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Bidirectional linkage between inflation and inflation uncertainty – the case of Eastern European countries

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This paper explores bidirectional linkage between inflation and its uncertainty by observing monthly data of 11 Eastern European countries. The methodological approach comprises two steps. First, inflation uncertainty series have been created by choosing an optimal Generalized Autoregressive Conditional Heteroskedasticity- (GARCH) type model. Subsequently, inflation and inflation uncertainty have been observed together by two models examining whether Friedman's and Cukierman–Meltzer's hypotheses hold for selected Eastern Europe Countries (EEC). Due to the heterogeneous behaviour of some series of inflation and inflation uncertainty, the unconditional quantile regression estimation technique has been applied because of its robustness to the particular non-normal characteristics and outliers' presence in the empirical data. According to the findings, both Friedman's and Cukierman–Meltzer's hypotheses have been confirmed primarily for the largest EEC with flexible exchange rate. In contrast, these theories are refuted in smaller, open economies with firm exchange rate regime.

Keywords: inflation; inflation uncertainty; GARCH; quantile regression; Eastern European countries

JEL Classification: C32; C51; E31

1. Introduction

Since the initiation of the economic reforms in the early nineties, the inflation stability has been one of the most important *de jure* priorities for monetary authorities in every Eastern Europe transition country. Nonetheless, the convergence towards the European Monetary Union (EMU) integration presents an additional argument for price stability achievement. Almost all Eastern European countries (EEC) suffered high inflation (in some cases hyperinflation), which was an inherited problem from the previous pre-transition period. Monetary authorities of these countries were hesitant about what kind of policy to pursue (tighter or looser) in order to mitigate the cost of inflation as much as possible, without slowing economic growth. Adopting a more strict monetary approach, which imply a higher interest rate, may eventually decrease economic growth and increase unemployment rate. On the other hand, following more flabby policy may cause the rising of uncertainty among economic agents and result in the collapse of price mechanism and allocation of scarce resources. Therefore, finding the linkage between inflation rate and

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inflation uncertainty has been a prime concern of policy-makers as well as various researchers throughout much of the past several decades.

The first scholar who analysed this question was Friedman (1977), who eventually received the Nobel Prize for his research on the topic. He asserted that rise in inflation might instigate an inconsistent and even erroneous monetary policy response that could lead to the increase in inflation uncertainty in future periods. When relatively high inflation occurs in some periods, market agents become unsafe about behaviour of monetary authorities, that is, they do not know whether the central bank is ready to tolerate costs of recession with the aim to tackle higher inflation or not. This kind of precarious monetary policy could induce greater volatility regarding future inflation. He also claimed that the presence of higher inflation uncertainty in the system violates the effectiveness of the price mechanism and causes the inefficient resource allocation. Likewise, he underscored that increased inflation uncertainty caused by higher inflation may reduce public welfare and economic growth. Due to the suspense about future policy-makers' actions, individuals alter or postpone their decisions about investments and savings. Under higher inflation uncertainty, the real value of future cash flows is unknown which has negative effects on the level of economic activities.

The causality relation might also run in the opposite direction, from inflation uncertainty to average inflation, as Cukierman and Meltzer (1986) argued. They claimed that central banks differ when it comes to the priority of their objectives, such as high output growth and low inflation. In such a manner, less conservative monetary authorities may have a greater tendency towards discretionary policy to create inflation surprises in the presence of more inflation uncertainty. This opportunistic act is an attempt of the central bank to incite higher short-term economic growth. They concluded that inflation and inflation uncertainty have positive correlation that runs from inflation uncertainty to inflation. On the other hand, according to Holland (1995), the inflation uncertainty has a negative impact on the inflation rate because of the central bank's stabilizing policy, the so-called 'stabilizing Fed hypothesis'. He claimed that as inflation uncertainty rises due to increasing inflation, the monetary authorities answer with contraction of money supply growth decreasing inflation uncertainty and the associated adverse welfare effects.

The literature on the relation between inflation and inflation uncertainty is vast, however to the best of authors' knowledge very few papers refer to East European countries. This paper complements the existing findings on this issue, investigating two-way relations between inflation and inflation uncertainty in 11 Eastern European emerging countries, namely: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. Four of these countries joined the European monetary union relatively recently and handed over its monetary sovereignty to the European Central Bank (ECB). The four countries are Slovenia (January 2007), Slovakia (January 2009), Estonia (January 2011), and Latvia (January 2014). The estimation procedure in the paper is two-fold. First, we generated inflation uncertainty proxy seeking an optimal auto-regressive moving average (ARMA)(p,q)-GARCH(1,1) type model. The choice was between ordinary symmetric Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model and the three asymmetric models: TGARCH, EGARCH, and PGARCH, which provide fewer restrictions on the behaviour of uncertainty. Consequently, the best-fitted model was used to generate the conditional variances series of inflation uncertainty. In the second step, inflation and inflation uncertainty were put together in two unconditional linear models examining whether the above-mentioned Friedman's and Cukierman–Meltzer's hypotheses stand for selected EEC. We applied the quantile regression estimation technique, robust to particular non-normal features, due to outliers' presence in some series.

The remainder of the paper is as follows. Section 2 envisages the theoretical survey and related studies on this issue. Section 3 introduces the research methodology. Section 4 considers the data description and Section 5 presents the research results. Section 6 presents the conclusion.

