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Research article

Re-considering the Fisher equation for South Korea in the application of nonlinear and linear ARDL models

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Abstract: This study aims to approach the Fisher effect issue from a different methodological perspective. To this aim, the nonlinear autoregressive distributed lag (ARDL) model, recently developed by Shin et al. (2014), is applied for South Korea between 2000Q4–2017Q4. This model allows us to decompose one variable (changes in inflation) into two new variables (increases and decreases in inflation) under the manners of nonlinearity and asymmetry. Hence, it enables us to monitor the Fisher effect in terms of increases and decreases separately. We also apply the linear version of the same model since the nonlinear ARDL model is the extended version of linear ARDL model. While the empirical findings of the nonlinear model support asymmetrically partial Fisher effects in the long-run for 1, 3, 5 and 10-years Korean bond rates, the linear model does not. Additionally, the nonlinear model detects lower size partial Fisher effects when the maturity of interest rates gets longer. Another finding of this study is that the nonlinear model may mathematically identify and introduce a different version of the partial Fisher effect based on singular (separate) effects of each decomposed variable in a parametric manner.

Keywords: Fisher effect; nonlinear and linear ARDL models; Korean bond rates

JEL codes: E0, E40, E43, G12, E6

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1. Introduction

The question of how inflation is linked to interest rates can be crucially important, especially for central banks adopting inflation targeting policies and use interest rates as operational targets. The answer to this question helps not only central banks but also other economic actors such as lenders, borrowers, and companies. Therefore, testing the linkage between interest rates and rates of inflation is one of the most studied topics by economists and economic policy makers. This relationship was first put forward and empirically tested by Irving Fisher. Fisher (1930) found very high coefficients of correlations between interest rates and the rates of inflation in the long-run for the UK and US for the periods of 1820–1924 and 1890–1927 respectively. According to Fisher (1930), changes in the rates of inflation would lead to a *one-to-one* movement in nominal interest rates without changing the real interest rates in the long-run. The effect of these changes in the rates of inflation on nominal interest rates is popularly known as the "Fisher effect" and is most often examined in the following equation, the so-called Fisher equation:

$$i_t = r_t^e + \pi_t^e + \varepsilon_t \tag{1}$$

where i_t presents the nominal interest rate, r_t^e is the *ex-ante* real interest rate, and π_t^e is the expected rate of inflation. ε_t is mean-zero error term. Under rational expectations, the Fisher equation can now be written in the following form since the rate of expected inflation equals the rate of actual inflation ($\pi_t^e = \pi_t$).

$$i_t = \alpha + \beta\pi_t + \varepsilon_t \tag{2}$$

In equation 2, if β equals 1, this supports the evidence of a full Fisher effect in the long-run. In other words, the adjustment of nominal interest rates to changes in inflation is *one to-one*. If β is greater[1] or less[2] than 1, this supports a partial Fisher effect. The positive sign of β implies that an increase in the rate of inflation raises the nominal interest rate and a decrease reduces it, supporting a full or partial Fisher effect.

This study investigates the validity of the Fisher effect for South Korea (henceforth Korea). In recent years, Korea was struggling with high inflation. After the 1997–1998 Financial Crisis, the Bank of South Korea (BOK) adopted an inflation targeting policy and used interest rates as one of the operational targets of this policy (Kim and Kim, 1999; Kim and Park, 2006; Jang, 2008; Kim, 2012; Inoue et al., 2012). Therefore, South Korea is a convenient sample country for testing the Fisher effect empirically since the country has long term experience with the connectivity between inflation and interest rates.

The rest of this paper is organized as follows. Section 2 presents a short literature review. Section 3 describes econometric methodology. Section 4 and Section 5 present the empirical results and concluding remarks respectively. The data set of this study is presented in the appendix.

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[1] According to Darby (1975), Feldstein (1976) and Tanzi (1976) if the nominal interest rates are taxed, the changes in nominal interest rates must be greater than the changes in expected inflation to maintain the constant ex-ante real interest rate (tax-adjusted Fisher equation).

[2] According to Mundell (1963) and Tobin (1965) nominal interest rates should adjust by less than *one-to-one* because an increase in expected inflation causes lenders to shift from nominal to real assets.

