3. A REEXAMINATION OF FRIEDMAN-BALL'S HYPOTHESIS IN SLOVAKIA - EVIDENCE FROM WAVELET ANALYSIS

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Abstract

This study investigates the bilateral co-movements between inflation and inflation uncertainty in a dynamic framework for Slovakia. Co-movements between variables are varying over time and show a complex characteristic in that they mostly occur in periods during which the macroeconomy or financial markets suffered severe shocks. Therefore, we employ wavelet analysis to detect the bilateral co-movements in both time and frequency domains based on Friedman and Ball's (1992) hypothesis. The empirical results show that there is a positive relationship between inflation and inflation uncertainty, thus highlighting that inflation precedes uncertainty in the short term and has the opposite causality in the long term. This conclusion is in accordance with the previous hypotheses of Friedman and Ball (1992) and Cukierman and Meltzer (1986), which means that higher inflation will increase the inflation uncertainty and vice versa. Therefore, the Slovak monetary authorities should stabilize the inflation uncertainty by adjusting the inflation level.

Keywords: inflation; inflation uncertainty; wavelet analysis

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1. Introduction

This paper investigates the bidirectional relationship between inflation and inflation uncertainty in Slovakia under the framework of Friedman and Ball's (1992) hypothesis by using wavelet analysis. Inflation is a macroeconomic problem that is described by the

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increased prices of goods and services. The consequences of inflation affect all areas of the economic activity, and they are linked to production and economic growth (Bánociová and Pavličková, 2013). Inflation uncertainty is proved to be harmful to output and economic development since it distorts the resource allocation (Friedman, 1977). As previous literature presented, the effects of inflation on economic performance are complex. Huge fluctuations in the inflation rate can significantly influence the savings and consumption decisions of individuals and even the investment and production decisions of businesses (Su *et al.*, 2016). Governments can influence the real economy through monetary policy because systematic inflation has real effects on economic performance (Grier and Grier, 2006). Inflation uncertainty may distort the price mechanism and even lead to the inefficiency of resource allocation. It also reduces the level of investments and affects nominal contracts that induce costly real effects (Balaji *et al.*, 2016). Significant attention was granted to the impact of inflation uncertainty on relevant macroeconomic variables. An elaborate debate on the welfare costs of inflation and inflation uncertainty can be found in Friedman (1977), Fischer and Modigliani (1978), Mallkiel (1979), Mullineaux (1980), Levi and Makin (1980), and Makin (1982). Furthermore, Evans (1991) reveals that inflation imparts considerable economic costs on society through increased inflation uncertainty.

Slovakia is a transition economy that has experienced high rates of inflation since the dissolution of Czechoslovakia. Since the political transformation in 1989, the development of Slovakia has been predominantly marked by the catching-up process. All transition economies of the region have recorded periods of high inflation rates caused by either expansionary fiscal or monetary policies or exchange rate depreciation (Akinbobola, 2012). From existing studies, it has been well established that inflation in transition countries is influenced by various domestic and international price shocks, especially the prices for imports and food prices (Bánociová and Pavličková, 2013). Slovakia recorded an average rate of inflation near double-digit levels until 2001 (Coricelli and Horváth, 2006), which disrupted the steady order of economic development. Hence, Slovakia instituted a process of massive economic structural reforms and market liberalization characterized by a more rigid price system (Dhyne *et al.*, 2006) and finally joined the European Union (EU) in 2004. As a result, the Consumer Price Index (CPI) in Slovakia was kept at a relatively low level. Additionally, it has obtained the highest economic growth of 14.3% among the EU members in 2007 (Statistical Office of the Slovak Republic, 2008). Inflation has entered a relatively stable stage. However, the pass-through from the exchange rate into inflation in Slovakia (an emerging and transitioning country) is higher than in developed countries (Kuijs, 2002). Thereby, developments in the economic activity and financial conditions of EU members are likely to exert significant effects on the business cycle of Slovakia economies. Significant shocks have occurred in Slovakia since 2008. The global financial crisis and the accompanying European sovereign debt crisis had serious shocks on the price level. The inflation rate reached only 1% in 2010, which is the lowest recorded rate since 1993. Nevertheless, there are studies on EU members on this topic (Joyce, 1995; Fountas, 2000). Coricelli and Horváth (2006) argue that there are large asymmetries between price rigidity in the new accession compared to old EU members. These asymmetries would exert significantly asymmetric effects on the monetary policies for new member states that join the Eurozone.