2. Literature review

The extant studies on this topic are abundant; however, the conclusions about the connection between inflation and its uncertainty are somewhat unclear due to ambiguous empirical evidence. The following paragraphs present some of the most recent works that advocates positive as well as negative correlation between inflation and inflation uncertainty, that is, stand in line or reject Friedman's and Cukierman–Meltzer's hypotheses. Jiranyakul and Opiela's (2010) examined ASEAN-5 countries using Granger causality regression, while inflation uncertainty series was generated by the AR(p)-exponential GARCH (EGARCH)(1,1) model. Results showed that rising inflation increases inflation uncertainty and vice versa in all five countries. The conclusion was that even in low-inflation emerging markets, as ASEAN-5 countries, inflation could lead to inflation uncertainty and vice versa. Jones and Olson (2013) evaluated the time-varying correlation between macroeconomic uncertainty, inflation, and output. They used the monthly, policy-related uncertainty index which spans from January 1985 through January 2012 and combines three index components (the number of references to policy-related uncertainty in 10 leading newspapers, the number of federal tax code provisions and extent of disagreement among economic forecasters over future federal government purchases and consumer price index (CPI) levels). Estimation results from a multivariate dynamic conditional correlation (DCC)-GARCH model indicated that the correlation between uncertainty and inflation became positive during the late 1990s and early 2000s.

Hartmann and Herwartz (2012) tested for causality between inflation and its associated uncertainty by means of both in-sample and out-of-sample modelling. They analysed a sizable number of developed economies and found evidence in favour of Friedman's hypothesis. The paper of Daal, Naka, and Sanchez (2005) also found the evidence which supports Friedman's stance. They scrutinized 22 developed and developing countries via the power GARCH methodology and Granger causality. The authors found the evidence that positive-inflationary shocks have stronger impacts on inflation uncertainty for both developed and emerging countries. Neanidis and Savva (2013) used an asymmetric bivariate Smooth Transition VAR EGARCH-M system for analysis in G7 countries. They found a positive effect of inflation uncertainty on the mean inflation. Using a large panel of developing and developed countries, Kim and Lin (2012) found two-way interactions between inflation and its variability. They confirmed Friedman's hypothesis, asserting that higher inflation increases inflation volatility. Additionally, they concluded that greater inflation volatility fuels inflation, which is consistent with Cukierman and Meltzer's arguments. Their findings provided evidence that the positive relationship between inflation and inflation uncertainty varies depending upon the position of a country. According to their results, the positive volatility effect of inflation is larger in the countries with less trade openness, more fiscal dominance, lower incomes, and inflation targeting policy than in the countries with the converse attributes.

Balcilar, Ozdemir, and Cakan (2011) investigated the dynamic relationship between monthly inflation and inflation uncertainty in three developed countries, namely Japan, the USA and the UK, by using linear and nonlinear Granger causality tests for a relatively large time span. Their empirical evidence indicates bidirectional causality between observed series. In accordance with Friedman's prediction, the linear vector autoregressive (VAR) and nonparametric regression models show that higher inflation rates lead to greater inflation uncertainty in all countries. They confirmed Cukierman–Meltzer's hypothesis as well, claiming that nonparametric estimates show that inflation uncertainty raises average inflation in all countries. The study of Jiranyakul and Opiela (2011) tested the impact of inflation uncertainty on inflation and output growth on Thailand. They modelled inflation and output uncertainty with a bivariate constant conditional correlation GARCH specification. The created series was inserted in Granger causality tests with the

purpose to make conclusions about the effect of monetary policy-induced inflation uncertainty. Causality tests displayed a positive relation from inflation to inflation uncertainty, which is in accordance with Friedman's prediction. Their result showed that inflation decreased as inflation uncertainty increased, which is in line with the 'stabilizing central bank' hypothesis. However, these results prove to be non-significant; hence, the conclusion is not consistent with the assumption that the Bank of Thailand minimizes the real costs of inflation. Berument, Yalcin, and Yildirim (2012) examined the direct relationship between inflation and inflation uncertainty using a dynamic method for the seasonally adjusted monthly data of the United States CPI. His methods of choice were stochastic volatility in mean models, trying to capture the shocks to inflation uncertainty within a dynamic framework. These particular models allow the dynamic effects estimation of innovations in inflation, as well as inflation volatility on inflation and inflation volatility over time, by embedding the unobserved volatility as an explanatory variable in the mean (inflation) equation. Empirical indication from the impulse responses propounded that shock to inflation volatility increases inflation which is consistent with Cukierman–Meltzer's proclamation.

Number of papers confirmed causality between inflation and inflation uncertainty in both directions, but some studies found only unidirectional nexus. For instance, Fountas (2010) examined the relationship between inflation uncertainty, inflation, and growth using the annual historical data of 22 industrial countries covering time span more than one century. Author represented inflation uncertainty by using the conditional variance of inflation shocks. The evidence proved the positive impact of inflation uncertainty on inflation supporting Cukierman–Meltzer's hypothesis. However, he found mixed evidence concerning the effect of inflation on inflation uncertainty, thus providing only partial support to Friedman's hypothesis. Daal et al. (2005) scrutinized a vast sample of 22 developed and developing countries. They found mixing results for Cukierman–Meltzer's claim. The authors reported significant positive effects for UK, Germany, Italy, but negative effects (not significant) for Canada and France. As for emerging countries, statistically significant negative effects were found for three Latin American countries and India, while positive effects were found for Egypt, Indonesia, Bahrain, and Argentina. They argued that the negative sign might be interpreted as a proof of stabilization behaviour in these countries.