2. Literature review

Researchers have been testing the Fisher effect using different econometric methodologies for different countries (including Korea) within different time frames. But the conflicting empirical results do not give a clear picture for the validity of the Fisher effect for all sampled countries. For instance, Aktham and Haitham (2006) tested the Fisher effect using the nonparametric test for six developing countries, including Korea, and found a full Fisher effect for all countries. Similarly, Kasman et al. (2006) applied the Engle-Granger cointegration test for 33 countries including Korea and found evidence of the Fisher effect for Korea. Nusair (2008) applied cointegration and found a full Fisher effect for Korea and partial Fisher effects for Malaysia, Singapore, and Thailand. Ahmad (2010) applied the smooth transition autoregressive (STAR) framework for many Asian countries, including Korea, and found the evidence of the Fisher effect for almost all countries. Argyro (2010) used the same methodology for countries within the Organization for Economic Co-operation and Development (OECD) and found a full Fisher effect only for Canada but partial effects for Korea and Belgium. Similarly, Toyoshima and Hamori (2011) used panel cointegration and found a full Fisher effect for the US, the UK, and Japan. Hatemi-J (2011) applied the case-wise bootstrap approach, developed by Hatemi-J and Hacker (2005), for the US and the UK and found a tax-adjusted Fisher effect in the presence of a structural break. Badillo et al. (2011) applied panel cointegration and found partial fisher effects for 15 European Union (EU) countries. Jareno and Tolentino (2012) used the Ordinary Least Squares (OLS) and found a partial Fisher effect in the long-run for Spain. Ozcan and Ari (2016) used panel ARDL and found partial Fisher effects for G7 countries. Saglam (2018) applied the Fourier approach and found evidence of the Fisher effect for 11 Asian countries including Korea. Furthermore, Kim and Park (2018) apply alternative models for Korea and the US and discuss the results of these models for the Fisher effect.

However, Said and Janor (2001) used cointegration for six Asian countries, including Korea, and found no evidence of the Fisher effect for Korea. Andrade and Clare (1994) used the Kalman Filter and cointegration for the UK and found no evidence of the Fisher effect for the country. Hamori (1997) applied the generalized method of moments (GMM) for Japan and found no evidence of the Fisher effect for this country. Ling (2008) applied Univariate unit root tests and the ARDL bounds test for cointegration for some Asian countries and found no evidence of the Fisher effect for Korea. Koustas and Lamarche (2010) used unit root tests and the three-regime self-exciting autoregressive (SETAR) model and found no evidence of the Fisher effect for Canada, France, Italy, and Japan. Ghazali and Ramlee (2003) applied the Autoregressive Fractionally Integrated Moving Average (ARFIMA) model and found no evidence of the Fisher effect for G7 countries. Sun and Phillips (2004) used the Bivariate Exact Whittle (BEW) estimator and found no evidence of the Fisher effect for the US. Hatemi-J and Irandost (2008) applied the Kalman filter for Australia, Malaysia, Japan and Singapore and found no evidence of the Fisher effect for these countries. Chen (2015) used the Granger causality test and found no evidence of the Fisher effect for China. Clemente et al. (2017) used the Bai–Perron procedure and found no evidence of the Fisher effect for G7 countries. Similarly, Caporale and Gil-Alana (2017) applied the classical I(0) / I(1) dichotomy technique and found no evidence for G7 countries.

This inconclusiveness in the validity of the Fisher effect might arise from the assumption that the relation between the nominal interest rate and the rate of inflation is linear (symmetric). In the common linear representation of the Fisher equation shown in equation 2, a positive sign (+) implies that an increase in the rate of inflation leads to an increase in the nominal interest rate and correspondingly, a decrease in the rate of inflation leads to a decrease in the nominal interest rate. However, this relationship maybe nonlinear (asymmetric). In other words, an increase or decrease in the rate of inflation may affect the nominal interest rate differently (asymmetrically). For instance, while an increase in the rate of inflation may lead to an increase in the nominal interest rate, a decrease may not lead to a decrease in it. Likewise, while an increase in the rate of inflation may lead to a decrease in nominal interest rate, a decrease may lead also to a decrease. Shortly, rising uncertainties in the economies and the asymmetric information problem in financial markets can easily cause economic actors to perform these kinds of asymmetric (nonlinear) behaviors.