This study employs wavelet analysis to revisit the causality between the inflation and its uncertainty in Slovakia. It contributes to the specialized contemporary literature by including both the time and the frequency domains. Wavelet analysis has obvious advantages compared to the conventional time-domain methods. First, it expands the underlying time series into space in which studies can visualize both the time- and frequency-varying information of the series in a more intuitive way (Aguiar-Conraria *et al.,* 2008). Second, wavelet coherence and phase differences simultaneously assess how co-movement and bidirectional causal links vary across frequencies and change over time in a time-frequency window. Third, wavelet analysis does not require strict conditions on time series, such as the unit root test, the co-integration test and the determination of the optimal lag length (Roueff and Sachs, 2011). Balcilar *et al.* (2010) prove that the dynamic link between the two series will be instable across different sub-samples in the presence of structural changes. Consequently, the conclusions in the full-sample period are unconvincing. Indeed, there have been times of structural changes in Slovakia since the Historical Change of Eastern Europe. After the peaceful dissolution of Czechoslovakia, as an independent state, Slovakia has initiated a series of reform processes and some market-oriented structural reforms to achieve macroeconomic stability. The country joined the EU in 2004 and the Euro zone in January 2009, which led to the reduction of the inflation rate and uncertainty. However, the global financial crisis in 2008 and the accompanying European sovereign debt crisis significantly reduced the high economic growth rates that were recorded so far. The average inflation rate in Slovakia was negative in three consecutive years. The result of the wavelet analysis indicates the significant positive causality between inflation and inflation uncertainty. It is consistent with the hypothesis of Friedman and Ball (1992) and Cukierman and Meltzer (1986), which indicates that inflation has a leading role in the inflation uncertainty in the short-term and the opposite interaction in the long-term in Slovakia. This finding suggests that we can achieve proper inflation uncertainty by controlling the inflation level.

This article is outlined as follows. Section 2 presents the literature review on this topic. Section 3 introduces the Friedman-Ball's theoretical hypothesis. Section 4 illustrates the methodology. Section 5 describes the corresponding data and provides the empirical results. Section 6 concludes the study.

2. Literature Review

Okun (1971) makes an initial statement that higher inflation in the current period is a driving factor for greater uncertainty about the future path of inflation rates. Friedman (1977) claims that there is a positive interaction between inflation and nominal uncertainty. He formalizes the potential of increased inflation to create nominal uncertainty that lowers welfare and even output growth. High inflation will create political pressure to reduce it. However, authorities may be concerned with the recessionary effects and therefore be reluctant to lower inflation, thus resulting in future inflation uncertainty. Fischer and Modigliani (1978) follow Friedman's view by revealing that an announcement of an unrealistic stabilization program in high inflation regimes may cause future inflation rates to be more uncertain. In contrast, Cukierman and Meltzer (1986) predict that higher inflation uncertainty will raise the inflation rate by increasing the incentives for the policy makers to create inflation surprises. However, Pourgerami and Maskus (1987) propose an opposite argument on the two variables' relationship and show that inflation has negative effects on its uncertainty. Specifically, in an accelerating inflation environment, market participants may input more resources in forecasting future inflation, which would reduce the inflation uncertainty. Holland (1995) proposes that higher inflation uncertainty will lower inflation due to the stabilization motives of policymakers. Conversely, Cosimano and Jansen (1988) and Baillie *et al.* (1996) find no significant relationship between inflation and inflation uncertainty. Daal *et al.* (2004) confirm that positive inflation shocks have stronger impacts on inflation uncertainty, but the evidence for causality in the opposite direction is mixed. Caporale *et al.* (2012) consider the structural break coinciding with the European Monetary Unit (EMU). They use a sequential dummy procedure and find that causality exists for EU countries after their participation in the EMU. A more recent study by Su *et al.* (2016) confirmed this bidirectional link. They stated that there is a bidirectional positive interaction of inflation and its uncertainty.