In the study of Chen, Shen, and Xie (2008), the flexible regression model of Hamilton (2001) was used to investigate the relationship between inflation and inflation uncertainty in the four Eastern Asian countries: Taiwan, Hong Kong, Singapore, and South Korea. They found compelling statistical evidence in favour of Friedman's hypothesis, except for Hong Kong. The results showed that inflation uncertainty increases in both high and low inflationary periods. They asserted that these findings could help policy-makers to identify a target rate of inflation and consequently minimize inflation uncertainty and diminish economic harm. Additionally, they discovered evidence which supports Cukierman–Meltzer's hypothesis in the case of Hong Kong, Singapore, and South Korea. This implied that monetary authorities of these three economies put a greater emphasis on growth, rather than on inflation stability. By contrast, Taiwan's monetary authorities demonstrated such behaviour only below a specific level of inflation uncertainty. In all the other cases, Taiwan's central bank chose stabilizing policy to prevent economic detriment brought by inflation uncertainty. Fountas, Ioannidis, and Karanasos (2004) investigated the relationship between inflation and inflation uncertainty in six European Union countries. Using the EGARCH methodology to create a measure of inflation uncertainty and the Granger method for causality assessment, they found that inflation significantly raises inflation uncertainty in all European countries except Germany, as predicted by Friedman. However, less robust evidence was found regarding the direction of the impact. For instance, increased inflation uncertainty lowers inflation in the Netherlands and Germany, while increased inflation uncertainty raises inflation in Spain, Italy, and to some extent in France. They concluded that these results

are in favour of a common European monetary policy applied by the ECB. The ECB monetary policy might lead to asymmetric real effects via the inflation uncertainty channel.

Chang (2012) tested whether changes in the specification of distribution and regime shifts impact the inflation–inflation uncertainty relationship in the USA. He found that these two factors have a vital effect on this relation. After taking into account the independent regime shifts and non-normal density distribution, the author disclosed slightly surprising results that inflation uncertainty has no impact on inflation, regardless of the inflation pressure. Likewise, contrary to Friedman’s hypothesis, he claimed that inflation has a negative impact on inflation uncertainty during the periods of high inflation volatility, while the influence of inflation on inflation uncertainty is statistically insignificant during periods of low inflation volatility.

3. Methodological approach

The closer inspection on the empirical data and the unconditional distributions of the selected countries in Section 4 shows that some series have prominent kurtosis and non-normal feature as inherent properties. Many authors who consider this issue preferred to use Granger causality test. However, in the case when normality conjecture is severely violated, such a method would be inappropriate and probably misleading. As emphasized by Lee and Zeng (2011), Miles and Schreyer (2012), Lin and Chu (2013), the least-squares estimator is inefficient and could induce erroneous and aberrant conclusions if there are outliers in the data. Large residuals caused by outliers produce a greater weight of the extreme observations after squaring, which eventually render bias estimates. The second problem is that the influence of the regressors on the dependant variable could be notably different regarding various points of the regressand’s distribution. As Koenker and Hallock (2001) asserted, the problem cannot be solved by running an ordinary least squares (OLS) on a subsets obtained by classifying the sample into high, medium, and low values of dependent variables. Therefore, we decided to use quantile regression inferential procedure, which is robust to the presence of outliers and non-normal characteristics.

The aim of the research is to test Friedman’s hypothesis (Equation (1)), as well as Cukierman–Meltzer’s hypothesis (Equation (2)) on the selected group of Eastern European countries. Accordingly, two linear equations that examine the bidirectional relationship between inflation and its uncertainty, regarding the ϕ th quantile of the dependent variable distribution, look like:

$$\nu_{t,n} = \alpha_{\phi} + \beta_{\phi} \pi_{t-1,n} + \varsigma_{\phi,t}, \quad (1)$$

$$\pi_{t,n} = \gamma_{\phi} + \lambda_{\phi} \nu_{t-1,n} + \xi_{\phi,t}, \quad (2)$$

where ν and π signify inflation uncertainty and inflation, respectively. α , β , γ , and λ are the unknown parameters to be estimated under the different quantile (ϕ) of the regressand’s distribution. ζ and ξ are the usual white noise error terms observed for the number of quantiles. Symbol (t) describes the number of observations, while (n) stands for the particular country. The values of β_{ϕ} and λ_{ϕ} are the measures of the particular quantile slope coefficient and they gauge the speed of mean reversion of the regressand within each quantile. Considering β parameter (the same applies for λ), quantile regression (QR) estimate (β) is the solution to the following minimization problem:

$$\min_{\beta \in \mathbb{R}^p} \left[\tau \sum_{Y_t \geq \hat{\beta} X_t} |Y_t - \hat{\beta} X_t| + (1 - \tau) \sum_{Y_t < \hat{\beta} X_t} |Y_t - \hat{\beta} X_t| \right]. \quad (3)$$