Therefore, this study differs from the previous studies using the linear model in equation 2 and approaches the subject of the Fisher effect from a different methodological perspective. In other words, this study investigates the validity of the Fisher effect for Korea both in terms of increases and decreases in the rates of inflation separately. The concepts of symmetry and asymmetry are explained in the next section.

3. Econometric methodology

For testing the validity of the Fisher effect, we apply the nonlinear ARDL model, recently developed by Shin et al. (2014). This model allows us to decompose changes in the rates of inflation (π_t) in equation 2 as two new variables: π_t^+ (increases) and π_t^- (decreases). The decomposition of $\pi_t^+$and π_t^- are constructed with the concept of the partial sum process as follows:

$$\pi_t^+ = \sum_{j=1}^{t} \Delta\pi_j^+ = \sum_{j=1}^{t} \max\,(\Delta\pi_j, 0) \tag{3}$$

$$\pi_t^- = \sum_{j=1}^{t} \Delta\pi_j^- = \sum_{j=1}^{t} \min\,(\Delta\pi_j, 0) \tag{4}$$

where $\pi_t^+$and π_t^- are the partial sum processes of increases and decreases in π_t. Hence, this model enables us to examine the validity of the Fisher effect in π_t^+ and π_t^- separately. Before the nonlinear ARDL model, we first present the model in equation 2. in the following linear form of the ARDL model by Pesaran et al. (2001) since the nonlinear ARDL model is an asymmetrically extended version of the linear ARDL model under nonlinearity.

$$\Delta i_t = \alpha_0 + \sum_{j=1}^{p} \alpha_{1j}\Delta i_{t-j} + \sum_{j=0}^{q} \alpha_{2j}\Delta\pi_{t-j} + \alpha_3 i_{t-1} + \alpha_4\pi_{t-1} + \varepsilon_t \tag{5}$$

In equation 5, while the decision of the short-run effect of the change in the rate of inflation on nominal interest rate is determined by the sign and significance of α_{2j}, the decision of the long-run effect is determined by the sign and significance of α_4. The Fisher effect is supported in the long-run if α_4 is significantly positive. For the support of a short-run Fisher effect, α_{2j} must also be significantly positive.

Following Shin et al. (2014), the model in the linear form in equation 5 is transformed to the following nonlinear ARDL model in equation 6 with decomposed variables as π_t^+ and π_t^-. The nonlinear model adds nonlinearity or asymmetry to the relationship between the nominal interest rate and the rate of inflation movements by reserving all merits of the linear ARDL model.

$$\Delta i_t = \alpha_0 + \sum_{j=1}^{p} \alpha_{1j} \Delta i_{t-j} + \sum_{j=0}^{q} \alpha_{2j} \Delta \pi_{t-j}^{+} + \sum_{j=0}^{n} \alpha_{3j} \Delta \pi_{t-j}^{-} + \alpha_4 i_{t-1} + \alpha_5 \pi_{t-1}^{+} + \alpha_6 \pi_{t-1}^{-} + \varepsilon_t \quad (6)$$

In equation 6, the decision of the short-run effects of increases (π_t^+) and decreases (π_t^-) in the rate of inflation on nominal interest rate is determined by the signs and significances of α_{2j} and α_{3j} respectively. Similarly, the decision of long-run effects of these two variables is determined by the signs and significances of α_5 and α_6. Thus, significantly positive α_5 and α_6 will support the validity of a full (if $\alpha_5 = \alpha_6 = 1$) or partial (if α_5 and $\alpha_6 \neq 1$) Fisher effect in the long-run, which is referred to as 1 (denoting a one-to-one relationship by Fisher (1930)). Similarly, significantly positive α_{2j} and α_{3j} will support a partial or full Fisher effect in same way in the short-run. Positive signs of $\alpha_{2j,}$ α_{3j}, α_5 and α_6 imply the same directional movements with the nominal interest rate (i_t). For instance, positive α_5 and α_6 imply that while an increase in the rate of inflation (π_t^+) raises the nominal interest rate (i_t), a decrease (π_t^-) reduces it, supporting the Fisher effect in the long-run. Positive α_{2j} and α_{3j} should be considered in the same way. To the best of our knowledge, this is the first study attempting to test the Fisher effect for Korea using the nonlinear ARDL model.