Although the studies about the mentioned relation attracted researchers' attentions, the results of these empirical results are still mixed. Existing studies generally state that a positive relation between inflation and inflation uncertainty exists in Japan and France, a negative link exists in the U.S. and Germany (Ball, 1992; Brunner and Hess, 1993; Evans and Wachtel, 1993; Grier and Perry, 1998; Fountas *et al*. 2004) and no significant association existed in India until the late 1980s (Balaji *et al*., 2016). There are scarce studies that are concentrated on Slovakia. Neanidis and Savva (2010) examine the newly EU-affiliated countries, and one of their findings is that inflation uncertainty has both negative and positive effects on inflation in Slovakia. However, the effect that inflation has on its uncertainty has not been proved. Furthermore, substantial studies employ the Granger casual test (Grier and Perry, 1998; Daal *et al.*, 2004) and the vector autoregression model (Balaji *et al*., 2016). However, they neglect the structural changes over long periods, and the traditional linear model in the full-sample interval cannot characterize this dynamic relation. Neanidis and Savva (2010) use dummy variables before and after the dates of EU accession to capture the existence of non-linear effects. Su *et al.* (2016) imply a bootstrap Granger full-sample causality and a sub-sample rolling window test to revisit the relationship and consider the impacts of structural changes. It is obvious that they do not take the different time and frequency domains into consideration.

3. The Friedman and Ball Hypothesis

Friedman (1977) studies the causal effect of inflation on its uncertainty and proposes a positive correlation between the level of inflation and inflation uncertainty, with higher inflation leading to greater uncertainty and lower output growth. Ball (1992) further claims that a higher current inflation rate induces more uncertainty about the future inflation rate because the public is not sure whether policymakers will t ry to reduce inflation. Holland (1993) explains the reason why inflation may precede uncertainty based on Evans and Wachtel's (1993) model. Evans and Wachtel (1993) present the inflation behavior as

$$\pi_t = a_t + b_t \pi_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim NID(0,1) \tag{1}$$

where: π_t is the inflation rate, ε_t is an independently and identically distributed disturbance, and a_t and b_t are time-varying parameters that reflect changes in the inflation regime. In this model, one regime implies that the inflation rate is stationary so that $b_t < 1$, and there are no restrictions on a_t. The other implies that the inflation rate is a random walk without drift so that $b_t = 1$ and $a_t = 0$.

Furthermore, Holland (1993) expresses the conditional variance of inflation that symbolizes inflation uncertainty as

$$E(\pi_t - \pi_t^*)^2 = E(a_t - a_t^*)^2 + E(b_t - b_t^*)^2 (\pi_{t-1})^2 + E(\varepsilon_t)^2, \;\; \varepsilon_t \sim NID(0,1) \tag{2}$$

where: π_t^*, a_t^*, and b_t^* denote conditional expectations on information from π_{t-1}, a_{t-1} and b_{t-1}, respectively. If regime changes cause unpredictable changes in the persistence of inflation, then $E(b_t - b_t^*)^2 > 0$, and the lagged inflation squared is positively associated with the inflation uncertainty. An increase in the rate of inflation would lead to an increase in inflation uncertainty.

Ball (1992) formalizes Holland's (1984) model of the relationship between inflation and inflation uncertainty in the context of an asymmetric game between the monetary authority and the public. In the model, exogenous shocks create low inflation equilibrium that will break down occasionally. If the current inflation is low, the inflation uncertainty will be low because the public considers that the monetary authorities will explore ways to maintain low inflation. By contrast, Cukierman and Meltzer (1986) support that higher inflation uncertainty leads to an increase in the inflation rate since it provides an incentive to policymakers to create an inflation surprise to stimulate real activity, which will lead to a positive correlation between uncertainty and optimal average inflation. Hence, the direction of causality runs from inflation uncertainty to inflation. In this paper, we intend to test whether Friedman and Ball's hypothesis (1992) and Cukierman and Meltzer (1986) are significant for Slovakia.

