implement the Kwiatkowski *et al.* (1992) and the Zivot and Andrews (1992) unit root tests.

The former, differently from all other testing procedures, assumes level (or trend) stationarity as the null hypothesis. The latter tests the null hypothesis of a unit root against the alternative of a stationary process with a single break in the intercept, in the trend, or in both.

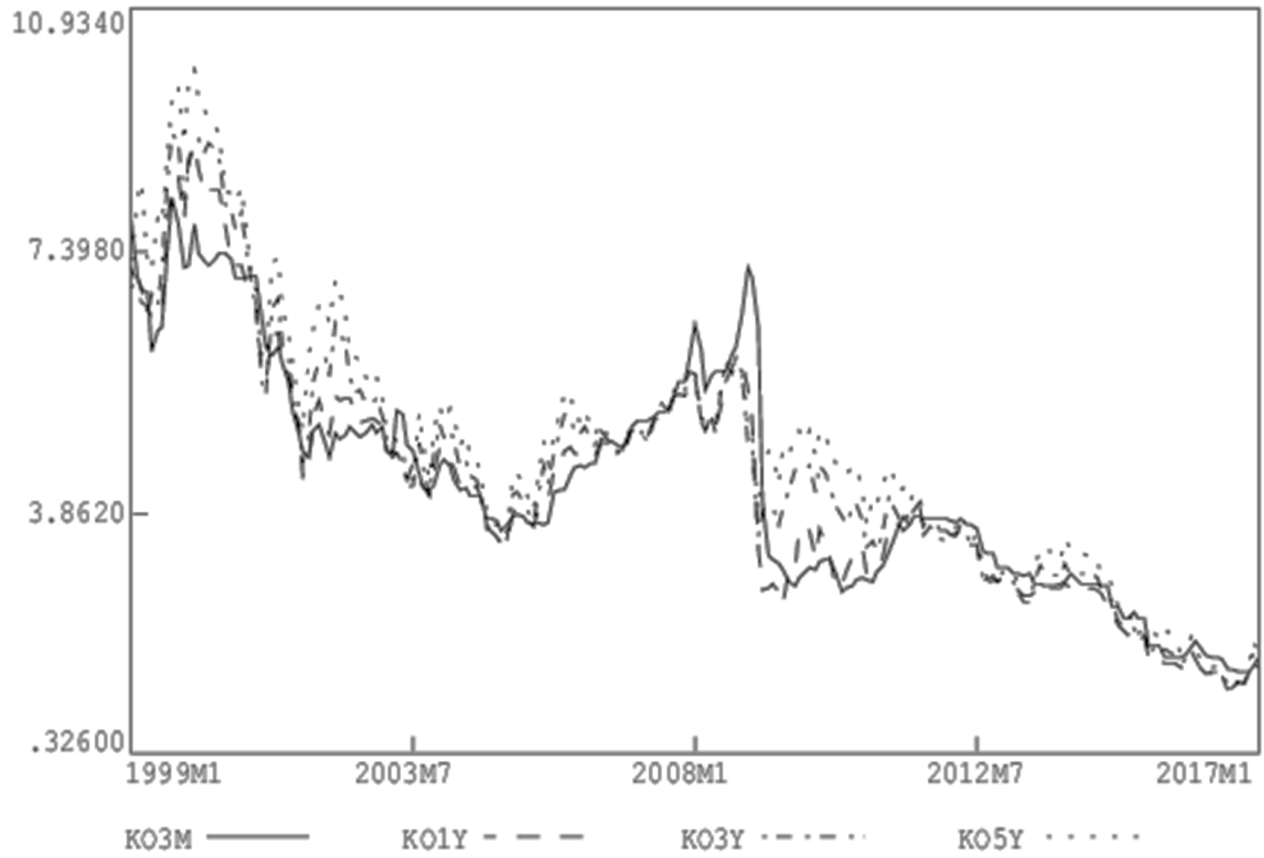
Table 1 summarizes the results. The upper section refers to the variables in levels, whereas the lower section refers to the variables in first differences.

These empirical findings are highly robust to alternative testing procedures.
Focusing on the upper section, all standard procedures are unable to reject the null of non stationarity, while this result is largely supported by the Zivot and Andrews (1992) test at all interest rates maturities[6]. The Kwiatkowski *et al.* (1992) test, moreover, consistently rejects the null of level or trend-stationarity at a 1% significance level. Turning to the lower section, all testing procedures reject the null of non stationarity at a 1% level across the full spectrum of assets maturities. Moreover, in line with these findings, the Kwiatkowski *et al.* (1992) test does not reject the null of level or trend-stationarity for all first-differenced variables.
To sum up, Table 1 provides overwhelming evidence that the Korean interest rates are I(1) variables in the absence of any significant structural break. This evidence provides therefore a consistent support for relying on a cointegration-based approach.
Figure 1 plots the dynamics of Korean nominal interest rates.

Strong long-run co-movements between asset returns are apparent from this figure. The estimated correlation matrix of variables yields correlation coefficients consistently higher than 0.9, with notably high values for asset returns at closest maturities. Overall, this preliminary data inspection provides therefore some informal evidence supporting the existence of cointegration.

[6] The Zivot and Andrews (1992) test never rejects the null of a unit root against the alternative of a stationary process under a significant break in the series. The only exception is KO3Y where one out of three test statistics rejects the null, albeit only at a 5% level. Overall, therefore, this evidence allows to exclude the existence of significant structural breaks in the Korean term structure.

FIGURE 1 – *Korea: Term Structure of Interest Rates – Monthly Data (1991.1-2017.1)*



Two major peaks in the Korean term structure are apparent. The former, at the beginning of the sample, reflects the prolonged destabilizing effects of the Asian financial crisis. The latter, around the central part of the sample, is instead related to the impact of the 2007-2008 global financial crisis.

Similarly to other Asian economies, South Korea was hardly hit by this international financial turmoil. Following the collapse of Lehman Brothers in September 2008, the Korean won plummeted against major currencies in the presence of huge capital outflows, while the domestic stock price index fell by about 36 % between August and October 2008. As shown in Figure 1, interest rates reached a peak during the first part of 2008, while subsequently exhibiting a sharp downturn as a consequence of repeated cuts in policy rates and massive liquidity injections by the Central Bank (Kim, 2012, section 3).