Another outcome of the usage of the nonlinear ARDL model is that it enables us to evaluate whether increases (π_t^+) and decreases (π_t^-) in the rates of inflation have symmetric or asymmetric effects on the nominal interest rates. While symmetric effects are defined with the same sign and the same size coefficients of $\pi_t^+$and π_t^-, asymmetric effects are defined with the same sign but different size coefficients or different sign coefficients. For instance, if significantly positive α_5 and α_6 are the same in size this will imply the validity of symmetric Fisher effects in the long-run. If they are same in sign (positive) but different in size this will imply the validity of asymmetric Fisher effects in the long-run. If $\pi_t^+$and π_t^- are in different signs, this will also imply asymmetric effects. The short-run symmetry and asymmetry should be considered in the same way between α_{2j} and α_{3j}.

Additionally, the decomposed variables (π_t^+, π_t^-) may also allow us to make contributions to the partiality concept of the Fisher effect in some degree if either α_5 or α_6 is significantly positive. For instance, a significantly positive α_5 will imply that an increase in the rate of inflation will lead to an increase in nominal interest rate, supporting a partial Fisher effect only from an increase in the rate of inflation (π_t^+) unilaterally. Similarly, a significantly positive α_6 (a decrease in the rate of inflation) will lead to a decrease in the nominal interest rate, supporting a partial Fisher effect only from a decrease in the rate of inflation (π_t^-) unilaterally. It is the same for the short-run partiality between α_{2j} and $\alpha_{3j.}$ In this newly proposed concept, the partiality is considered with unilateral (singular) effects of π_t^+ and π_t^- separately on the nominal interest rates in an individual parametric manner. This study also uses 1 as a threshold parameter for the decision of partial and full Fisher effects. However, this new concept of the study may bring a different perspective to the partiality of the Fisher effect by supporting the original approach based on 1. Thus, this study's method should be viewed as a supportive approach and not an alternative approach to the partiality of Fisher effect referred to as 1. The structure of the nonlinear model with its decomposed variables may mathematically allow us to approach the partiality concept of the Fisher effect from this perspective. It should also be noted that the nonlinear ARDL model is constructed on the potential nonlinear (asymmetric) relations between interest rates and rates of inflation. Therefore, this methodology differs from the previous aforementioned studies in the literature section. Another difference is that the nonlinear model is a dynamic model and it incorporates the lagged dependent variable to the model as an explanatory variable.

4. Empirical results

Before the proceeding cointegration test we employ the Ng-Perron (2001) unit root test. This test mitigates the size distortion problems of the Phillips-Perron (PP) test. The test results of Ng-Perron are reported in Table 1.

The test results in Table 1 indicate that the series are stationary at different levels. Thus, we apply bounds testing to reveal whether the series are cointegrated. The test results of bounds testing for the linear and nonlinear models are reported in Panel A and B in Table 2.

Table 1. Ng-Perron unit root test results.

Variables	MZ_a	MZ_t	*MSB*	*MPT*
$i_{(1)}$	0.12	0.08	0.64	27.86
$i_{(3)}$	−0.01	−0.01	0.62	26.16
$i_{(5)}$	−0.03	−0.02	0.62	25.84
$i_{(10)}$	0.29	0.20	0.69	32.56
$\Delta i_{(1)}$	−9.62**	−2.09**	0.21**	2.92**
$\Delta i_{(3)}$	−25.23***	−3.55***	0.14**	3.61***
$\Delta i_{(5)}$	−28.20***	−3.75***	0.13***	3.23***
$\Delta i_{(10)}$	−19.22***	−3.03***	0.15***	1.49***
π	−16.01***	−2.82***	0.17***	1.55***
π^+	1.38	2.37	1.70	206.07
$\Delta\pi^+$	−33.44***	−4.08***	0.12***	0.74***
π^-	−0.66	−0.31	0.48	16.11
$\Delta\pi^-$	−32.99***	−4.05***	0.12***	2.77***
			Critical Values	
1%	−13.80	−2.58	0.17	1.78
5%	−8.10	−1.98	0.23	3.17