4. Wavelet Analysis

4.1 Continuous wavelet transform

Time series can be decomposed by the wavelet transform into numerous basis wavelets, which are transformed from a given mother wavelet by stretching and translating versions of it. As a result, it can be transformed into time domains and frequency domains, and the volatility of the series can be observed more intuitively. Continuous wavelet transform (CWT) is always utilized to extract features and detect data self-similarities (Grinsted *et al.*, 2004; Loh, 2013). Therefore, *CWT* is utilized to decompose the time series into wavelets. Generally, when utilizing the *CWT*, a given time series $x(t)$ can be transformed as follows:

$$W_x\,(\tau, s) = \int_{-\infty}^{+\infty} x\,(t)\psi_{\tau,s}^{*}\,(t)\,dt \tag{3}$$

where: * indicates the complex conjugation and $\psi_{\tau,s}^{*}\,(t)$ is the complex conjugate function. $\psi_{\tau,s}(t)$ is the basis wavelet function and can be deformed by the mother wavelet $\psi\,(t)$ as $\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\,\psi(\frac{t-\tau}{s})$. s is the wavelet scale that controls the mother wavelet, and τ is the location parameter that controls the center of the wavelet. By changing *s* and translating along τ, the amplitudes of $x(t)$ can be observed intuitively across scales and over time (Torrence and Compo, 1998).

There are numerous mother wavelets, such as the Haar, the Morlet, and the Mexican hat. This study utilizes the Morlet mother wavelet, which is the most popular and applicable and was introduced by Grossman and Morlet (1984). It is shown as follows:

$$\psi(t) = \pi^{-1/4}e^{i\omega_0 t}e^{-\omega_0^2/2} \tag{4}$$

where: $\pi^{-1/4}$ ensures the sum square of the Morlet is equal to 1 (*i.e.*, $\int_{-\infty}^{+\infty}\psi^2\,(t)dt = 1$) and $e^{-\omega_0^2/2}$ ensures that the Morlet satisfies the admissibility condition. The Morlet can achieve the optimal balance between time domains and frequency domains when $\omega_0 = 6$ (Grinsted *et al.*, 2004). Based on Aguiar-Conraria and Soares (2013), the Fourier frequency *f* is given by $f(s) = \omega_0/2\pi s$. The Fourier frequency *f* can be denoted as follows when ω_0 equals 6: $f = 6/2\pi s \approx 1/s$. In this case, the scale of the wavelet is approximately equal to the reciprocal of the Fourier frequency. As a result, the time series decomposes into a joint time-frequency plane in which the short (long) wavelet scale corresponds to the higher (lower) frequency. Moreover, considering the complexity of the Morlet, we divide the *CWT* into the real part and the imaginary part. As such, the amplitudes and phases of the *CWT* can be calculated for further estimations of the wavelet power spectrum, the wavelet coherence and the phase difference.

4.2 Wavelet power spectrum

The localized variance of time series $x(t)$ at each scale or frequency can be measured by the wavelet power spectrum (the auto-wavelet power spectrum) and simply defined as $|W_x(\tau,s)|^2$. Furthermore, since Hudgins *et al.* (1993) propose the cross-wavelet transform of $x(t)$ and $y(t)$ as $W_{xy}(\tau,s) = W_x(\tau,s)W_y^*(\tau,s)$, the cross-wavelet power spectrum is accordingly written as

$$\left|W_{xy}(\tau,s)\right|^2 = |W_x(\tau,s)|^2\left|W_y^*(\tau,s)\right|^2 \tag{5}$$

where: * indicates the complex conjugation. The localized variance of time series $x(t)$ and $y(t)$ can be measured by the cross-wavelet power spectrum in the specified frequency domains. In this study, the wavelet power can be found by the color bars on the right side, where red colors are recognized as high power and blue colors correspond to low power.

4.3 Wavelet coherence and phase difference

Wavelet coherence can simultaneously consider both the time and frequency components and the strength of correlation between the time-series components (Loh, 2013). As a result, compared to the conventional correlation analysis, wavelet coherence provides a more convincing measure of co-movement between variables (Zhou, 2010; Liow, 2012; Loh, 2013). Implying the cross-wavelet and auto-wavelet power spectrums, the wavelet coherence of two series can be estimated as follows (Torrence and Webster, 1999):

$$R_{xy}^2(\tau,s) = \frac{\left|S\left(s^{-1}W_{xy}(\tau,s)\right)\right|^2}{S(s^{-1}|W_x(\tau,s)|^2)S\left(s^{-1}\left|W_y(\tau,s)\right|^2\right)} \tag{6}$$

where: S is the smoothing operator constructed by the accumulation in time and frequency (Torrence and Compo, 1998). The wavelet coherence $R_{xy}^2(\tau,s) \in [0,1]$ is calculated in a time-frequency dimension. Values close to zero indicate weak correlation, while values close to one provide evidence of strong correlation.