In order to measure inflation uncertainty, we have followed number of papers such as Fountas et al. (2004), Conrad and Karanasos (2005), Wilson (2006), Fountas and Karanasos (2007), and Ozdemir and Fisunoglu (2008) and decided to measure conditional variance of inflation in a similar way, via the GARCH framework. It permits inflation’s variability testing over time. In terms of specification robustness, authors experimented with several GARCH models, the ordinary symmetric GARCH model and the three asymmetric models: TGARCH, EGARCH, and PGARCH. The mean equation in every GARCH model was composed of ARMA(p,q) specification. The general form of ARMA(p,q) parameterization could be described as follows:

$$\pi_{t,n} = C_n + \sum_{i=1}^p \omega_{i,n} \pi_{t-i,n} + \sum_{j=0}^q \varpi_{j,n} \varepsilon_{t-j} + \varepsilon_{t,n}, \tag{4}$$

$$\varepsilon_{t,n} | I_{t-1} \sim \text{NID}(0, h_{t,n}), \tag{5}$$

where $\pi_{t,n}$ is inflation, $\pi_{t-i,n}$ and $\varepsilon_{t-j,n}$ represent autoregressive and moving average term, respectively, considering specific country (n). The random white noise process, given by Equation (5), is normally and independently distributed and depends on the information set I_{t-j} . The conditional and unconditional means of ε_t are equal to zero. The conditional variance (h_t) of ε_t are given below, assuming four GARCH specifications: ordinary symmetric GARCH (Equation (6)), TGARCH (Equation (7)), EGARCH (Equation (8)), and PGARCH (Equation (9))

$$h_{t,n} = a_n + b_n h_{t-1,n} + c_n \varepsilon_{t-1,n}^2, \tag{6}$$

$$h_{t,n} = a_n + b_n h_{t-1,n} + c_n \varepsilon_{t-1,n}^2 + d_n \varepsilon_{t-1,n}^2 I_{t-1}; I_{t-1} = 1 | \varepsilon_{t-1} < 0; I_{t-1} = 0 | \varepsilon_{t-1} \geq 0, \tag{7}$$

$$\ln(h_{t,n}) = a_n + b_n \ln(h_{t-1,n}) + c_n \left| \frac{\varepsilon_{t-1,n}}{\sqrt{h_{t-1,n}}} \right| + d_n \frac{\varepsilon_{t-1,n}}{\sqrt{h_{t-1,n}}}, \tag{8}$$

$$h_{t,n} = a_n + b_n h_{t-1,n} + c_n (|\varepsilon_{t-1,n}| - \psi \varepsilon_{t-1,n})^\delta. \tag{9}$$

Inflation in every country is evaluated by each single GARCH model. The goal was to find the best-fitted model which recognizes the specific inflation dynamics of the observed country. The optimal GARCH model was subsequently used to create inflation uncertainty series and eventually utilized for verification/rejection of Friedman’s and Cukierman–Meltzer’s hypotheses in Equations (1) and (2).

4. Data description

4.1. Empirical data analysis

Data set used in this paper comprises monthly observations of the inflation in the selected group of EEC. The observed period ranges from February 1996 to December 2013 for every country except for Bulgaria and Croatia. The starting date for Bulgaria is January 1997 and for Croatia February 1998. All data were collected from the Eurostat database. Table 1 discloses the nature of unconditional distribution of inflation series, as well as their unit-root tests. It introduces summary statistics of the observed series for every country: first four moments, median value, augmented Dickey–Fuller unit-root test, and Jarque–Bera (JB) test of normality. The findings suggest that some inflation series expresses significant erratic behaviour followed by severe

Table 1. Summary statistics of unconditional distribution of inflation series.

	BUL	CRO	CZH	EST	HUN	LAT	LIT	POL	ROM	SLK	SLO
Mean	1.933	0.242	0.263	0.393	0.573	0.375	0.293	0.400	1.726	0.398	0.390
Median	0.4	0.2	0.2	0.3	0.5	0.4	0.2	0.3	0.8	0.2	0.4
St.dev.	17.291	0.422	0.585	0.519	0.679	0.627	0.583	0.554	2.969	0.782	0.554
Skew.	13.376	0.123	2.408	1.175	1.133	0.432	1.191	1.528	5.803	4.113	-0.163
Kurt.	185.43	3.037	12.303	7.154	5.534	3.786	5.715	7.507	49.528	24.197	2.642
JB	28,8977.6	0.489	983.18	204.04	103.48	12.224	116.81	265.65	20,599.7	4631.28	2.099
ADF(8)	-11.59*	-10.89*	-3.82*	-7.24*	-2.89**	-4.06*	-10.69*	-8.12*	-5.86*	-12.52*	-9.95*

Note: JB stands for Jarque-Bera coefficient of normality, ADF(8) denotes coefficient of augmented Dickey-Fuller unit-root test performed with eight lags.

Source: authors' calculation.

*Statistical significance at 1% level.

**Statistical significance at 5% level.

non-normal characteristics. Very high JB coefficients are reported in Bulgaria, Czech Republic, Romania, and Slovakia. Likely reason for such a behaviour is the presence of outliers, which is embodied in the high kurtosis value. The large skewness coefficient in these countries also speaks in favour of that claim. It implies that the right tail of the unconditional distribution is thicker than the left one pointing to the presence of extreme value concentration around the mean.

Likewise, it implies a larger mean value compared to the median. In the study of Blanchard and Simon (2001), the authors claimed that the evidence of kurtosis may reflect extreme changes in the mean, which could distort point estimates. For that reason, the quantile regression method could be very convenient for avoiding potential parameter biases because of its robustness to the extreme values. The ADF test performed with eight lags confirmed that all the series are ergodic and thus strongly rejects null hypothesis of unit-root presence, so spurious regression should not be a matter of concern.