Note: ***, ** and * denote statistical significances at 1%, 5% and 10% levels respectively. The optimal lags were automatically selected by using the Modified Akaike Information Criterion. Δ denotes the first differences of the series. The numbers in parentheses, representing Korean interest rates in different maturities, are as follows: (*1*): 1-year bond rates, (*3*): 3-year bond rates, (*5*): 5-year bond rates, (*10*): 10-year bond rates.

Table 2. Test results of bounds testing.

			Panel A: Linear					
			Critical Values					
	k	*F stat.*	I0 Bound			I1 Bound		
			10%	*5%*	*1%*	*10%*	*5%*	*1%*
(1)	1	9.86***	2.68	3.40	3.81	3.53	4.36	4.92
(3)	1	5.40*	4.05	5.30	6.10	4.49	5.83	6.73
(5)	1	4.58*	4.05	5.30	6.10	4.49	5.83	6.73
(10)	1	5.34***	2.68	3.40	3.81	3.53	4.36	4.92
			Panel B: Nonlinear					
			Critical Values					
	k	*F stat.*	I0 Bound			I1 Bound		
			10%	*5%*	*1%*	*10%*	*5%*	*1%*
(1)	2	4.27**	2.63	3.55	4.13	3.35	4.38	5.00
(3)	2	4.84**	3.38	3.88	4.99	4.02	4.61	5.85
(5)	2	4.67**	2.63	3.55	4.13	3.35	4.38	5.00
(10)	2	4.04*	3.38	3.88	4.99	4.02	4.61	5.85

Note: *k* is number of regressors. *** and * denote cointegration at the 1% and 10% significance levels. The numbers in parentheses, representing Korean interest rates in different maturities, are as follows: (*1*): 1-year bond rates, (*3*): 3-year bond rates, (*5*): 5-year bond rates, (*10*): 10-year bond rates.

The critical values of *F*-statistics are tabulated by Pesaran et al. (2001: 300). If the computed statistic falls below the lower bound, it means that the variables are I(0) and cointegration is impossible. If it is above the upper bound, it suggests cointegration. If it falls within the lower and upper bounds, inference is inconclusive. Our calculated statistics are above the upper bounds at 1%, 5% or 10% significances both in the linear and nonlinear models. Thus, we can conclude that the series are cointegrated in both models in the long-run. Hence, the estimates of the linear ARDL model in the long-run and short-run are reported in Panels A and B in Table 3.

The test results of the linear model in Panel A do not support partial or full Fisher effects in the long-run for all interest rates since their estimated coefficients are not significantly positive. On the other hand, the test results of Panel B support partial Fisher effects in the short-run for all interest rates in level ($\Delta\pi_t$) and lag 2 ($\Delta\pi_{t-2}$) since their estimated coefficients are significantly positive and less than 1. However, the adjustments of almost all interest rates to changes in the rates of inflation are weak since their coefficients are low in size. Therefore, the linear ARDL model detects partial Fisher effects only in the short-run and not in the long-run. The long-run and short-run estimates of nonlinear ARDL model are reported in Panels C and D in Table 4.

Table 3. The estimates of linear ARDL model.

