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# How do oil price changes affect inflation in Central and Eastern European countries? A wavelet-based Markov switching approach

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## ABSTRACT

This paper investigates how oil price changes affect consumer price inflation in eleven Central and Eastern European countries. We use a wavelet-based Markov switching approach in order to distinguish between the effects at different time horizons. We find that the transmission of oil price changes to inflation is relatively low in the Central and Eastern European countries as an increase in the oil price of 100% is followed by a rise in inflation of 1–6 percentage points. The strongest impact from rising oil price on inflation is found for the longer time-horizons for most of the countries, which means that the indirect spillover effect is more intensive than the direct one. Also, the results indicate that exchange rate is not a significant factor when oil shocks are transmitted towards inflation, except in the occasions when high depreciation occurs. Slovakia and Bulgaria are the countries which experience the highest and most consistent pass-through effect throughout the observed sample, and this may be due to these countries having some of the highest oil import/GDP ratios.

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## 1. Introduction

Oil represents one of the most important commodities in the world, and as such has an important and profound effect on the world economy. Also, oil is susceptible to large price swings due to various global economic and political factors, thus the interest about the oil price impact on the real economy is rekindled in recent years (see e.g. Hamilton, 2003; Dibooglu & AlGudhea, 2007; Novotny, 2012; Broadstock, Wang, & Zhang, 2014; Cuestas & Gil-Alana, 2018). Oil price changes may arise mainly from two sources – i.e. fast-growing demand due to high global economic growth or declining supply as a result of shortfalls in production. Cashin, Mohaddes, Raissi, and Raissi (2014) found that supply-driven oil price shocks increase production costs, resulting in a rise of inflation. On the other hand, a demand-driven oil price shock leads to a temporary inflation rise. They claimed that the increase in oil prices in the period 2002–2007 was attributed to

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booming economic activity and a higher demand for oil in emerging economies. In the period after 2007, the oil price plunge is associated with supply-side factors, due to the global financial crisis. Kilian (2009) stated that oil price increases have been caused mainly by a combination of global aggregate demand shocks and precautionary demand shocks, rather than oil supply shocks, as is commonly assumed.

From the theoretical perspective, both direct and indirect channels link the two variables (see Álvarez, Hurtado, Sánchez, & Thomas, 2011). The direct effect occurs when rising oil prices transfer to the prices of refined oil products, such as fuels or heating oil, which are consumed by households. This spillover effect occurs almost immediately, and the impact on the consumer price index depends on the share of households' expenditure on refined oil products in total expenditure. On the other hand, the indirect effect is reflected in the price changes of goods and services, which use oil or oil products (e.g. petroleum) in the production process as inputs. According to Álvarez et al. (2011), this transmission has a considerably lower speed of pass-through than the direct impact, while the magnitude of this effect depends on various factors, such as market competition or cyclical developments in the economy. In addition, it should also be aware about the so-called second-round effect. This channel is explained by the fact that initial consumer price changes, which are caused by rising oil prices, may trigger behavioural responses from firms and workers, reflecting the changes in their inflation expectations. Cognigni and Manera (2008) argued that firms may adapt to rising oil prices by passing on their overall rising production costs to consumer prices, which are not so oil dependent. On the other hand, workers may respond by demanding higher wages. In both cases, the consumer price index rising. Furthermore, Baumeister and Kilian (2016) asserted that oil price shocks can influence future oil price expectations, and such expectations enter into the net present value calculations of future investment projects, particularly the cash flow, which depends on the price of oil.

It is generally believed among economic practitioners and policy makers that oil price shocks have at least partial pass-through effect on inflation in both developed and emerging/developing economies (see e.g. Mirzaei & Al-Khouri, 2016). According to Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018), despite the relevance of this topic for both academics and policymakers, very few studies have investigated this issue in emerging economies, mainly due to data availability, which is especially true for the Central and Eastern European countries (CEECs). Therefore, this paper attempts to fill the gap in the literature by conducting a thorough analysis of the effect of oil price changes on inflation in a time-frequency framework in the eleven CEECs – the Czech Republic, Poland, Hungary, Slovakia, Lithuania, Latvia, Estonia, Romania, Bulgaria, Slovenia and Croatia. All these countries became EU members in 2004, 2007 or 2013, and some of them (Slovakia, Slovenia and the Baltic states) subsequently entered the euro area. The common interest of all these economies is to sustain low and preferably converging inflation, which gravitates around the aggregate rate of inflation of the whole euro area (see e.g. Horvath & Koprnicka, 2008; Cocriş & Nucu, 2013; Živkov, Njegić, & Pećanac, 2014; Cavallo & Ribba, 2014; Goczek, 2015; Lyziak, 2016; Reigl, 2017). Hence, a reasonable understanding of the interdependence between oil and national inflations will help these economies in this effort.