TABLE 1 - *Unit Root Tests on Korean Interest Rates (Levels)*

Test	KO3M	KO1Y	KO3Y	KO5Y
ADF ADF (T)	-1.65 -2.79	-1.38 -2.41	-1.23 -2.80	-1.43 -2.58
Z(t) Z(t) (T) Z(ρ) Z(ρ) (T)	-1.965 -2.925 -5.827 -15.793	-1.38 -2.41 -3.23 -11.30	-1.291 -2.905 -3.461 -16.565	-1.224 -2.914 -3.209 -16.497
KPSS KPSS (T)	3.81*** 0.265***	4.09*** 0.289***	4.18*** 0.341***	4.18*** 0.405***
ZA intercept ZA trend ZA both	-3.654 -3.157 -3.998	-3.686 -3.871 -4.593	-4.062 -4.059 -5.397*	-3.398 -3.388 -4.762

(*First Differences*)

Test	KO3M	KO1Y	KO3Y	KO5Y
ADF ADF (T)	-5.66*** -5.65***	-4.77*** -4.81***	-5.49*** -5.47***	-5.47*** -5.47***
Z(t) Z(t) (T) Z(ρ) Z(ρ) (T)	-10.16*** -10.12*** -119.7*** -119.8***	-11.66*** -11.62*** -147.3*** -147.3***	-12.75*** -12.71*** -160.7*** -160.7***	-14.29*** -14.26*** -174.7*** -174.6***
KPSS KPSS (T)	0.054 0.041	0.038 0.034	0.032 0.032	0.035 0.035
ZA intercept ZA trend ZA both	-9.427** -8.763** -9.400**	-6.701** -6.553** -6.893**	-11.03** -10.94** -11.80**	-12.42** -12.21** -12.86**

Explicative notes to Table 1:

***: significant at the 1 % level ; **: significant at the 5 % level.

(T) beside a test statistic means that a time trend is included in the auxiliary regression.

ADF: Augmented Dickey Fuller unit root test (Dickey and Fuller, 1979).

Z(t): Phillips-Perron Z(t) test statistic (Phillips and Perron, 1988).
Z(ρ): Phillips-Perron Z(ρ) test statistic (Phillips and Perron, 1988).

KPSS: Kwiatkowski-Phillips-Schmidt-Shin stationarity test (Kwiatkowski *et.al.*, 1992).

ZA: Zivot-Andrews unit root tests allowing for a single break in the intercept, trend, or both (Zivot and Andrews, 1992).

The critical values for these tests are as follows:

ADF: -3.47 (1%); -2.88 (5%).
ADF (T): -4.00 (1%); -3.43 (5%).

Z(t): -3.47 (1%) ; -2.88 (5%).
Z(t) (T): -4.00(1%) ; -3.43 (5%).

Z(ρ): -20.18 (1%) ; -13.93 (5%).
Z(ρ) (T): -28.17 (1%) ; -21.16 (5%).

KPSS: 0.739 (1%) ; 0.463 (5%).
KPSS (T): 0.216 (1%) ; 0.146 (5%).

ZA intercept: -5.43 (1%) ; -4.80 (5%).
ZA trend : -4.93 (1%) ; -4.42 (5%).
ZA both : -5.57 (1%) ; -5.08 (5%).

Towards the end of the sample, the term structure shows a downward trend, reaching an all time low during the latter half of 2016. This tendency is mostly due to the spillover effects of unconventional monetary policies implemented by major industrialized countries, which exerted a significant impact on the term structures of many Asian economies (see e.g. Belke *et al.*, 2018; Miyajima *et al.*, 2014).

3. EMPIRICAL EVIDENCE

This section assesses the validity of the EHTS exploiting a cointegration approach, as suggested in Campbell and Shiller (1987) and Hall *et al.* (1992) seminal papers.
Cointegration analysis is firstly applied at a bivariate level, and subsequently extended inside a multivariate framework. The last part of this section implements causality tests between the policy rate and nominal interest rates at different maturities, in order to explore the effectiveness of the transmission mechanism of monetary policy.

3.1 Standard Cointegration Tests

According to the Expectations Hypothesis, the return on a long-term financial asset depends on expected short-term rates on this asset and a constant risk premium component, namely:

$$i_t^{(n)} = 1/k \sum_{i=0}^{n} E_t(i^{(m)}{}_{t+i}) + \theta_{nm} \tag{1}$$

where $i_t^{(n)}$, $i_t^{(m)}$ denote, respectively, the long term and the short term interest rates (m < n), k = n/m is an integer, E_t is the expectations operator, and θ_{nm} is a constant risk premium component that may vary with the maturity of the rate.

A large bulk of empirical literature relies on cointegration tests applied by reparametrizing equation (1) inside the following linear regression framework:

$$i_t^{(n)} = \alpha + \beta\, i_t^{(m)} + \varepsilon_t \quad (2)$$

where $i_t^{(n)}$, $i_t^{(m)}$ are the long and short rates defined above, α and β are parameters, and ε_t are the regression residuals.

The Expectations Hypothesis assumes that nominal yields are linked through a long-run equilibrium relationship. Since nominal interest rates are usually I(1) series, the validity of the EHTS can be explored applying a bilateral cointegration analysis to equation (2) along the whole range of assets maturities. More specifically, the validity of the EHTS is assessed testing for a cointegration relationship between $i_t^{(n)}$ and $i_t^{(m)}$ with a cointegrating vector (1, -1) (see e.g. Campbell-Shiller, 1987; Taylor, 1992). This restriction is commonly known as the "symmetry " or "zero-sum" restriction, and expresses a one-to-one equilibrium relationship between the long-run interest rate and short-term rates at various maturities. Additionally, testing the further restriction $\alpha = 0$ in equation (2), allows to disentangle between the "Pure" version of the EHTS ($\alpha = 0$) and the "Liquidity Premium" version ($\alpha > 0$) assuming risk premium components at different temporal horizons.

Drawing on the above discussion, the investigation starts implementing standard cointegration tests inside a bivariate framework.

The data set includes a 3-month commercial paper rate (as a proxy for the policy rate) and government bond yields at a one-year, three-year and five-year maturity. Therefore, three testable specifications of equation (2) are considered, exploring the existence of a long-run equilibrium relationship between the policy rate ($i_t^{(m)}$) and nominal yields at longer maturities ($i_t^{(n)}$, with n = 1, 3, 5 years).

Table 2 reports the results from Engle-Granger (1987) bivariate cointegration tests.

ADF test statistics reject the null hypothesis of non stationary regression residuals at standard significance levels. This result is robust across all long-term maturities. This evidence points out three long-run equilibrium relationships between the short-term policy rate and long-term yields, thus providing robust empirical support to the expectations hypothesis.