	(*1*)		(*3*)		(*5*)		(*10*)	
Var.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
				Panel A: Long Run				
π_t	0.02	0.88	−0.18	0.27	−0.04	0.67	−0.15	0.26
				Panel B: Short Run				
Δi_{t-1}	0.17	0.10	0.26**	0.02	0.29**	0.03	–	–
Δi_{t-2}	−0.05	0.56	–	–	−0.11	0.31	–	–
Δi_{t-3}	0.12	0.14	–	–	0.03	0.73	–	–
Δi_{t-4}	0.40***	0.00	–	–	–	–	–	–
Δi_{t-5}	0.14	0.11	–	–	–	–	–	–
$\Delta \pi_t$	0.02	0.45	0.04	0.24	0.09*	0.07	0.08**	0.03
$\Delta \pi_{t-1}$	−0.03	0.28	0.04	0.36	0.01	0.75	0.08	0.03
$\Delta \pi_{t-2}$	0.11***	0.00	0.07*	0.08	–	–	0.14***	0.00
$\Delta \pi_{t-3}$	–	–	0.01	0.74	–	–	0.05	0.18
Constant	2.72***	0.00	1.98***	0.00	2.41***	0.00	2.43***	0.00
ECT_{t-1}	−0.46***	0.00	−0.29***	0.00	−0.36***	0.00	−0.35***	0.00
R^2	0.98	–	0.95	–	0.96	–	0.97	–
$Adj. R^2$	0.96	–	0.93	–	0.94	–	0.96	–
χ^2_{SC}	3.62	0.16	3.22	0.19	0.20	0.88	6.66	0.15
χ^2_{FF}	0.13	0.71	2.57	0.11	4.50	0.10	0.65	0.42
χ^2_{NOR}	15.77	0.00	0.21	0.90	8.48	0.01	0.18	0.91
χ^2_{HET}	20.20	0.93	13.28	0.34	21.82	0.53	15.47	0.79
EG_{MAX}	−6.94	0.00	6.97	0.00	0.677	0.00	−6.36	0.00

Note: χ^2_{SC} is Breusch-Godfrey LM test for autocorrelation, χ^2_{NOR} is the Jarque-Bera test for normality, χ^2_{FF} is Ramsey test for functional form misspecification, χ^2_{HET} for White heteroscedasticity, EG_{MAX} is largest value of the Engle-Granger residual-based ADF test. All these additional diagnostic test results signify that there is no autocorrelation, misspecification of the optimum models and heterogeneity. The series are normally distributed and cointegrated. Analysis results are reliable.

The test results of Panel C in Table 4 for the nonlinear ARDL model support partial Fisher effects in the long-run for all interest rates since their estimated coefficients are significantly positive and less than 1. However, 1-year bond rates (1) respond to the increases (π_t^+) and decreases (π_t^-) in the rates of inflation the most. On the other hand, the sizes of the estimated coefficients of the increases (π_t^+) in the rates of inflation are higher than the sizes of estimated coefficients of the decreases (π_t^-). This means that the effects of increases (π_t^+) in the rates of inflation on the nominal interest rates are more than the effects of decreases (π_t^-) for 1, 3, and 5-years bond rates. Furthermore, the nonlinear model detects a very low size partial Fisher effect for the 10-years bond rates comparatively with other interest rates. Additionally, when the maturity of the interest rates gets longer, the degree of Fisher effects weakens. The comparative results of both models indicate that while the nonlinear ARDL model detects partial Fisher effects for all interest rates, the linear ARDL model does not.

Table 4. The estimates of nonlinear ARDL model.