The phase difference is employed to provide detailed evidence on the positive or negative co-movements and the lead-lag relationships between variables because the wavelet coherence is squared. The relationship between $x(t)$ and $y(t)$ can be characterized by the phase difference (Torrence and Webster, 1999; Bloomfield *et al.*, 2004) as follows:

$$\phi_{xy} = \tan^{-1}\left(\frac{\Im\left\{S\left(s^{-1}W_{xy}(\tau,s)\right)\right\}}{\Re\left\{S\left(s^{-1}W_{xy}(\tau,s)\right)\right\}}\right), \text{with } \phi_{xy} \in [-\pi,\pi] \tag{7}$$

where: $\Im$ and $\Re$ are the hypothetical and real parts of the smooth power spectrum, respectively.

Specifically, a phase difference of zero suggests that the two underlying series move in the same direction at the specified time-frequency. Meanwhile, a phase difference of π $(-\pi)$ indicates that they move in the opposite direction. If $\phi_{xy} \in (0,\frac{\pi}{2})$, then the two series move positively (in phase) with $x(t)$ leading $y(t)$. If $\phi_{xy} \in (\frac{\pi}{2},\pi)$, then the series move negatively (out of phase) with $y(t)$ leading $x(t)$. If $\phi_{xy} \in (-\pi,-\frac{\pi}{2})$, then the series move negatively with $x(t)$ leading $y(t)$. If $\phi_{xy} \in (-\frac{\pi}{2},0)$, then the series move positively with $y(t)$ leading $x(t)$.

5. Data and Empirical Result

We employ the data of the monthly consumer price index (CPI)[5] for Slovakia for the period ranging from 1991 to 2015. The data is collected from the Federal Reserve Economic database[6]. Inflation is widely recognized as the monthly difference of the logarithm of the CPI (Grier and Perry 1998; Fountas *et al.*, 2004; Jiranyakul and Opiela, 2010). One of the crucial variables to be used in the empirical analysis is the inflation uncertainty. The empirical literature begins with the assumption that the standard deviation of inflation is a valid measure of the differences in inflation uncertainty (Fischer, 1981). However, uncertainty is distinguished from the variability by its unpredictability and stochasticity (Grier and Perry, 1998). Predictable fluctuations in a variable will show up in standard deviation measures, although they produce no true economic uncertainty. Generalized autoregressive conditional heteroscedasticity models (GARCH) techniques specifically estimate a model of the variance of unpredictable fluctuations in a variable rather than simply calculating a variability measure from past outcomes (moving standard deviation) or conflicting individual forecasts (Engle, 1982; Bollerslev, 1986). That is, a GARCH model estimates a time-varying residual variance that corresponds well to the notion of uncertainty in Friedman and Ball's (1992) hypotheses. Furthermore, GARCH models with fat-tail distributions are better suited for analyzing the volatilities of shocks (Ali, 2013).

Although the GARCH technique captures the properties of clustering and leptokurtosis in uncertainty, their distributions are symmetric, and they fail to model this leverage effect. Indeed, it has been verified by Brunner and Hess (1993) and Fountas and Karansos (2007) that the behavior of inflation uncertainty is asymmetric rather than symmetric. They find that the effects of positive inflation shocks or the effects of negative shocks on inflation uncertainty are significantly different. The signs and the magnitudes of the shocks have asymmetric effects on average inflation. As a result, the empirical results in GARCH may not be accurate. Thereby, certain nonlinear extensions of GARCH have been proposed. For instance, these include Nelson's (1991) exponential GARCH (E-GARCH) model, Glosten *et al.*'s (1993) GARCH (GJR-GARCH) and Heston and Nandi's (2000) power GARCH (PGARCH).