TABLE 2 - *Bivariate Cointegration Tests (Monthly Data: 1999M1 - 2017M1)*

Long-Run Equations	ADF
1-Year Rate - Policy Rate	- 4.37***
3-Year Rate - Policy Rate	- 4.55***
5-Year Rate - Policy Rate	-4.24***

Estimated equation: $i_t^{(n)} = \alpha + \beta\, i_t^{(m)} + \varepsilon_t$
where: $i_t^{(m)}$: 3-month Commercial Paper rate;
$i_t^{(n)}$: Government Bond Yields at 1-year (n=1), 3-year (n=3), and 5-year (n=5) maturity.
Critical values for the Augmented Dickey Fuller (ADF) test are from Engle and Yoo (1987), Table 3, and refer to a sample size of 200 observations: -3.78 (1%); -3.25 (5%); -2.98 (10%).
The number of lags in auxiliary regressions for the ADF test is selected through standard model selection criteria (AIC, SBC, HQC).
***: test statistic significant at a 1% level.

Table 3 displays cointegrating vectors at various maturities, the Wald tests for the "symmetry" restriction ($\beta = 1$), and the Wald tests for the joint restriction assuming the absence of risk premium and equi-proportional yields dynamics ($\alpha = 0; \beta = 1$).

Focusing on α parameters, their values increase for nominal interest rates at longer maturities. This is in line with the predictions of the "Liquidity Premium" theory although, according to our estimates, the risk premium component is significant only at the longest time horizon (5-year).
As regards β coefficients, their values are very close to one and highly significant. This corroborates the informal evidence of section 2, and supports the main testable implication of the Expectations Hypothesis.

The Wald test for the hypothesis that $\beta = 1$ is never rejected, for all interest rates pairs, at standard significance levels. The joint restriction of zero risk premium and equi-proportional interest rates movements ($\alpha = 0; \beta = 1$) is instead almost always rejected, the only exception being the shortest end of the yield curve (i.e. the cointegrating regression involving the 1-year interest rate).

TABLE 3 - *Bivariate Cointegrating Regression*
Cointegrating Vectors and Wald Tests on Parameters Restrictions
(Monthly Data: 1999M1 - 2017M1 ; 217 Observations)

Long-Run Equations	α	β	Wald Test: $\beta = 1$	Wald Test: $\alpha = 0; \beta = 1$
1-Year Rate - Policy Rate	-0.12 (-1.50)	1.02*** (55.5)	1.37 [0.240]	2.61 [0.270]
3-Year Rate - Policy Rate	0.126 (1.04)	1.018*** (37.7)	0.435 [0.509]	20.34 [0.000]
5-Year Rate - Policy Rate	0.267* (1.78)	1.056*** (31.7)	2.80 [0.094]	84.06 [0.000]

Cointegrating vectors normalized on long-term interest rates; Estimated equation: $i_t^{(n)} = \alpha + \beta\, i_t^{(m)} + \varepsilon_t$
t-statistics in parentheses below parameters values; marginal significance levels in square brackets behind Wald statistics.
* : significant at a 10% level ; *** : significant at a 1% level.

To sum up, the results from bivariate cointegration tests provide consistent support to the EHTS, highlighting the existence of equi-proportional interest rates patterns across the whole spectrum of assets maturities. These findings, moreover, provide empirical support to the "Liquidity Premium" version of the EHTS, albeit only for longer term maturities.

3.2 Multivariate Cointegration Tests

The present section analyzes the validity of the EHTS through a multivariate cointegration approach. To this purpose, I apply the Johansen (1995) methodology to explore the rank of the cointegration space of spread vectors, and to test parameters restrictions associated with alternative versions of the EHTS[7].

[7] Although alternative methodologies are available to determine the number of common trends, the standard FIML approach outlined in Johansen (1995) provides the natural framework to assess the restrictions on the parameters of cointegrating vectors consistent with alternative versions of the EHTS (see Engsted and Tanggaard, 1994, section 2, for a technical discussion on this topic).

This additional investigation is motivated by various reasons. First, from a strictly econometric viewpoint, the Johansen approach provides more reliable results than standard OLS regressions since it is a system estimator which includes lagged variables and thus significantly reduces residuals serial correlation. A further advantage is that this multivariate testing procedure is much less prone to biases caused by small samples measurement errors. Moreover, in a slightly more theoretical perspective, this multivariate approach is likely to deliver more accurate statistical inferences, since it is plausible to assume that most term structure innovations jointly affect the whole spectrum of interest rates maturities.

The bivariate cointegration approach can be easily extended to a system of (N) nominal interest rates. In this case, the EHTS predicts that each yield series is cointegrated with the short term yield $i_t^{(m)}$. Therefore, in a system of N yields, the (N-1) spread vectors belonging to the set [(-1, 1, 0, ..., 0), (-1, 0, 1, ..., 0), ..., (-1, 0, 0, ..., 1)'] are linearly independent and underlie a cointegration space of rank (N - 1). Testing the EHTS in a multivariate cointegration framework exploits one basic implication of this theory, namely that a system of (N) non-stationary yields should have one common stochastic trend driving interest rates (see e.g. Hall *et al.*, 1992; Engsted and Tanggaard, 1994).

Table 4 reports the results from Johansen (1995) cointegration tests.

The upper section displays the values of the Maximal Eigenvalue test (λ max), whereas those of the Trace test (λ trace) appear in the lower section.

Although the Trace test is usually regarded as more reliable in the literature[8], our empirical findings are highly homogeneous across alternative test statistics. As shown in Table 4, the null hypotheses of absence of cointegration ($r = 0$), or that there are at most one ($r \leq 1$) or two ($r \leq 2$) cointegrating vectors, are consistently rejected at standard significance levels.

Overall, this evidence is fully consistent with previous results, pointing out the existence of three cointegrating vectors in the four-dimensional system of Korean interest rates.

[8] Toda (1994) reports a better small sample performance of λ trace with respect to the alternative likelihood ratio statistic. Analogous results are obtained in Lütkepohl *et al.* (2000), assuming a wider set of data generation processes and higher dimensional systems.

TABLE 4 - *Cointegration Tests in a Four-Dimensional System (Monthly Data: 1999M1 - 2017M1)*

Null	Alternative	λ max
r = 0	r = 1	91.8**
r ≤ 1	r = 2	47.3**
r ≤ 2	r = 3	33.6**
r ≤ 3	r = 4	2.82

Null	Alternative	λ trace
r = 0	r ≥ 1	175.5**
r ≤ 1	r ≥ 2	83.7**
r ≤ 2	r ≥ 3	36.4**
r ≤ 3	r = 4	2.82

λ max and λ trace are the two statistics for the test of the cointegration rank.
The data vector includes nominal interest rates at 3-month, 1-year, 3-year and 5-year maturities.
Cointegration with restricted intercepts and no trends in the VAR.
Optimal lag length: p = 1. **: significant at the 5% level.
The 95% critical values for λ max are: r = 0, 28.27; r ≤ 1, 22.04; r ≤ 2, 15.87; r ≤ 3, 9.16.
The 90% critical values for λ max are: r = 0, 25.8; r ≤ 1, 19.86; r ≤ 2, 13.81; r ≤ 3, 7.53.
The 95% critical values for λ trace are: r = 0, 53.48; r ≤ 1, 34.87; r ≤ 2, 20.18; r ≤ 3, 9.16.
The 90% critical values for λ trace are: r = 0, 49.95; r ≤ 1, 31.93; r ≤ 2, 17.88; r ≤ 3, 7.53.