	(*1*)		(*3*)		(*5*)		(*10*)	
Var.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
			Panel C: Long Run					
π_t^+	0.33***	0.00	0.24***	0.00	0.13***	0.00	0.03*	0.05
π_t^-	0.29***	0.00	0.22***	0.00	0.11***	0.00	0.05***	0.00
			Panel D: Short Run					
Δi_{t-1}	−0.38*	0.06	0.36***	0.00	0.14	0.11	−	−
Δi_{t-2}	−0.80***	0.00	−0.35***	0.00	−0.23**	0.01	−	−
Δi_{t-3}	−0.44**	0.02	−	−	−	−	0.17**	0.01
Δi_{t-4}	−	−	−	−	−0.17*	0.05	−	−
Δi_{t-5}	−	−	0.61***	0.00	−	−	−0.18**	0.04
Δi_{t-6}	−	−	−0.31*	0.05	−	−	−	−
$\Delta \pi_t^+$	−	−	−	−	−	−	−0.14*	0.05
$\Delta \pi_{t-1}^+$	−	−	0.33***	0.00	0.09	0.19	−0.23***	0.00
$\Delta \pi_{t-2}^+$	−0.26***	0.00	−0.29***	0.00	−0.08	0.16	−	−
$\Delta \pi_{t-3}^+$	−0.06	0.29	−0.41***	0.00			−	−
$\Delta \pi_{t-4}^+$	−0.17***	0.00	−0.11*	0.05	−0.15**	0.01	0.35***	0.00
$\Delta \pi_{t-5}^+$	−0.12**	0.04	−	−	−	−	−	−
$\Delta \pi_{t-6}^+$	−	−	0.15***	0.00	−	−	−	−
$\Delta \pi_{t-7}^+$	−	−	−0.15**	0.01	−	−	−	−
$\Delta \pi_t^-$	−	−	0.43***	0.00	−0.17***	0.00	−	−
$\Delta \pi_{t-1}^-$	−0.38***	0.00	−0.34***	0.00	−0.22***	0.00	0.11**	0.01
$\Delta \pi_{t-2}^-$	−0.15**	0.03	−	−	−	−	−	−
$\Delta \pi_{t-3}^-$	−0.23***	0.00	−	−	−	−	−	−
$\Delta \pi_{t-4}^-$	−	−	0.14**	0.01	−	−	−0.14*	0.08
$\Delta \pi_{t-5}^-$	0.08	0.29	−	−	−	−	−	−
$\Delta \pi_{t-7}^-$	−	−	0.62***	0.00	−	−	−	−
Constant	−1.48***	0.00	−0.45	0.15	−0.56***	0.00	−	−
R^2	0.94	−	0.87	−	0.71	−	0.74	−
$Adj. R^2$	0.83	−	0.73	−	0.59	−	0.60	−
DW	1.95	−	1.97	−	1.98	−	2.13	
χ_{SC}^2	26.95	0.00	17.12	0.00	32.02	0.00	20.24	0.00
χ_{FF}^2	0.40	0.53	0.74	0.39	0.31	0.57	0.68	0.42
χ_{NOR}^2	3.61	0.16	1.38	0.50	5.86	005	0.87	0.64
χ_{HET}^2	25.76	0.96	20.32	0.88	12.88	0.74	7.15	0.62
W_{LR}	43.57	0.00	27.52	0.00	22.02	0.00	18.53	0.00
W_{SR}	13.81	0.00	6.38	0.01	6.02	0.00	12.96	0.00
EG_{MAX}	−9.71	0.00	−9.54	0.00	−7.72	0.00	−1.81	0.35

Note: χ_{SC}^2 is Breusch-Godfrey LM test for autocorrelation, χ_{NOR}^2 is the Jarque-Bera test for normality, χ_{FF}^2 is Ramsey test for functional form misspecification, χ_{HET}^2 for White heteroscedasticity, EG_{MAX} is largest value of the Engle-Granger residual-based ADF test. W_{LR} and W_{SR} are long and short-run Wald tests. All these additional diagnostic test results signify that there is no autocorrelation, misspecification of the optimum models and heterogeneity. The series are normally distributed and cointegrated. Analysis results are reliable.

Nevertheless, the test results in Panel C in Table 4 indicate that increases (π_t^+) and decreases (π_t^-) in the rates of inflation have asymmetric effects on the nominal interest rates in the long-run for all interest rates since the estimated coefficients of π_t^+ and π_t^- are same in sign but different in size. Hence, when we combine the concepts of the Fisher effect and symmetry-asymmetry, the results support asymmetrically partial Fisher effects in the long-run for all interest rates. Moreover, the test results in Panel D also support partial Fisher effects in the short-run only for 3 and 5-years bond rates in different lags since their estimated coefficients are significantly positive. The same test results indicate that increases (π_t^+) and decreases (π_t^-) in the rates of inflation have asymmetric effects on all interest rates in the short-run (except the 10-year bond rates for $\Delta\pi_t^+ = \Delta\pi_{t-4}^-$, thereby signifying symmetric effects). But we should confirm the asymmetry formally. To this end, we apply the Wald test and find that significant long-run (W_{LR}) and short-run (W_{SR}) Wald statistics confirm these asymmetries in the long-run ($\alpha_5 \neq \alpha_6$) and short-run ($\sum_{j=0}^{q} \alpha_{2j} \neq \sum_{j=0}^{n} \alpha_{3j}$).