In order to investigate the unidirectional oil-inflation causality interlink, we assume the presence of a non-constant relationship, allowing inflation to depend on the two

independent state regimes that govern the conditional mean process. In other words, we employ the parametric Markov switching approach, which is capable of recognizing different regimes, whereby the oil price is exogenous from the viewpoint of the CEE countries. In addition to the regime shifts, we also want to examine the extent of the oil price changes to inflation in different time-horizons. By doing this, we try to determine in which time-horizon the oil shocks have the highest impact on inflation. Moreover, we measure the effect of oil shocks on inflation when oil price is expressed in USD, but also when oil price is expressed in national currencies. The latter approach takes into account the exchange rate changes. Finally, we also measure a time-varying spillover effect via rolling regression, which can assess the size of this effect in different time-periods.

However, it should be said that studies which include different time-horizons are relatively scarce. This is the case because the sample reduction problem appears when researchers try to match the frequency of data with the different time-horizons (see Conlon & Cotter, 2012). Therefore, we use a relatively novel, non-parametric technique named wavelet, which elegantly circumvents the problem of sample size reduction and does the computation without loss of valuable information. We apply discrete wavelet transformation in order to transform empirical series into the set of wavelet signals, which resolution corresponds to different time-horizons. Subsequently, we embed these wavelet signals into the Markov switching model to gauge the nonlinear spillover effect. Also, it should be mentioned that the wavelet technique is appealing for researchers for a number of other reasons. For instance, this method avoids the heteroscedasticity bias in time series and can successfully deal with empirical series which is non-stationary, and which contains some outliers. A number of recent papers have employed wavelet methodology to analyse various economic phenomena in different time-horizons (see e.g. Nikkinen, Pynnönen, Ranta, & Vähämaa, 2011; Madaleno & Pinho, 2012; Barunik & Vacha, 2013; Dajčman, 2012; Tsai & Chang, 2018; Živkov, Balaban, & Đurašković, 2018; Jiang, Meng, & Nie, 2018).

According to Salisu, Isah, Oyewole, and Akanni (2017), the existing papers dealing with the oil-inflation relation provide heterogeneous results. They claimed that numerous factors, such as the selected countries, the utilized models, the observation of particular data-samples and different estimation techniques could be the likely reasons for the mixed findings. For instance, some papers such as Stavrev (2006), Cologni and Manera (2008) and Gelos and Ustyugova (2017) reported a significant impact of oil on inflation. The paper of Stavrev (2006) is one of the rare studies which have considered the CEECs in this context. He asserted that the new EU8 countries are more energy intensive than the old members, and consume approximately 50% more energy than the rest of the EU member states. These circumstances create greater inflationary pressure from oil in the new EU8 members in comparison with the old ones. Gelos and Ustyugova (2017) researched the inflationary impact of commodity price shocks across countries, over the period 2001–2010, using several approaches. They found that economies with higher food shares in their CPI baskets, fuel intensities, and pre-existing inflation levels were more susceptible to sustained inflationary effects from commodity price shocks. Cologni and Manera (2008) stated that inflationary shocks are transmitted to the real economy by increasing interest rates. They found that oil price shocks significantly affected the inflation rate in Canada, France, Germany, Italy and the US.

On the other hand, a number of researchers, who have conducted research on this topic in the last two decades contended that the oil shocks seem to have had a limited impact on inflation. For example, Choi et al. (2018) examined the impact of global oil prices on domestic inflation, using a sample of 72 advanced and developing economies. They asserted that a 10% increase in global oil prices, affects domestic inflation, on average, by about 0.4 percentage points, whereby this effect vanishes after two years. These results are similar for both advanced and developing economies. The study carried out by De Gregorio, Landerretche, and Neilson (2007) on a large set of developed and emerging countries found evidence of an important decline in the pass-through from the price of oil to inflation, during recent decades. They documented that this decline is a fact for the majority of observed economies. In addition, their results showed a significant fall in the average pass-through for industrial economies and, to a lesser degree, for emerging ones. Álvarez et al. (2011) investigated the effect of oil price changes on Spanish and euro area consumer price inflation and concluded that the inflationary impact of oil price changes in both economies is limited. They reported that the direct contribution of 10% oil price changes to consumer price inflation averages 0.2 percentage points both in Spain and the euro area, which is a relatively small amount. Hooker (2002) reported strong evidence that oil price changes made a substantial direct contribution to the core of US inflation before 1981, but little or no pass-through since that. Blanchard and Riggì (2013) studied the macroeconomic performance of a sample of developed economies in the aftermath of the oil price shocks of the 1970s and the last decade. They reached the conclusion that the influence of oil price shocks changed over time, and calculated steadily smaller effects on prices and wages, as well as on output and employment.