The existence of (N-1) cointegrating vectors in a system of N nominal yields is consistent with the theoretical predictions of the EHTS, according to which one common factor drives the structure of nominal yields. Since each yield series is cointegrated with the short-term policy rate, the stationarity of spread vectors prevents nominal yields from drifting too far apart, thus eliminating the occurrence of profitable opportunities in line with one basic testable implication of the EHTS.

Having established the rank of the cointegration space, the restrictions on cointegrating vectors parameters are now examined.

The former "symmetry" restriction assumes that spread vectors cointegrate with a cointegrating vector (1, -1). This implies a stable, one-to-one, equilibrium relationship between the short-term policy rate and the whole spectrum of assets maturities[9].

The latter restriction assumes equi-proportional movements between the short-term policy rate and long-term interest rates, and the absence of significant risk premium components[10].
Table 5 summarizes the results of likelihood ratio tests on these restrictions.

Focusing on the upper section, the validity of the "zero-sum" restriction is rejected at standard significance levels. The estimated term premia components at various maturities (θ_{ls} in Table 5) are in line with those obtained through the bivariate approach (α parameters in Table 3). Similarly to the quantitative estimates obtained in the previous section, these risk premia components monotonically increase in the time to maturity. Moreover, again in line with previous evidence, these components are statistically significant only at the longest edge of the maturity structure (5-year), whereas those associated with shortest maturities are either not significant or less statistically significant.

The lower section of Table 5 focuses on the joint restrictions of "symmetry" and "zero risk premia". The likelihood ratio statistic strongly rejects the null hypothesis. In line with previous evidence, this multivariate approach provides consistent support to the "Liquidity Premium" theory.

Overall, these results support the existence of three stationary spread vectors suggesting that, in line with the EHTS, one common stochastic trend drives the term structure of Korean interest rates. Moreover, in line with previous evidence, these results support the "Liquidity Premium" version of this theory.

Differently from previous results, however, these findings do not support to the validity of the "zero-sum" restriction on cointegrating vectors.

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[9] Inside the bivariate econometric framework of section 3.1, this restriction corresponds to imposing $\beta = 1$ in equation (2).
[10] Inside the bivariate econometric framework of section 3.1, this restriction corresponds to imposing both $\beta = 1$ and $\alpha = 0$ in equation (2).

TABLE 5 - *EHTS Restrictions: (a) Symmetry*

	Vector 1	Vector 2	Vector 3
i_{3m}	1.000	1.000	1.000
i_{1y}	-1.000	-0.000	0.000
i_{3y}	0.000	-1.000	0.000
i_{5y}	0.000	-0.000	-1.000
θ_{ls}	0.033 (0.058)	0.278 (0.106)	0.584 (0.145)

Likelihood Ratio Test of Symmetry Restrictions: 12.24 [0.007]

EHTS Restrictions: (b) Symmetry + Zero Risk Premia

	Vector 1	Vector 2	Vector 3
i_{3m}	1.000	1.000	1.000
i_{1y}	-1.000	-0.000	0.000
i_{3y}	0.000	-1.000	0.000
i_{5y}	0.000	-0.000	-1.000
θ_{ls}	0.000	0.000	0.000

Likelihood Ratio Test of Symmetry Restrictions and Zero Risk Premia: 39.7 [0.000]

Conditional standard errors in parentheses below parameters estimates.
The likelihood ratio test for the symmetry restriction (a) is distributed as a χ^2 with three degrees of freedom.
The likelihood ratio test for the joint restriction (b) is distributed as a χ^2 with six degrees of freedom.
p values in square brackets behind Likelihood Ratio test statistics.

The rejection of the "zero-sum" restriction when a large set of nominal yields is included in the empirical analysis is not an unusual result in the literature (see e.g. Engsted and Tanggaard, 1994, section 3; Konstantinou, 2004, section 4)[11].

[11] It is interesting to observe, however, that restricting this multivariate analysis to alternative sets of three-dimensional systems (instead of focusing on a four-dimensional system as in the present section), the "zero-sum" restriction turns out to be consistently supported at standard significance levels. These additional findings are available upon request.

This result is usually ascribed to the existence of time-varying liquidity premia, deviations from the rational expectations hypothesis, or structural differences between short and long-term maturity structures.

Further investigation about the influence of these factors is clearly worthwhile, as well as an extension of the analysis in a panel framework in order to obtain more robust statistical inferences.

3.3 Causality Tests

The standard approach to monetary policy relying on inflation targeting assumes that the Central Bank controls a short-term policy rate on the basis of a social welfare function incorporating inflation and output as its main arguments (Clarida *et al.*, 1999). Monetary policy impulses are then transmitted to longer term interest rates, and hence to the real economy, through the no arbitrage equilibrium condition underlying the EHTS.

In order for the above mechanism to work properly, the long-run equilibrium condition implied by the EHTS requires the existence of a unidirectional causal relationship from the short-term policy rate to longer term interest rates. If this is not the case, the short-term policy instrument is no more exogenous, and the ultimate effects of monetary policy are made more uncertain by complicated feedback reactions in the nominal interest rates structure.

The analysis of previous sections has established the existence of long-run equilibrium relationships inside the Korean term structure. However, cointegration analysis is not sufficient to establish the direction of causality between variables. In the present section the focus is on this issue, which is important in order to gauge the effectiveness of the transmission mechanism of monetary policy. This topic deserves a particular interest in the case of Korea, since it has never been addressed in previous research[12].