4.2. *Generating inflation uncertainty series*

We created the inflation uncertainty series for every country via best-suited form of the above-mentioned conditional variance specifications. If GARCH models totally capture unconditional skewness and leptokurticity, the standardized residuals should reflect a normal distribution, as emphasized by Fang and Miller (2009). Otherwise, if standardized residuals still register heterogeneous behaviour after GARCH process utilization, then empirical data are probably polluted with structural breaks. Accordingly, we have found the best-fitted GARCH model comparing three benchmark indicators: the Schwarz Information Criterion (SIC), ARCH Lagrange Multiplier (LM) test, and the JB coefficient value. Decisive indicators were the SIC and JB test, while the ARCH LM test was used due to the GARCH process employment. The ARCH LM results show whether an ARCH pattern is still present in the inflation series after GARCH model utilization. The relatively high p -value for the ARCH LM test in Table 2 suggests that GARCH parameterization is appropriate for the conditional variance processes for all models. The decision about the best model was made based on the lowest SIC and JB coefficient. In most cases, the lowest SIC corresponds to the lowest JB value. In few occasions when it was not a case, the advantage was given to the model with the lowest JB (it applies for Romania and Slovakia). Only in the case of Poland, the advantage was given to the model with the lowest SIC, since all the models reported very low JB coefficients. All JB coefficients in Table 2 were significantly reduced after GARCH model introduction compared to the JB coefficients of the empirical distribution in Table 1. It leads to the conclusion that all chosen models captured and solved unconditional skewness and leptokurtic distribution very well.

In the case of the Czech Republic and Slovakia, dummy variables had to be added to the mean equation to accommodate structural shift in the series. The procedure was conducted in similar way as presented in the research of Cunado, Biscarri, and de Gracia (2006), Fang and Miller (2009), Ewing and Malik (2013), that is, dummy variable takes unity from the break date onward and zero otherwise. We determined the time of structural breaks without prior knowledge of time period, utilizing a statistical technique of Bai and Perron (2003). The technique is known as sequential tests of $l + 1$ versus l globally determined breakpoints. This process was applied sequentially, commencing with a single break, until the null is not rejected. Accordingly, the applied test reported one break in the case of the Czech inflation (September 1998) and five breaks in the Slovakian inflation (September 1998, May 2001, February 2005, April 2008, and December 2010). Table 2 presents optimal ARMA(p,q) specifications of every GARCH(1,1) model, wherein grey label signifies the best-suited model. The optimal model was consequently utilized for the creation of the inflation uncertainty series. According to Table 2, the most prevalent models are GARCH and EGARCH. It is obvious that all the optimal models have relatively high AR and MA values

Table 2. An overview of four country-specific conditional variance specifications and the best fitted model.

	GARCH			EGARCH			TGARCH			PGARCH		
	SIC	ARCH	JB	SIC	ARCH	JB	SIC	ARCH	JB	SIC	ARCH	JB
BUL	ARMA(6,6)			ARMA(9,8)			ARMA(7,6)			ARMA(7,6)		
	2.426	0.461	0.123	2.557	0.503	0.586	2.522	0.572	0.498	2.533	0.710	0.736
CRO	ARMA(9,8)			ARMA(5,6)			ARMA(9,9)			ARMA(7,8)		
	1.419	0.826	0.269	1.171	0.813	0.025	1.237	0.523	0.144	1.298	0.898	0.045
CZH	ARMA(6,0)			ARMA(5,7)			ARMA(6,7)			ARMA(10,2)		
	1.607	0.425	73.263	1.479	0.605	25.779	1.908	0.721	267.937	1.746	0.637	169.158
EST	ARMA(5,7)			ARMA(7,4)			ARMA(8,7)			ARMA(8,7)		
	1.266	0.826	3.248	1.319	0.684	5.134	1.356	0.719	5.952	1.377	0.531	3.676
HUN	ARMA(7,6)			ARMA(6,5)			ARMA(6,5)			ARMA(9,8)		
	1.608	0.971	0.229	1.599	0.946	1.768	1.613	0.949	2.666	1.570	0.757	3.152
LAT	ARMA(9,7)			ARMA(5,3)			ARMA(6,4)			ARMA(4,2)		
	1.795	0.147	0.167	1.755	0.522	0.068	1.757	0.432	0.644	1.874	0.176	0.039
LIT	ARMA(5,2)			ARMA(5,3)			ARMA(7,6)			ARMA(9,6)		
	1.592	0.635	8.151	1.691	0.925	13.893	1.684	0.996	11.035	1.800	0.928	16.605
POL	ARMA(8,8)			ARMA(8,4)			ARMA(6,4)			ARMA(5,2)		
	1.218	0.692	0.028	0.935	0.668	0.409	0.931	0.629	0.343	1.066	0.557	0.403
ROM	ARMA(9,8)			ARMA(9,5)			ARMA(9,2)			ARMA(7,5)		
	2.251	0.382	3.297	2.656	0.084	2.566	2.347	0.160	17.039	2.304	0.724	11.587
SLK	ARMA(9,6)			ARMA(9,10)			ARMA(9,7)			ARMA(8,9)		
	2.191	0.300	21.712	1.752	0.453	47.818	1.989	0.993	115.485	2.459	0.908	314.755
SLO	ARMA(9,6)			ARMA(7,7)			ARMA(7,2)			ARMA(7,7)		
	1.665	0.382	0.076	1.626	0.223	0.037	1.757	0.413	0.076	1.729	0.343	0.234

Note: SIC stands for Schwarz Information Criterion. ARCH denote ARCH(LM) heteroscedasticity test with 10 lags. JB is Jarque-Bera coefficient for normality.