Very few studies have addressed various term-horizons in which oil shocks impact on the real economy. For example, Zhao, Zhang, Wang, and Xu (2016) investigated the effects of oil price shocks on output and inflation in China, using dynamic stochastic general equilibrium (DSGE) model. They found that oil supply shocks, driven by political events, mainly produce short-term effects on China's output and inflation. Salisu et al. (2017) researched the role of asymmetries in the oil price-inflation nexus, considering both net oil exporting and net oil importing countries, covering the time-span from 2000 to 2014 on a dynamic panel data model. They disclosed a significant long-term positive relationship between oil price and inflation. According to them, inflation suffers a greater impact from oil prices in net oil importing countries than in their oil exporting counterparts in the long-run. Kilian (2008) claimed that exogenous oil supply shocks typically cause a temporary reduction in real GDP growth which is concentrated in the second year after the shock. As for inflation, he asserted that responses are more varied, where the median CPI inflation peaks three to four quarters after the shock.

This study departs from the existing literature along several dimensions. To the best of our knowledge, this paper is among the rare ones to investigate the oil-inflation nexus in Central and Eastern European countries. Also, this paper is the first one to combine two different methodologies in order to underline a holistic approach to this issue. In other words, the paper emphasizes a nonlinear time-varying spillover effect, but also accurately calculates the magnitude of this effect in different time-horizons. The former is done via the Markov switching model, while the latter issue is addressed by using wavelet signal-decomposition methodology.

The rest of the paper is structured as follows. Section 2 provides a literature review, whereas the third section explains methodologies used for the research – the Markov switching model and wavelet technique. Forth section contains dataset, while the fifth section presents empirical results. The last section concludes.

## 2. Methodology

### 2.1. The Markov switching model

In order to capture the effect of oil shocks on inflation rates, with an assumption of non-constant relations between these variables, we employ the Markov regime-switching model of Goldfeld and Quandt (1973). This model allows the coefficients to shift between a finite number of discrete states according to an unobserved process. The Markov switching model is governed by a Markov chain, which is a process where the future state depends only on the current state and the probability of a particular value (see e.g. Kumah, 2011; Regland & Lindstrom, 2012).

For our research efforts, we assume two states ( $S_t = 1, 2$ ). Following Chang (2012), our conjecture is that the state variable ( $S_t$ ) appears in two different regimes. In other words, when  $S_t$  value is equal to 1, inflation is characterized by increasing inflationary pressure, whereas when  $S_t$  value is equal to 2, the economic system belongs to decreasing inflationary pressure. We also allow the variance of the error term to switch simultaneously between the states. Therefore, our estimation equation looks like equation (1):

$$INF_t = c_{st} + \alpha_{st}OIL_t + \varepsilon_t; \quad \varepsilon_t \sim N(0, \sigma_{st}^2), \quad (1)$$

where  $INF_t$  represents the national consumer price index (CPI), transformed into log returns in the following way:  $INF_t = 100 \times \log(CPI_t/CPI_{t-1})$ . In this way, we can obtain inflation rates.  $OIL_t$  is the oil price, transformed in the same way as  $CPI_t$  to get the oil log returns. The term  $c_{st}$  is the regime-dependent constant, whereas  $\alpha_{st}$  stands for the regime switching coefficient, which gauge the spillover effect from oil to national inflation. The parameters in this equation are estimated by the maximum likelihood algorithm described by Hamilton (1990). According to the above, model (1) can provide information on how much weight oil assigns to a particular national inflation rate in two different regimes.

Kanas (2009) and Frommel (2010) asserted that switching between regimes does not occur deterministically but with a certain degree of probability. They explained that the unobserved and discrete state variable  $S_t$  depends serially on  $S_t - 1, S_t - 2, \dots, S_t - r$ , which is then called the  $r$ 'th order Markov switching process. The unobserved state variable  $S_t$  takes on the value of 1 (high inflation) or 2 (low inflation) and the transition between states is governed by a first-order Markov process, according to expression (2):

$$\left. \begin{aligned} P(S_t = 1 | S_{t-1} = 1) &= p_{11} \\ P(S_t = 1 | S_{t-1} = 2) &= p_{12} \\ P(S_t = 2 | S_{t-1} = 1) &= p_{21} \\ P(S_t = 2 | S_{t-1} = 2) &= p_{22} \end{aligned} \right\} \quad \text{where } p_{11} + p_{12} = p_{21} + p_{22} = 1 \quad (2)$$

A good characteristic of the transition probabilities in Equation (2) is that they determine the probability at each point in time in which a specific state occurs, rather than

imposing particular dates a priori. In such a way, the empirical data may indicate the nature and incidence of the regime changes.