In order to explore the causal relationships, a standard bivariate Vector Error Correction Model (VECM) is applied. The dynamic linkages in the term structure are explored extending the range

[12] Since the adoption of an inflation targeting regime in the late 1990's, a large literature has developed to investigate various aspects of Korean monetary policy. These aspects include, among others, the macroeconomic effects of alternative monetary policy rules (Chung *et al.*, 2007; Jung, 2011), the empirical features of the Central Bank's reaction function (Piao and Joo, 2011), and the relevance of the bank lending channel (Hsing, 2014). However, to the best of our knowledge, no applied research exists on the direction of causality inside the Korean term structure of interest rates.

of long-term maturities from 1-year to 5-year, namely focusing on the following interest rate pairs: (i^{3m}, i^{1y}), (i^{3m}, i^{3y}), (i^{3m}, i^{5y}); where i^{3m} is the 3-month commercial paper rate taken as a proxy for the short-term policy rate ($i_t^{(m)}$), and i^{1y}, i^{3y}, i^{5y} are longer term interest rates ($i_t^{(n)}{}_t$, with n = 1-year, 3-year, 5-year).
Given the existence of cointegration, a bivariate VECM may be specified as follows:

$$\Delta i_t^{(m)} = \delta_1 + \gamma_1 RES_{t-1} + \text{lagged}\,(\Delta i_t^{(m)}, \Delta i_t^{(n)}) + \varepsilon_{1t} \tag{3}$$

$$\Delta i_t^{(n)} = \delta_2 + \gamma_2 RES_{t-1} + \text{lagged}\,(\Delta i_t^{(m)}, \Delta i_t^{(n)}) + \varepsilon_{2t} \tag{4}$$

where $\Delta i_t^{(m)}$ represents changes in the short-term policy rate; $\Delta i_t^{(n)}$ represents changes in long-term interest rates (n = 1-year, 3-year, 5-year); RES_{t-1} is the error correction term from the cointegrating equation; δ_1 and δ_2 are parameters; γ_1 and γ_2 are speed of adjustment coefficients; ε_1 and ε_2 are white-noise residuals.

The estimated error correction parameters (γ_1 , γ_2) provide information about long-run causality, and this is usually referred as a test of weak exogeneity in the literature (Engle *et al.*, 1983). A negative and significant error correction parameter implies that the left-hand variable in the corresponding VECM equation is not exogenous, since it adjusts to eliminate deviations from the long-run equilibrium. Lagged coefficients in each VECM equation provide instead information about short-run causality, in line with standard Granger-Sims causality tests. Finally, a joint test that the error correction parameter and lagged coefficients are zero in a single VECM equation, provides a test of strong exogeneity of the corresponding left-hand variable.

The VECM outlined in equations (3)-(4) was estimated for the alternative interest rate pairs mentioned above. The VECM order was selected through standard information criteria and, in all cases, an optimal lag order of two (p = 2) was chosen. Diagnostic tests on single equations pointed out that a VECM(2) specification removes residuals serial correlation for all interest rates pairs.

Table 6 summarizes the results.

TABLE 6 - *Vector Error Correction Models for Short and Long Interest Rates (Monthly Data: 1999M1 - 2017M1)*

	$i^{(m)}, i^{(1y)}$	$i^{(m)}, i^{(3y)}$	$i^{(m)}, i^{(5y)}$
γ_1	-0.248*** (-5.66)	-0.146*** (-4.84)	-0.104*** (-3.97)
γ_2	-0.133** (-2.48)	-0.006 (-0.16)	-0.002 (-0.06)
Null Hp: Lagged values of $\Delta i_t^{(n)} = 0$ in equation normalized on $\Delta i_t^{(m)}$	18.02*** [0.000]	14.99*** [0.001]	7.35*** [0.025]
Null Hp: Lagged values of $\Delta i_t^{(m)} = 0$ in equation normalized on $\Delta i_t^{(n)}$	5.03 [0.081]	5.59 [0.061]	1.19 [0.550]
Strong Exogeneity for $\Delta i_t^{(m)}$	85.29*** [0.000]	51.3*** [0.000]	30.07*** [0.000]
Strong Exogeneity for $\Delta i_t^{(n)}$	15.05*** [0.002]	5.72 [0.126]	1.25 [0.739]

Estimated VECMs are specified as follows:
$\Delta i_t^{(m)} = \delta_1 + \gamma_1 RES_{t-1} + \text{lagged} (\Delta i_t^{(m)}, \Delta i_t^{(n)}) + \varepsilon_{1t}$
$\Delta i_t^{(n)} = \delta_2 + \gamma_2 RES_{t-1} + \text{lagged} (\Delta i_t^{(m)}, \Delta i_t^{(n)}) + \varepsilon_{2t}$
Number in parentheses below estimated parameters values are t-statistics.
Number in square brackets behind Wald statistics are marginal significance levels.
*** : significant at the 1% level
** : significant at the 5% level

Focusing on the upper rows, the γ_1 parameters turn out to be strongly significant along the full range of maturities, whereas the γ_2 parameter is statistically significant only at the shorter end of the Korean yield curve ($i_t^{(m)}$, i^{1y}). These results provide substantial evidence of unidirectional causality from long-term interest rates to the policy rate, whereas only for the ($i_t^{(m)}$, i^{1y}) pair there is evidence of bi-directional causality.

Overall, estimated error correction parameters show that the short-term policy rate is not weakly exogenous, since it adjusts to eliminate temporary deviations from the equilibrium.

This evidence supporting unidirectional causality is broadly confirmed by likelihood ratio statistics describing short-run interactions between nominal yields. As shown in the central rows of Table 6, the null hypothesis that lagged long rate variations are zero ($\Delta\ i_t^{(n)} = 0$) in the equation normalized on the policy rate ($\Delta\ i_t^{(m)}$) is strongly rejected at all spread maturities. Conversely, the null hypothesis that lagged policy rate variations are zero ($\Delta\ i_t^{(m)} = 0$) in the equation normalized on long-term interest rates ($\Delta\ i_t^{(n)}$) is never rejected at standard significance levels[13]. These Granger-Sims causality tests are therefore closely in line with previous results, confirming that the Korean term structure is mainly driven by yields at longer maturities.

The lower rows of Table 6, finally, assess the hypothesis of strong exogeneity of nominal interest rates. The null hypothesis of strong exogeneity of the policy rate is rejected at all spread maturities. As regards long-term yields, this null is not rejected for longer term yields (3-year, 5-year), whereas an opposite result holds for the 1-year yield. This last result is driven by the existence of long-run bi-directional causality for the shortest spread structure ($i_t^{(m)}$, i^{1y}). Actually, as mentioned before, this is the only case in which unidirectional causality from long rates to the policy rate is not supported by data.

To sum up, these results provide large support to the existence of long-to-short causality in the Korean term structure of nominal yields. For most spread structures, unidirectional causality from long-term interest rates to the policy rate is documented. For the shorter spread structure involving the 1-year rate, there is instead evidence of bi-directional causality and, consequently, the null of strong exogeneity is rejected both for the policy rate and for the long-term (1-year) interest rate.

The main message from this empirical evidence is that the Korean term structure is mostly driven by yields at longer maturities, whereas the short-term policy rate adjusts to correct temporary divergences from the equilibrium and ensure the stationarity of spreads relationships.

As widely recognized in the literature, an unidirectional causal relationship of this kind is consistent with the EHTS. Actually, since spreads between yields at the longer edge of the term structure contain information about future short-term rates, current short-term rates react to account for this information (Hall *et al.*, 1992, section 4).