Source: authors' calculation.

suggesting the long-memory presence. However, this is not an unusual occurrence when it comes to the monthly inflation. For example, Balcilar et al. (2011) and Fountas and Karanasos (2007) also reported the presence of long memory in their studies which goes even beyond 12 lags.

Table 3 discloses summary statistics of the inflation uncertainty series, which are all tagged with letter 'G' (indicating GARCH) in front of the name of the country. All inflation uncertainty series are stationary at the 10% significance level. Some series (Romania, Slovakia and Czech Republic) report intense non-normal characteristics with very high kurtosis coefficients. Those series also have large skewness coefficients, indicating a heavier right tail, which points to the presence of extreme values. Due to the presence of severe non-normality in some series of inflation and inflation uncertainty, which may cause serious coefficient bias, we have tested both Friedman's and Cukierman–Meltzer's hypotheses with the QR inferential procedure.

5. Research results

5.1. Friedman's hypothesis

This section discusses the results (β coefficients in Equation (1)) regarding Friedman's theory, estimated with both the quantile regression method and OLS. The results indicate strong evidence in support of Friedman's assertion for most countries. The models in which statistically significant quantile coefficients have a positive sign confirm Friedman's prediction. It applies for 7 out of 11 countries, namely Bulgaria, Czech Republic, Hungary, Lithuania, Poland, Romania, and Slovakia. However, it is apparent that the statistical significance and the size of the estimated slope parameters vary across the quantiles of the dependent variable distribution. It might indicate the presence of outliers and fickle behaviour of the some inflation uncertainty series and thus it stands in favour of the usage of the QR-inferential procedure. Accordingly, comparing the fifth quantile or median slope coefficient with OLS parameters, it could be noticed that quantile parameters deviate from OLS estimates in most cases, sometimes even considerably. This statement applies to results in Table 4 as well as in Table 5. Therefore, the OLS estimates are biased due to leptokurtosis presence in the inflation uncertainty distribution, that is, their values are different compared to median estimates.

Observing higher estimated quantiles, Friedman's theory is confirmed in the case of the Czech Republic, Hungary, Lithuania, Poland, Romania, and Slovakia. It means that a higher rate of inflation precedes and causes a higher inflationary instability. For instance, the last three quantiles are rising and statistically significant in Czech Republic, which means that a 1% increase in inflation leads to 0.09%, 0.15%, and 0.52% increase in inflation uncertainty. As for Hungary, last five quantile parameters are significant, but without meaningful progression as in the case of Czech Republic. Lithuania and Poland reported a moderate rise of the quantile slope coefficients, but in the case of Romania and Slovakia that progression is more pronounced, similar to the findings in Czech Republic. This is in line with Table 3 results, where the inflation uncertainty series in Czech Republic, Romania, and Slovakia have the largest kurtosis and JB coefficients, which point out to significant outliers and hence it could be the reason for such a high value in the last quantiles. It should be noticed that Slovakia is the only member of EMU that has positive quantile slope coefficients according to Friedman's theory. Relatively high inflation values prior to 2004 could be responsible for such unstable, non-normal characteristics of Slovakian inflation. Slovak koruna was accessed in the Exchange Rate Mechanism II (ERM II) in November 2005. Since then, inflation was gradually stabilized. Besides the other obligations, this arrangement was based on a firm pledge by the Slovak authorities to promote wage stability that are kept in line with productivity growth, thereby contributing notably to the price stability. As for Bulgaria, Friedman's hypothesis is confirmed, but only at a relatively low level of quantiles. According to Gulde (1999), Bulgaria introduced a currency board on 1 July 1997, after several

Table 3. Summary statistics of inflation uncertainty series.

	GBUL	GCRO	GCZH	GEST	GHUN	GLAT	GLIT	GPOL	GROM	GSLK	GSLO
Mean	0.629	0.127	0.216	0.153	0.186	0.282	0.231	0.134	2.277	1.503	0.185
Median	0.532	0.116	0.160	0.152	0.161	0.283	0.213	0.091	0.379	0.262	0.184
St.dev.	0.509	0.037	0.229	0.069	0.099	0.024	0.098	0.117	8.703	4.344	0.030
Skew.	0.839	1.284	4.881	0.000	0.908	-0.161	0.969	1.632	8.467	6.891	0.350
Kurt.	2.828	4.372	36.409	1.404	3.787	1.406	3.190	5.241	81.194	60.489	2.955
JB	23.487	65.717	10600.4	22.279	33.921	23.242	33.118	136.54	54942.8	29997.6	4.272
ADF(8)	-3.21**	-8.59*	-8.98*	-246.4*	-3.46*	-14.17*	-2.58***	-3.13**	-8.38*	-10.07*	-9.20*

Note: JB stands for Jarque-Bera coefficient of normality. ADF(8) denotes coefficient of augmented Dickey-Fuller unit-root test performed with eight lags.

Source: authors' calculation.

*Statistical significance at 1% level.