Additionally, decomposed variables (π_t^+, π_t^-) may mathematically identify a different version of a partial Fisher effect in the short-run as described in previous sections since either α_{2j} or α_{3j} is significantly positive. Thus, significantly positive $\Delta\pi_{t-1}^+$ and $\Delta\pi_{t-6}^+$ in lags 1 and 6 for 3-years bond rates and $\Delta\pi_{t-4}^+$ in lag 4 for 10-years bond rates will support the proposed version of partial Fisher effects through increases (π_t^+) only. In other words, an increase in the rate of inflation will lead to an increase in the nominal interest rates, supporting the Fisher effect partially-unilaterally. Similarly, significantly positive $\Delta\pi_t^-$, $\Delta\pi_{t-4}^-$ and $\Delta\pi_{t-7}^-$ in levels and lags 4 and 7 for 3-years bond rates and $\Delta\pi_{t-1}^-$ in lag 1 for 10-years bond rates will support the same proposed version of partial Fisher effects through decreases (π_t^-) only. In other words, a decrease in the rates of inflation will lead to a decrease on the nominal interest rates, supporting the Fisher effect partially-unilaterally. Therefore, the proposed version of partial Fisher effects will be valid for π_t^+ and π_t^- only in levels and lags 1, 4, 6 and 7. Here, the proposed version of partial effect is interpreted in an individual parametric manner. Nevertheless, this doesn't mean that we ignore the use 1 as a threshold parameter proposed by Fisher (1930) for a one-to-one relationship. As mentioned before, this proposed version of partiality is not an alternative way to determine partiality as defined by Fisher. It is just a supportive method that is technically and mathematically provided by the structure of the nonlinear ARDL model.

5. Concluding remarks

In this study, we approach the concept of the Fisher effect from a different methodological perspective for South Korea. This country has adopted an inflation targeting policy and has used interest rates as one of the transmission channels for this policy. Therefore, Korea is a unique sample country to monitor the relationship between nominal interest rates and the rates of inflation in terms of the Fisher effect. To this aim, we apply the nonlinear ARDL model, recently developed by Shin et al. (2014). This model allows us to decompose the changes in the rates of inflation as two new variables. Thus, it enables us to monitor the Fisher effect in terms of increases and decreases separately. With this model, we will be able to also monitor whether the effects of increases and decreases in the rates of inflation on the nominal interest rates are symmetric or asymmetric. Another potential outcome of this model is that it enables us to make a contribution to the partiality concept of the Fisher effect to some degree.

The empirical findings of the nonlinear model are threefold. First, this model uncovers potentially existing but concealed long-run partial Fisher effects for Korea which the linear model does not detect. Second, increases and decreases in the rates of inflation affect the nominal interest rates in Korea asymmetrically. This means that increases in the rate of inflation affect the nominal interest rates more than the decreases in the long-run (with the exception of 10-years bond rates). This study also found that 1-year bond rates respond to the increases and decreases in the rates of inflation the most. In other words, the highest degree Fisher effect is detected on 1-year bonds rates in Korea. On the other hand, when the maturity of the interest rates gets longer, the degree of Fisher effect decreases in the long-run. Third, the structure of the ARDL model with its decomposed variables mathematically provides us a method to describe and introduce a different version of partiality for the Fisher effect in the short-run for Korea.

In conclusion, the empirical results of this study reveal that the new techniques in-time series and cointegration may help researchers monitor the Fisher effect in greater detail and also from a different methodological perspective. The understanding of the mechanism and the degree of relationship between nominal interest rates and inflation with the support of these new techniques may also be helpful for the countries adopting inflation targeting policies such as Korea.

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Conflict of interest

The authors declare no conflict of interest in this paper.

Appendix

The data of quarterly nominal interest rates were obtained from the database of Korean Statistical Information Service (KOSIS). The rates of quarterly inflation were calculated by GDP implicit price deflator (2010=100). The data of GDP deflator were obtained from IMF Data Planet.

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