[13] As documented in Table 6, fourth row, the null hypothesis of absence of significant lagged effects of the policy rate can be rejected only at a 10% level, and only for yield spreads up to a 3-year maturity.

Although the existence of long-to-short causality is consistent with the EHTS, the lack of policy rate exogeneity raises some problems for the practical implementation of monetary policy.
Since the late 1990's, the Bank of Korea has introduced an inflation targeting regime where the short-term policy rate systematically reacts to output and expected inflation. This monetary rule assumes that monetary impulses are smoothly transmitted to the whole range of assets maturities, and that longer term interest rates subsequently affect the real sector.

In this perspective, the non-exogeneity of the policy rate might undermine the stability of the monetary transmission mechanism, due to relevant feedbacks from long to short-term interest rates.
One possible way out from this potentially destabilizing framework is represented by a strengthening of forward guidance in the inflation targeting strategy implemented by the Bank of Korea.

As emphasized in Praet (2013), the transmission mechanism from the short-term policy rate to the borrowing conditions that ultimately determine aggregate spending, is not so much affected by actual changes in the short-term policy instrument, but rather by how Central Banks influence expectations about the evolution of this instrument in the predictable future. Assuming that the EHTS holds, a causal relationship from the short-term policy rate to longer term interest rates crucially depends on forward guidance, namely the communication instrument by which the Central Bank conveys its monetary strategy going forward, conditional on developments in the economic outlook. A given change in the short-term rate, in other words, will have a greater impact on the term structure of nominal yields in the same direction, if it is accompanied by a signalling effect (i.e. forward guidance) that the new level of the policy rate is likely to persist over time. A large evidence is accumulating, at least for major industrialized countries, that Central Banks's perceived orientation by economic agents is as important as their actions[14]. Focusing on the case-study analyzed in this paper, it seems therefore reasonable to conclude that a greater emphasis on forward guidance would establish a significant causal

[14] Gürkaynak *et al.* (2005) investigate the effects of US monetary policy on asset prices using high-frequency event-study analysis. They find that these effects are not adequately captured by a single factor (represented by changes in the federal funds rate target), and that a second policy factor, associated with FOMC statements, has a much greater impact on longer-term Treasury yields. Brand *et al.* (2010) obtain similar evidence using Euro area data.

relationship from short to longer term asset maturities, in line with the empirical evidence recently observed for other major Asian economies[15].

To sum up, the main policy implication from VECM causality tests is that the Central Bank should put greater emphasis on the expectations channel through which agents anticipate the future monetary policy path. This would provide a more stable and efficient transmission mechanism of monetary impulses relying, differently from the present situation, on a truly exogenous short-term policy instrument. In this new framework, term structure adjustments towards stationary spreads relations would then occur through adjustments in medium and long-term interest rates, as predicted by seminal work on the EHTS (Engsted and Tanggaard, 1994, section 3).

4. ROBUSTNESS TESTS

This section assesses the robustness of the empirical evidence along three directions. First, new estimates of cointegrated vectors inside a bivariate econometric framework are provided. Second, new evidence from multivariate cointegration tests is obtained, using a different lag structure in the Cointegrated VAR. Third, the robustness of the long-to-short causality pattern documented in section 3.3 is explored, using a different lag order in the underlying VECM specification.

4.1 DOLS Estimates of Cointegrating Vectors

Standard cointegration tests performed in section 3.1 provide clear evidence supporting the existence of three long-run equilibrium relationships. However, since this bivariate approach relies on the OLS estimator, parameters estimates of cointegrated vectors can be significantly improved using a more efficient estimation technique[16].

The Dynamic Ordinary Least Square (DOLS) estimator developed in Stock and Watson (1993) controls for the endogeneity of explanatory variables by inserting leads and lags of the changes of all exogenous variables. DOLS represents a more powerful estimation technique, where standard errors are corrected for heteroscedasticity (Saikkonen, 1991; Stock and Watson, 1993).

[15] In recent empirical investigation on India and Malaysia, for instance, the short-term policy rate has been found to be strongly exogenous (see Tronzano, 2015 b, c).

[16] I thank an anonymous referee for suggesting an extension of the empirical investigation along these lines.

Moreover, by inserting leads and lags of the exogenous variables in first-differences, the explanatory variables in levels become super-exogenous and the regression results are unbiased (Wooldridge, 2009). The use of DOLS, finally, can also be motivated on the basis of the (relatively) small dimension of the data set. Monte Carlo experiments carried out in Stock and Watson (1993) show that DOLS perform better in small samples, relatively to other asymptotically efficient estimators.

In line with the above discussion, the empirical evidence obtained inside a bivariate econometric framework was reassessed using the DOLS estimator. Starting from a maximum of four leads-lags, a structure of two leads-lags was selected for all bivariate long-run regressions.
Table 7 summarizes these results.

Focusing on slope coefficients, the DOLS estimator yields consistently higher estimates than OLS, particularly at medium and long-term maturities (3 years, 5 years). More specifically, slope coefficients are again strongly significant but, differently from OLS results, their quantitative estimates are always significantly higher than one.
This is clearly reflected in the results from the Wald tests of the "symmetry" restriction ($\beta = 1$) which consistently reject the null hypothesis, in most cases at a 1% significance level. These empirical findings stand in sharp contrast with the previous OLS evidence, and appear more closely in line with the rejection of the "symmetry" restriction obtained through the Johansen system estimator (see Table 5).

Overall, therefore, the results of Table 7 reiterate the importance of using a more powerful estimator, inside a bivariate econometric framework, in order to obtain more accurate estimates of some crucial model's parameters[17].

[17] Other (minor) differences with respect to the OLS estimator are also observed as far as the joint hypothesis of "symmetry" and "zero risk premia" is concerned. As documented in Table 7, the DOLS estimator rejects this null at all interest rates maturities, whereas in the case of OLS estimates this null cannot be rejected in the long-run equation normalized on the 1-year interest rate.

TABLE 7 - *DOLS Estimator*

Cointegrating Vectors and Wald Tests on Parameters Restrictions

Long-Run Equations	α	β	Wald Test: $\beta = 1$	Wald Test: $\alpha = 0; \beta = 1$
1-Year Rate - Policy Rate	-0.19 (-2.68)	1.04*** (64.2)	8.20 [0.004]	8.20 [0.017]
3-Year Rate - Policy Rate	0.007 (0.05)	1.05*** (40.6)	4.34 [0.037]	34.77 [0.000]
5-Year Rate - Policy Rate	0.133 (0.91)	1.09*** (33.5)	7.89 [0.005]	102.73 [0.000]

Cointegrating vectors normalized on long-term interest rates; Estimated equation:

$$i_t^{(n)} = \alpha + \beta\, i_t^{(m)} + \sum_{j=-k}^{k} \Delta i_{t-k}^{(m)} + \varepsilon_t .$$

An optimal lead/lag structure of 2 (k = 2) was selected for long-run equations at all maturities.
t-statistics in parentheses below parameters values; marginal significance levels in square brackets behind Wald statistics.
*: significant at a 10% level ; **: significant at a 5% level; ***: significant at a 1% level.