We use a series of non-linear GARCH models to estimate the inflation uncertainty and present the results in Table 1. The parameters in the GARCH, GJR-GARCH and EGARCH are significant at the 99% confidence interval. Then, we use the Akaike information criterion (AIC) and log-likelihood to measure the optimal model among these methods. It can be seen that the value of AIC in the GJR-GARCH is the smallest and the value of log likelihood is the biggest. Thus, the optimal choice is the GJR-GARCH for measuring the inflation uncertainty, which is given by $\sigma_t^2 = c_1 + \sum_{j=1}^{p} c_2\sigma_{t-j}^2 + \sum_{i=1}^{q} c_3\varepsilon_{t-i}^2 + \sum_{i=1}^{q} c_4\varepsilon_{t-i}^2 * I_{t-i}$, where the p and q are equal to 1.

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[5] *These data are collected and reported at a monthly frequency. Thus, estimating the models using data at lower frequencies (quarterly or annually) involves averaging or even discarding some information without gaining a longer sample, at least in the case of quarterly data. Moreover, monthly data are more appropriate from the point of view of the monetary authority due to the long lags in the implementation of monetary policy. Monthly sampling provides a robustness check for the quarterly results.*

[6] *The data source is linked as https://fred.stlouisfed.org.*

Table 1

Comparing the different GARCH model parameters

Models	$C(1)$	$C(2)$	$C(3)$	$C(4)$	AIC	Log likelihood
GARCH	8.749***	5.281***	-7.570***	13.546***	-6.550	954.749
GJR-GARCH	13.191***	2.630***	218.389***	13.546***	-6.677	969.649
EGARCH	-14.030**	-2.912***	8.682***	20.377***	-6.637	967.415
PGARCH	1.088	-2.349**	139.045***	19.776***	-6.659	974.220

Note: *, **, *** denote significance at 10, 5 and 1% levels, respectively.

In the sample period, huge fluctuations occur on the inflation, and the inflation uncertainty also varies with the inflation. From 1991 to 2015, significant economic events shocked Slovakia, which may have induced a series of unpredictable structural changes. Specifically, since the authoritarian Communist rule in Czechoslovakia ended in 1989, Slovakia became an independent state on January 1993 after the peaceful dissolution of Czechoslovakia. Slovakia has initiated a thorough reform process and market-oriented structural reforms to achieve macroeconomic stability. The reform programs included various combinations of stabilizing measures, deregulation, liberalization, institutional reforms and privatization (Iša, 1996). It passed through a transition process from being a centrally planned economy to becoming a free market-oriented economy. The National Bank of Slovakia abolished the fixed exchange rate in October 1998, and since then its explicit goal has been the stability of the price level in the area of managed floating. The higher price liberalization decreases the inflation level (Bánociová and Pavličková, 2013). Inflation dropped from an average annual rate of 12% in 2000 to just 3.3% in 2002. After joining the EU in 2004, combined with the rising labor costs and changes in indirect taxes, inflation rose again. Slovakia became a member country of the Eurozone. From then on, it passed through a high and sustained economic growth compared to the EU member countries. However, the global financial crisis in 2008 and the accompanying European sovereign debt crisis have had adverse consequences on the economy. The inflation rate reached only 1% in 2010, which is the lowest recorded rate since 1993.