## 2.2. Wavelet methodology

The objective of this paper is to assess the magnitude of oil price changes on inflation in eleven CEECs, but we also want to see how and if this impact differs across various time-horizons. In order to do that, we use the wavelet signal-decomposing process, which can elegantly adapt itself to recognize features across a wide range of frequencies (time-horizons). Wavelet methodology is a nonlinear and energy preserving transformation, which projects original time-series onto a sequence of basic functions, which are called wavelets. In other words, wavelet analysis decomposes empirical time series into more elementary functions (named 'scales'), which contain information on a series. In particular, the set of scales denotes different time-horizons, where the lower scales illustrate high-frequency fluctuations (shorter time-horizons), while the higher scales portray the low frequency fluctuations (longer time-horizons). The wavelets thus help researchers to understand the development of the economic relationship between various economic variables at a particular scale and time, which would otherwise remain hidden under traditional approaches.

Discrete wavelet transformation is used to transform the empirical time series of oil and inflation into segments of the time domain, called *scales*, which represent different lengths of time-horizons. These transformed wavelet series are then imbedded into the Markov switching model for the assessment of transmission effect from oil price changes towards national inflations. To be more specific, we use the non-orthogonal wavelets, known as the maximum overlap discrete wavelet transformation (MODWT), which is based on a highly redundant non-orthogonal transformation. Decomposed signals, in a MODWT framework, are given in the following way:<sup>1</sup>

$$S_j(t) = \sum_k S_{j,k} \phi_{j,k}(t), \quad (3)$$

$$D_j(t) = \sum_k d_{j,k} \psi_{j,k}(t) \quad j = 1, 2, \dots, J, \quad (4)$$

where symbols  $S_j(t)$  and  $D_j(t)$  denote the fluctuation and scaling coefficients, respectively, at the  $j$ 'th frequency level. Functions  $\phi$  and  $\psi$  are generated as follows:

$\phi_{j,k}(t) = 2^{-j/2} \phi\left(\frac{t - 2^j k}{2^j}\right)$  and  $\psi_{j,k}(t) = 2^{-j/2} \psi\left(\frac{t - 2^j k}{2^j}\right)$ . According to the above, an empirical time series  $y(t)$  can be expressed in terms of those signals as:

$$y(t) = S_j(t) + D_j(t) + D_{j-1}(t) + \dots + D_1(t). \quad (5)$$

The multiresolution analysis is performed by means of Daubechies least asymmetric (LA) wavelet filter of length  $L = 8$ , which is also known as the LA(8) wavelet filter.

## 3. Dataset

For this study, we use monthly data from Brent oil and CPI of eleven CEECs – the Czech Republic, Poland, Hungary, Slovakia, Lithuania, Latvia, Estonia, Romania, Bulgaria, Slovenia

and Croatia. The time-span ranges between January 1996 and June 2018. We are unable to consider a longer time-sample, since the availability of the CPI indices begins from 1996. As we previously stated in Section 2.1, all monthly CPI indices as well as Brent oil are transformed into log returns. We collect monthly data of Brent oil in terms of the US dollar from the US Energy Information Administration website, while the monthly CPI indices are retrieved from the Eurostat database. Considering Brent oil in terms of the US dollar, we can measure the isolated effect on inflation from the shocks in oil market. However, in order to be more informative, we also calculate the spillover effect when oil prices are expressed in the local currencies. From this perspective, we can take into account both exchange rate changes *vis-à-vis* the US dollar and the market oil price changes. This approach is more realistic, because exchange rate fluctuations have a substantial impact on domestic inflation, and this factor can significantly increase the already existing oil price changes. Since five countries from the sample (Slovakia, Slovenia and the Baltic states) adopted euro, we conduct this type of calculation only on six other countries, which still have national currencies. Theoretically, we can observe Brent oil in euros for the countries which use this currency, but since these countries adopted euro relatively recently, these time-series are too short for the wavelet transformation process.