4.2 Alternative Lag Structure in the Cointegrating VAR

As extensively discussed in the literature, the results from the Johansen's procedure may be sensitive to the choice of the lag structure in the Cointegrating VAR (see, for instance the discussion in Gonzalo (1994, section 3.1).

According to Gonzalo (1994), uncertainty about the exact number of lags represents the most serious drawback of Johansen's approach. In a similar vein, examining the robustness of Johansen's cointegration tests to alternative lags specifications, Cheung and Lai (1993) conclude that this procedure is rather sensitive to under-parametrization although not so much to over-parametrization, thus reiterating the importance of a careful lag order choice when implementing this approach.

The results from multivariate cointegration tests discussed in section 3.2 assume a lag structure of one (p = 1) in the Cointegrating VAR, on the basis of standard lag selection criteria such as Akaike (AIC), Schwarz (SBC) and Likelihood Ratio tests. However, since the above criteria leave some degree of uncertainty as regards the optimal lag structure[18], it is worthwhile to reassess their robustness assuming a higher lag structure (p = 2).

The rationale for this robustness analysis lies therefore both in the evidence provided by the SBC choice criterion and in the risks associated with CVAR's under-parametrization underlined in Cheung and Lai (1993).

Table 8 summarizes these new results.

Comparing Table 8 with previous empirical evidence (see Tables 4 and 5) reveals that the results from multivariate cointegration analysis are broadly unaffected assuming a higher lag structure in the cointegrating VAR.

In line with section 3.2, both λ max and λ trace strongly support the existence of three cointegrating vectors (see Table 8, upper section). Moreover, as regards EHTS restrictions, the empirical evidence displays again close similarities, since Likelihood Ratio tests reject the "symmetry" restriction (at a 10% level) and the joint restrictions of "symmetry" and "zero risk premia" (see Table 8, lower section).

Overall, therefore, the results of Table 8 are closely in line with the empirical evidence of section 3.2, reiterating the existence of three long-run equilibrium relationships in the Korean term structure, the absence of equi-proportional movements between the policy rate and nominal interest rates, and the existence of significant term premia components.

[18] More specifically, both AIC and Likelihood Ratio tests turn out to be rather uninformative in the context of our analysis. SBC, on the other hand, suggests an optimal lag structure of one (p = 1), although a higher lag length (p = 2) provides still relatively high values of the SBC test statistic.

TABLE 8 - *Robustness Analysis on Multivariate Cointegration Results*

CVAR(2): Cointegration Tests

Null	Alternative	λ max
r = 0	r = 1	60.5**
r ≤ 1	r = 2	31.03**
r ≤ 2	r = 3	25.2**
r ≤ 3	r = 4	4.66

Null	Alternative	λ trace
r = 0	r ≥ 1	121.5**
r ≤ 1	r ≥ 2	60.9**
r ≤ 2	r ≥ 3	29.9**
r ≤ 3	r = 4	4.66

CVAR(2): EHTS Restrictions

Likelihood Ratio Test for "Symmetry" Restrictions (distributed as a χ^2 (3))	7.34 [0.062]
Likelihood Ratio Test for "Symmetry" and Zero Risk Premia Restrictions (distributed as a χ^2 (6))	31.7 [0.000]

See Tables 4 and 5 for critical values of cointegration tests and explicative notes.

4.3 Robustness Analysis on VECM Models for Causality Tests

As a final robustness exercise, the results from causality tests are re-examined allowing for a different VECMs specification.

The order of bivariate VECM's estimated in section 3.3 was always set to 2 (p = 2), on the basis of AIC and Likelihood Ratio test statistics. However, for all bivariate VECM's estimated in this section, SBC consistently suggested a shorter VECM structure (p = 1). It is therefore interesting to investigate whether the long-to-short causality pattern identified in the Korean term structure is robust to a different lag order in the underlying VECM's.

Table 9 summarizes this empirical evidence.

TABLE 9 - *Robustness Analysis for Causality Tests*
VECM (1) Models for Short and Long-Term Interest Rates

	$i^{(m)}, i^{(1y)}$	$i^{(m)}, i^{(3y)}$	$i^{(m)}, i^{(5y)}$
γ_1	-0.218*** (-5.26)	-0.132*** (-4.53)	-0.104*** (-4.13)
γ_2	-0.135*** (-2.68)	-0.002 (-0.07)	0.012 (0.35)
Null Hp: Lagged values of $\Delta i_t^{(n)} = 0$ in equation normalized on $\Delta i_t^{(m)}$	18.04*** [0.000]	11.18*** [0.001]	7.48*** [0.006]
Null Hp: Lagged values of $\Delta i_t^{(m)} = 0$ in equation normalized on $\Delta i_t^{(n)}$	3.13 [0.076]	0.20 [0.651]	2.50 [0.114]
Strong Exogeneity for $\Delta i_t^{(m)}$	88.43*** [0.000]	49.81*** [0.000]	34.62*** [0.000]
Strong Exogeneity for $\Delta i_t^{(n)}$	11.45*** [0.000]	0.21 [0.90]	2.53 [0.281]

Estimated VECMs are specified as follows:
$\Delta i_t^{(m)} = \delta_1 + \gamma_1 RES_{t-1} + \text{lagged } (\Delta i_t^{(m)}, \Delta i_t^{(n)}) + \varepsilon_{1t}$
$\Delta i_t^{(n)} = \delta_2 + \gamma_2 RES_{t-1} + \text{lagged } (\Delta i_t^{(m)}, \Delta i_t^{(n)}) + \varepsilon_{2t}$
Number in parentheses below estimated parameters values are t-statistics.
Number in square brackets behind Wald statistics are marginal significance levels.
*** : significant at the 1% level
** : significant at the 5% level

Comparing Table 9 with previous findings (see Table 6) it is apparent that, for all bivariate interest rates pairs including the policy rate, the empirical evidence is completely unaffected. This result holds for all topics addressed in section 3.3, namely long-run causality, short-run causality and strong exogeneity tests.

As regards the former issue, the estimates of γ_1 and γ_2 provide further substantial evidence supporting unidirectional causality from long-term rates to the policy rate, thus suggesting that the policy rate is not weakly exogenous[19]. In close similarity with section 3.3, moreover, this long-to-short causality pattern involves also short-run interactions, as documented by Granger-Sims causality tests reported in the third and fourth rows. Finally, as regards strong exogeneity tests, VECM(1) models consistently reject the null of strong exogeneity of the policy rate, thus fully replicating previous results.