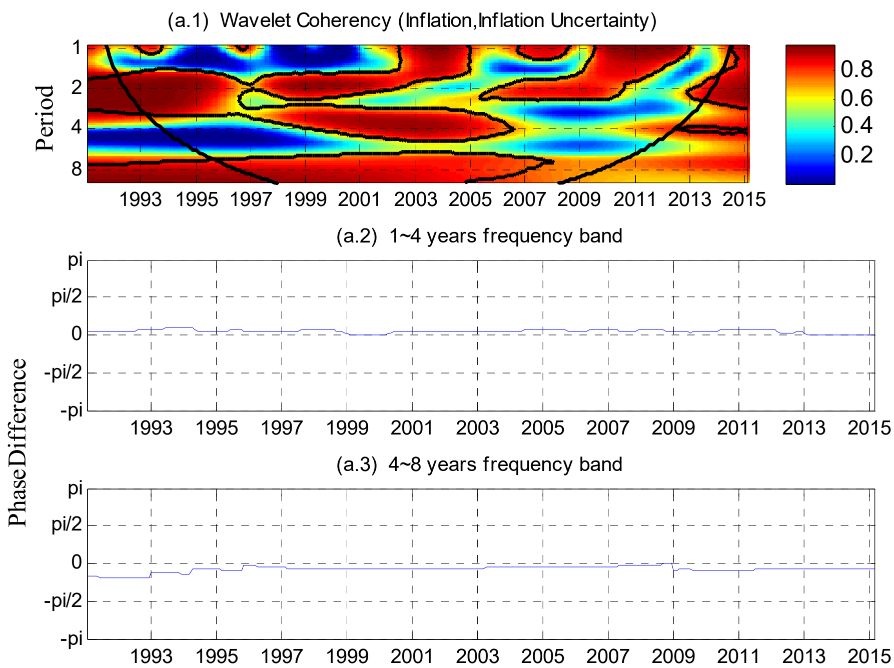
To assess the statistical significance of the correlation in the time-frequency space, we use Monte Carlo simulations. Figure 1 shows the estimated wavelet coherence and the phase difference results. Time is shown on the horizontal axis, while the vertical axis refers to the frequency. The thin black line borders the cone of influence (COI), which is the edge effect that arises from the boundary conditions on a dataset with a finite length (Torrence and Compo, 1998; Percival and Walden, 2000). The periods outside the COI (lighter shade) must be neglected since they do not possess statistical influence. The wavelet figures depict the power at each time-frequency region inside the black lines associating with colder colors (the colder the color is, the less dependent the series are, with blue at the extreme) with lower power and hotter colors (in the extreme, red) with higher power. Cold regions outside the significant areas represent time and frequencies with no dependence in the variables (Conraria *et al*., 2013). Thus, we can clearly see both the frequency and the time intervals where the variables move together significantly. A continuous wavelet transform at any given point uses the information of neighboring data points so that the areas at the beginning and end of the time interval should be interpreted with caution, as discussed in the previous sections. The horizontal axis shows the time, and the vertical axis shows the time scales in years. (For convenience, in the vertical axis of the spectrum, we have converted frequencies into cyclical periods in years.) Time scale 1 denotes 1-4 years (we separate it into 1-2 and

2-4 years when analyzing the results to make them clearer), and time scale 2 denotes 4-8 years.

We then employ the wavelet analysis to test the bidirectional causal relationship between inflation and inflation uncertainty in Slovakia. From Figure 1, the strong causal relationship between the two series in most periods can be found. More specifically, Figure 1 (a.1) and (a.2) show that from 2002 to 2005 and 2007 to 2013, inflation leads the inflation uncertainty positively ([0, π/2]) in the scale of 1-2 years. Furthermore, between 1993 and 2007, the causal relationship can be observed in the 2-4 years frequency. Combined with Figure 1 (a.1) and (a.3), we can find that from 1995 to 2008 inflation uncertainty positively leads inflation ([0, -π/2]) and shows uncertainty with an average coherence of 0.8 across the band in the 4-8 years frequency. In the other periods, no linkage exists between the inflation and inflation uncertainty, which reflects that there is not always a bidirectional relationship between inflation and its uncertainty.

Figure 1

Causality between Inflation and Inflation Uncertainty (1992 M1-2015 M3)



Notes: 1. The thick black contour denotes the 5% significance level estimated from Monte Carlo simulations. The y-axis refers to the frequencies (measured in years), and the x-axis refers to the time period 1992 M1-2015M3. The color bar on the right side corresponds to the strength of the correlation at each frequency. Specifically, the deeper the color, the higher coherence, which means a stronger correlation.