**Statistical significance at 5% level.

***Statistical significance at 10% level.

Table 4. Quantile regression and OLS estimates for the Friedman's hypothesis.

Inflation uncertainty	OLS	Quantile estimates of parameter β in Equation (1)						
		0.05th	0.2th	0.35th	0.5th	0.65th	0.8th	0.95th
GBUL	0.083*	0.060	0.113	0.208*	0.166**	0.082	0.057	0.027
GCRO	-0.020*	-0.015	-0.027*	-0.023**	-0.015	-0.025*	-0.019**	-0.026*
GCZH	0.083*	-0.010	0.010	0.014	0.046	0.086*	0.147**	0.521*
GEST	-0.020**	0.006	0.006	-0.005	-0.042*	-0.023	-0.021	-0.010
GHUN	0.032*	0.004	0.018	0.036*	0.048*	0.046*	0.026**	0.034**
GLAT	-0.029*	-0.028*	-0.030*	-0.030*	-0.030*	-0.031*	-0.024*	-0.019*
GLIT	0.052*	0.004	0.018	0.021***	0.049***	0.080*	0.111*	0.108***
GPOL	0.129*	0.043*	0.063*	0.088*	0.116*	0.143*	0.165*	0.199*
GROM	2.301*	0.052	0.109	0.318	0.591	0.838*	2.425*	4.876*
GSLK	3.839*	0.021	0.244	0.686*	1.420*	1.955**	2.940	7.007***
GSLO	-0.043*	-0.029*	-0.040*	-0.043*	-0.044*	-0.049*	-0.051*	-0.053*

Source: authors' calculation.

*Statistical significance at 1% level.

**Statistical significance at 5% level.

***Statistical significance at 10% level.

Table 5. Quantile regression and OLS estimates for the Cukierman and Meltzer's hypothesis.

Inflation	OLS	Quantile estimates of parameter λ in Equation (2)						
		0.05th	0.2th	0.35th	0.5th	0.65th	0.8th	0.95th
BUL	0.287**	-1.343	-0.231	0.108	0.141	0.505**	0.907*	1.962*
CRO	-0.391	-0.687	-1.78E-15	-0.927	3.33E-16	3.33E-16	-9.06E-17	-2.098
CZH	-0.049	0.089	0.254	0.197	0.305*	0.110	0.146***	-0.274*
EST	-1.305*	6.66E-16	-0.633	-0.829	-0.769	-1.710*	-1.351**	-2.661*
HUN	2.442*	-0.579	1.165	1.790*	2.127*	2.270*	3.022*	5.945*
LAT	-2.639	2.196	-3.410	-1.997	-1.519	-3.417	-4.894	-3.792
LIT	2.351*	1.006	1.131	1.800*	2.087*	2.253*	3.072*	4.092**
POL	2.509*	0.485	1.600*	1.797*	2.310*	2.729*	3.017*	5.003*
ROM	0.092*	0.036	0.055*	0.069*	0.067*	0.167	0.161	0.975*
SLK	0.017	0.012	0.012*	0.011*	0.016**	0.013	0.007	0.082
SLO	0.689	2.186	1.78E-15	2.05E-16	2.04E-17	2.25E-16	5.61E-16	1.670

Source: authors' calculation.

*Statistical significance at 1% level.

**Statistical significance at 5% level.

***Statistical significance at 10% level.

failed stabilization attempts, thus reducing the annual inflation that soared to almost 500% in January 1997 and surpassed 2.000% in March 1997. Under the currency board, Bulgaria reduced annual inflation to 13% by mid-1998 and to 1% by the end of 1998. Currency board arrangements significantly contributed to the price stability in the following years and therefore higher quantiles did not prove significant in the Bulgarian model.

On the other hand, negative and statistically significant quantile parameters have been found in Croatia, Estonia, Latvia, and Slovenia, which is opposite to Friedman's claim. Negative parameters indicate that an increase in inflation does not lead to more inflation uncertainty, but quite contrary, higher inflation reduces its volatility. It implies that central banks of those countries have strong anti-inflation incentives and therefore willingness to bear the costs of disinflation. The negative quantile slopes in the models of those countries are relatively low and equable. Indicative fact is that Friedman's theory is refuted only in relatively small, open economies which adopted strict measures regarding their exchange rate stability. Most of these countries have become EMU members (Estonia, Latvia, and Slovenia) and lost their monetary governance after joining the EMU. Estonia kroon joined ERM II in 28 June 2004, Latvian lats joined in 2 May 2005, and Slovenian tolar joined in 28 June 2004. However, these countries have been conducting strong anti-inflationary policy long before the membership, as an effort to accomplish convergence criteria. Taking into account the pass-through effect from exchange rate towards inflation, these stern measures, along with the accession in the ERM II mechanism, certainly contributed to their inflation stability, and probably caused the failure of Friedman's hypothesis.

5.2. Cukierman–Meltzer's hypothesis

The mixing country-specific evidence is reported in Cukierman–Meltzer's hypothesis in Table 5 (λ coefficients in Equation (2)). Similar to the results in Table 4, statistical significance and the level of the estimated slope parameters vary across the quantiles of the inflation distribution. In 6 out of 11 countries (Bulgaria, Hungary, Lithuania, Poland, Romania, and Slovakia), mostly higher estimated quantile parameters are in favour of Cukierman–Meltzer's theory. The implications of these outcomes are that the monetary authorities of these economies behave

opportunistically, putting a greater emphasis on growth than on inflation stability. This indicates that monetary policy-makers are ready to follow a discretionary path of the increasing economic growth at the cost of higher inflation in the short run. Table 5 also demonstrates that national central banks adjust their monetary measures differently to inflation uncertainty, depending on their relative preference towards inflation stabilization.