Overall, the strong support for a long-to-short causality pattern emerging from this new empirical evidence confirms a risk of instability in the Korean monetary policy transmission mechanism. This evidence, therefore, reiterates the need to reinforce a forward guidance approach in the practical implementation of monetary policy.

5. CONCLUDING REMARKS

This paper explores the validity of the EHTS for Korea since the period immediately subsequent to the 1997-1998 Asian financial crisis. This country represents an interesting case-study for various reasons outlined in the introductory section.

The econometric investigation exploits a cointegration-based approach, along the lines put forward in Campbell and Shiller (1987) and Hall *et al.* (1992) seminal papers.

The empirical findings may be summarized as follows.

Standard bivariate cointegration tests reveal that the short-term policy rate is cointegrated with nominal yields. The zero-sum restriction, assuming the existence of one-to-one dynamic patterns between the policy rate and longer term interest rates is not rejected inside this set up.

In line with the above evidence, a multivariate cointegration approach detects one common stochastic trend in the Korean term structure. Moreover, this more efficient estimator supports the existence of liquidity premia increasing in the time to maturity. Differently from OLS estimates, however, the "symmetry" restriction assuming that spread vectors cointegrate with a cointegrating vector (1, -1), is rejected inside this framework.

[19] Moreover, in line with section 3.3, only at the shortest maturity structure (1 year) there is evidence of bi-directional causality (γ_1 and γ_2 jointly significant).

Drawing on the robust evidence supporting cointegration, the analysis is complemented with a standard VECM approach exploring causal relationships among variables. The main result is that causality runs, in most cases, from long to short term interest rates. More specifically, for most spread structures, the short-term policy rate is not weakly exogenous (whereas only for the spread at the shortest maturity the evidence supports the existence of bi-directional causality). These findings are broadly in line with standard Granger-Sims causality tests assessing short-run interactions between nominal yields.

A robustness analysis implemented in section 4 confirms the main empirical findings summarized above. Using a more efficient estimator inside a bivariate set up (DOLS), the "symmetry" restriction turns out to be rejected, in line with the evidence provided by the Johansen estimator. Moreover, both the results from this system estimator and those from VECM causality tests are highly robust to alternative lag structures in the underlying econometric framework.

There are two policy implications to be drawn from this research, both related to the short-term interest rate rule underlying the inflation targeting approach adopted since the late 1990's:

1. This rule should be implemented putting a greater emphasis on the expectations channel through which economic agents anticipate the future monetary policy path;
2. A gradualist approach is recommended in the management of the policy rate.

The former implication hinges on one important result from causality tests, namely that the short-term interest rate assumed as a proxy for the policy rate is not weakly exogenous. This finding might undermine the monetary transmission mechanism through complicated feedback effects. In this perspective, a greater emphasis of monetary authorities on forward guidance would establish a causal relationship from short to medium and long-term assets maturities, leading to a more stable and efficient monetary transmission mechanism.

The latter policy implication is related to the evidence from multivariate cointegration tests, namely the rejection of the "symmetry" restriction and the existence of significant risk premia at the long end of the maturity spectrum.

Both results imply that monetary policy should be implemented following a gradualist approach, that is avoiding abrupt changes in the short-term instrument.

The one-to-one low frequency relationship between short and long-term interest rates represents a basic feature of the EHTS. If this one-to-one equilibrium relationship does not

hold, the long-run effects of monetary impulses become more difficult to quantify. The rejection of the "symmetry" restriction requires therefore a gradualist approach in the management of the policy rate, in order to smooth out unforeseen effects of monetary policy.
The existence of term premia components at longer maturities might further complicate the transmission of monetary impulses along the yield curve. If these term premia are maturity-dependent but time-invariant, as assumed in the "Liquidity Premium" theory, there are no additional problems in the implementation of monetary policy. However, as suggested by a large strand of literature, the assumption of constant risk premia is quite unrealistic, and this generates additional uncertainty in the monetary transmission mechanism, further reinforcing the case for a gradualist approach.

Although this paper provides interesting insights about the validity of the EHTS in Korea, there are many other research directions, not covered in the present empirical investigation for space reasons, which are left for future research.
Some straightforward extensions include the use of data sampled at different frequencies, an increase in the spectrum of assets maturities, and the analysis of nominal yields relative to other financial instruments.
The existence of significant risk premia at longer maturities calls for further investigation about the possible time-varying nature of these components and their relationships with macroeconomic fundamentals (see, at this purpose, Ang and Piazzesi, 2003 and Diebold *et al.*, 2006 seminal papers).
Since many Asian economies have recently introduced financial liberalization measures, another fruitful research line is represented by a joint analysis of South Korea and other Asian countries in a panel framework. A panel approach provides actually a significant increase in test power with respect to single-country studies when assessing the validity of the EHTS (see, e.g. Holmes *et al.*, 2011).
Other relevant extensions, finally, are represented by empirical tests focusing on potential structural breaks, on the role of foreign interest rates in the cointegrating relationships, and on the problems raised by the zero lower bound on nominal rates[20].

As regards structural breaks, unit root tests carried out in section 2 exclude their existence in single interest rates series. However, visual inspection of Figure 1 suggests that further research

[20] The author is grateful to an anonymous referee for bringing to his attention this last group of research issues.

should allow for potential structural breaks when estimating a long-run relationship for the Korean term structure.

Turning to the role of foreign interest rates, recent work has emphasized the effects of nonstandard monetary policies on international yields relationships (Belke *et al.*, 2018) and the influence of international spillovers in the interest rates setting of central banks (Beckmann *et al.*, 2017). This suggests that US or Japanese rates might serve as anchors for Korean rates, and calls for a proper investigation about the influence of these factors.

Last but not least, the problems raised by the fact that interest rates worldwide have (nearly) reached the zero lower bound should be properly tackled in empirical research. If nominal interest rates reach the lower bound of zero, traditional monetary policy targets can no longer be used and classical Taylor rules must be modified focusing on a real interest rate target (Belke and Klose, 2013).

The main implication for the empirical literature exploring the EHTS is that shadow interest rates should be used, in order to allow for the necessary downward variability in interest rates measures. Wu and Xia (2016) outline a shadow rate term structure model, and use the shadow federal funds rate computed by this model in a Factor-Augmented Vector Autoregression in order to measure the stance of unconventional monetary policy and its impact on the macroeconomy during the recent Great Recession period. An extension of this approach to the applied EHTS literature represents a promising research direction, since this shadow term structure model provides an excellent data description when the economy is at the zero lower bound.

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