2. We use MATLAB to run the code, which was originally written by Aguiar-Conraria and Soares (2010).

Specifically, between the years 2002 and 2005, inflation precedes inflation uncertainty and plays a positive role. In this period, chaos erupted in the domestic political party election. Meanwhile, the process of participation in the EU was also in full swing. When Slovakia officially became a member of the EU, the ongoing reforms and integration processes created favorable conditions for strong economic growth. With the inflation rate increasing tremendously, the inflation uncertainty remained at a relatively high level. The short-term links were significant again from 2007 to 2013 when the global financial crisis and the European sovereign debt crisis occurred. In this timeframe, inflation rates in Slovakia experienced a new upward trend. To survive this debt crisis, the European Financial Stabilization Fund (EFSF) expansion plan was proposed. However, this plan did not pass the vote of Slovakia, which leads to the current government being forced to step down. Finally, the Slovak government agreed on the EFSF proposal at the end of 2011. As a result, the public increased their expectations of future inflation uncertainty. In the medium-term perspective (2-4 years frequency), the causal relationship lasted from 1993 to 2007. Since Slovakia became an independent state, it achieved high-speed growth in its macroeconomy as a consequence of the progressive structural reforms and modernization (Iša, 1996). Inflation was generally declining, and the inflation uncertainty was also on a downward trend. In 2007, when the global sub-prime crisis erupted and furiously spread around the world, the causality between these two series is interrupted. In addition, there exists a significant causal link in the long-term (4-8 years frequency) horizon during 1995 and 2008. Moreover, inflation uncertainty precedes the inflation positively, which is consistent with the empirical evidence provided by Grier and Perry (1998) and Berument *et al.* (2005). The long-term causal linkage was destroyed by the financial crisis in 2008, which reduced global demand. The inflation rate dropped sharply and reached approximately 1% in 2010. It provided an incentive to Slovak policymakers to create an inflation surprise to stimulate output growth (Cukierman and Meltzer, 1986). The central bank cut the benchmark interest rate by 50 basis points and enlarged the scale of loans to support enterprises.

Overall, bidirectional causality exists between inflation and inflation uncertainty, both in the short term and the long term. Specifically, inflation precedes the inflation uncertainty positively in the short and medium term, which is consistent with the opinions of Friedman and Ball (1992). High inflation will lead to higher uncertainty. From the perspective of short-term interactions, the causal relationship in two series occurs two times, which are 2002-2005 and 2007-2013. As a result, domestic shocks and impacts by neighboring European countries will lead to the intrinsic causal relationship, while the huge external fluctuation would hinder the medium- and long-term causality. In the long-term horizon, inflation uncertainty precedes inflation positively, which can be attributed to the stimulation motives to retain relatively higher output growth (Cukierman and Meltzer, 1986). The interaction relation ended in 2008 because the Euro areas were dented by the economic downturn of the subprime financial crisis. During this period, substantial declines were observed in industrial production and exports (Dąborowski, 2011), which resulted in the decline of demand for industrial production. Consequently, the inflation rates in Slovakia fell continuously and reached their lowest level, which was close to zero (Su et al., 2016). The subsequent European debt crisis depressed investors’ enthusiasm and played a negative role in the confidence for the inflation expectation. However, in the current circumstances, the average inflation rate in Slovakia was negative in consecutive years from 2014-2015, and we cannot find evidence to support this co-movement relationship. This is reasonable because the European Central Bank (ECB) implemented a target inflation policy that interfered in the co-movement between these two variables. Thereby, in these periods of negative inflation, the stabilization policy should consider that output is a more appropriate target than inflation because inflation has been very low during the crisis (since 2009). The urgent priority for Slovakia is to aim to encourage economic growth in this condition. Additionally, inflation evolution should be adequately compensated by the interest rate setting (Sinicakova and Gavurova, 2017).

6. Conclusion

This study attempts to investigate the relationship between inflation and inflation uncertainty based on Friedman and Ball's (1992) hypothesis in a dynamic framework in Slovakia. To examine this relationship accurately, we employ the wavelet analysis method, which allows us to assess how causality varies in both the time and frequency domains. The empirical results argue that the positive relationship between inflation and inflation volatility is well established. Specifically, inflation positively leads to inflation uncertainty in the short and medium term, which is in line with Friedman and Ball's (1992) hypothesis. Furthermore, inflation uncertainty positively leads inflation over long-term periods (Cukierman and Meltzer, 1986). However, structural changes may have effects on the causal relationship. The short-term linkage of these two series occurs in the fluctuation period. Meanwhile, the volatility of the international economic framework will exert medium- and long-term shocks on Slovakia's inflation and inflation uncertainty. As higher inflation will increase the inflation uncertainty in the short term, disinflation programs could be adopted to lower inflation in order to reduce the current uncertainty (Berument *et al.*, 2011). However, in a period of negative inflation, the stabilization policy should consider that output is a better target than inflation because inflation was very low during the crisis. Thereby, the policy implication is to balance the level of inflation rates in order to reduce the negative consequences of uncertainty.

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