For instance, observing Bulgarian three highest quantile estimates, it would mean that in the case of high inflation uncertainty, 1% increase in uncertainty leads to 0.51%, 0.91%, and 1.96% increase in inflation. The stronger evidence of Cukierman–Meltzer’s hypothesis has been obtained in the case of Hungary. Hungarian quantile slope coefficients point to conclusion that the increase of 1% in uncertainty produces the rise in inflation up to 6% at the highest quantile. The same, relatively high impact of inflation uncertainty on inflation could be noticed in Lithuania and Poland. On the other hand, in spite of significant outliers’ presence in the Romanian and Slovakian inflation series reported in Table 1, the influence of inflation uncertainty on inflation is relatively moderate and it happens at the lowest quantiles.

The findings in the case of the Czech Republic are to some extent ambiguous. Although the median and somewhat 0.8th quantile stand in line with Cukierman–Meltzer’s hypothesis, the largest quantile has a negative sign, which is opposite to this theory. This evidence supports the stabilization hypothesis put forward by Holland (1995). If monetary authorities have a higher resistance to the inflation uncertainty and eventually higher inflation, it could be expected that policy-makers act in favour of inflation stabilization, which could explain a negative effect of inflation uncertainty on inflation. In the case of the Czech Republic, it seems that monetary policy-makers implement restrictive monetary policy in a way to stabilize inflation when inflation volatility reaches a relatively high level.

On the other hand, in the cases of Croatia, Estonia, Latvia, and Slovenia, Cukierman–Meltzer’s hypothesis is overwhelmingly refuted. None of the quantile estimates of Croatian, Latvian, and Slovenian model is significant at the 10% level, while in the case of Estonia last three quantiles are significant, but with a negative sign. It is indicative that Friedman’s hypothesis was discarded in the same countries in which Cukierman–Meltzer’s theory does not hold. One of the reasons probably lies in the implementation of trustworthy and stable exchange rate policy. Any attempt to stimulate the economy with expansionary monetary policy would create pressure to exchange rate depreciation/devaluation. Therefore, primary goal for these countries is to achieve inflation stability, rather than to create inflation surprises stimulating the economy growth in short term. If central bank acted opportunistically, long-term inflation dynamics could be disrupted as well as credibility and accountability of the monetary authorities. Therefore, it is not beneficial to small, open economies which rely heavily on foreign investment and export incomes.

Romer (1993) asserted that trade openness is a relevant factor, concerning the interrelationship between the inflation level and its volatility. He claimed that more open economies display lower levels of inflation. Likewise, a possible negative relationship could arise only from the dynamic inconsistency of a discretionary monetary policy. Unanticipated monetary expansion could lead to currency depreciation/devaluation, which could cause higher costs for business entities and fewer gains from surprise inflation. With lower gains, discretionary monetary policy has no incentives to expand, and thus it will probably stick to the policy of stable inflation.

6. Summary and conclusion

This paper investigates the two-way relationship between inflation and inflation uncertainty, that is, Friedman’s and Cukierman–Meltzer’s hypothesis, by observing 11 Eastern European countries and using monthly data. The task encompassed two steps. First, four GARCH-type models were scanned and the best-suited model has been chosen to generate inflation uncertainty series. Decisive

benchmark indicators were the SIC, ARCH LM test, and the JB coefficient. Analysis of inflation and inflation uncertainty series showed that some series exhibit serious non-normal characteristics with the outliers' presence. In order to circumvent biased estimates, the method of choice was quantile regression in the second step, which is robust to particular non-normal features.

According to the findings, Friedman's theory has been confirmed in Bulgaria, Czech Republic, Hungary, Lithuania, Poland, Romania, and Slovakia. For instance, the last three quantiles are rising and statistically significant in Czech Republic, while in Hungary last five quantile parameters are significant, but without major progression. Lithuania and Poland have a moderate rise of quantile slope coefficients, but in the case of Romania and Slovakia that progression is more pronounced similar to the Czech findings. On the other hand, Friedman's hypothesis has been refuted in Croatia, Estonia, Latvia, and Slovenia due to negative and statistically significant quantile parameters. These findings indicate that central banks of those countries have strong anti-inflation motives, probably because of the stable exchange rate policy. Similar to the case of Friedman's theory, the mixing country-specific evidence is reported on Cukierman–Meltzer's hypothesis. Mainly in those countries where Friedman's theory has been confirmed, Cukierman–Meltzer's hypothesis also applies. It implies that these economies behave opportunistically, putting a greater emphasis on economic growth than on inflation stability. The cases of Croatia, Estonia, Latvia, and Slovenia refute firmly Cukierman–Meltzer's hypothesis, which means that for these monetary authorities the inflation stabilization is priority. This is probably because any attempt to stimulate the economy with expansionary monetary policy would create pressures to exchange rate depreciation/devaluation.

The empirical evidence presented in the paper could be informative to investors who are interested in investing in these countries by indicating direction and preferences of the particular monetary authorities when it comes to the issue of inflation and its uncertainty.

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