Using wavelet methodology in the Markov switching framework, this paper investigates non-linear shock transmission from Brent oil to national inflations for four different time-horizons, which correspond to four MODWT scale levels. Different time-horizons match the wavelet scales in the following manner: scale 1 corresponds to 2 months, scale 2–4 months, scale 3–8 months and scale 4–16 months. This enables us to determine whether the impact of oil price changes on inflation varies over time, which can be used by monetary authorities to devise an appropriate response, if required. We treat the first two scales as short-term observations, whereas the third and fourth scales correspond to midterm and long-term, respectively. [Table 1](#) presents the concise descriptive statistics of the raw data, that is, the first four moments and Jarque-Bera test of normality. [Figure 1](#) presents the empirical dynamics of Brent oil and the eleven inflation rates.

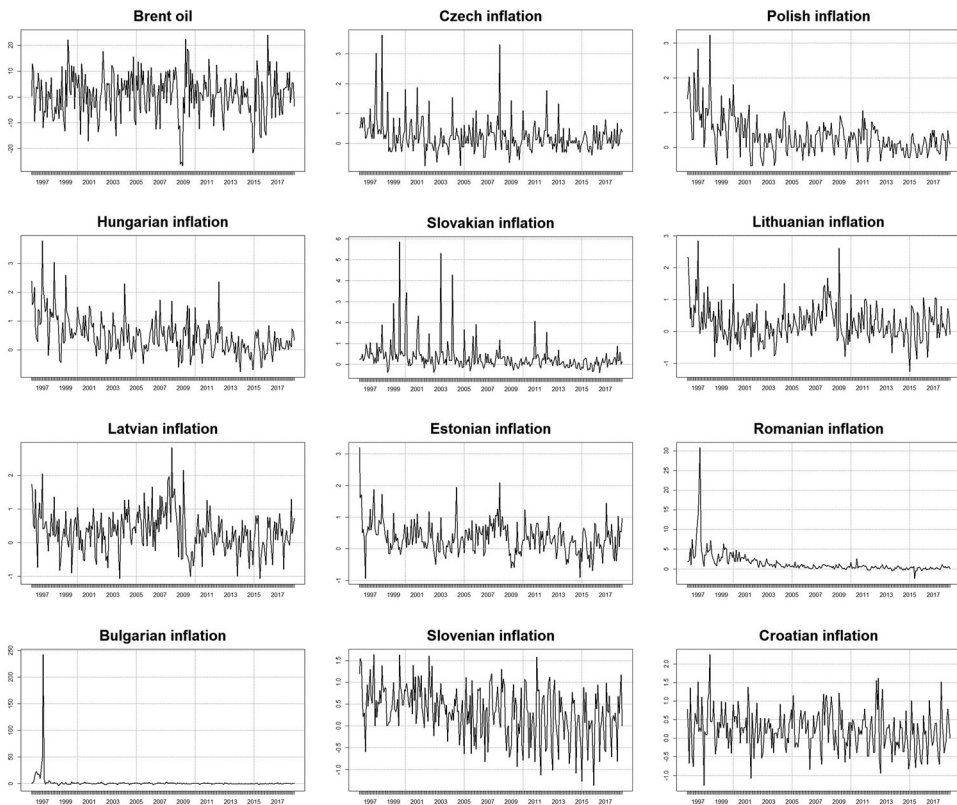
It can be seen in [Table 1](#) that Bulgaria and Romania have the highest average monthly inflation rates. However, this is only because these countries had exceptionally high inflation in 1997 (see [Figure 1](#)), while in the rest of the sample, inflation rates of these countries were quite low. Due to these outliers, we record that Bulgarian and Romanian

**Table 1.** Descriptive statistics of Brent oil price changes and national consumer price inflation

		Mean	St. dev.	Skew.	Kurt.	JB
Inflation rate	Brent oil	0.83	8.35	-0.34	3.60	9
	The Czech Republic	0.23	0.54	2.65	14.83	1883
	Poland	0.33	0.53	1.64	8.06	408
	Hungary	0.48	0.65	1.27	6.08	178
	Slovakia	0.33	0.71	4.47	28.74	8321
	Lithuania	0.26	0.57	1.06	5.87	143
	Latvia	0.33	0.60	0.45	4.01	21
	Estonia	0.35	0.51	1.05	6.94	223
	Romania	1.40	2.75	6.21	57.70	35,261
	Bulgaria	2.04	15.36	14.47	224.95	561,536
	Slovenia	0.32	0.58	-0.33	2.97	5
Croatia	0.21	0.52	0.29	3.72	10	

Note: JB stands for the values of Jarque-Bera coefficients of normality.

Source: Authors' calculations.



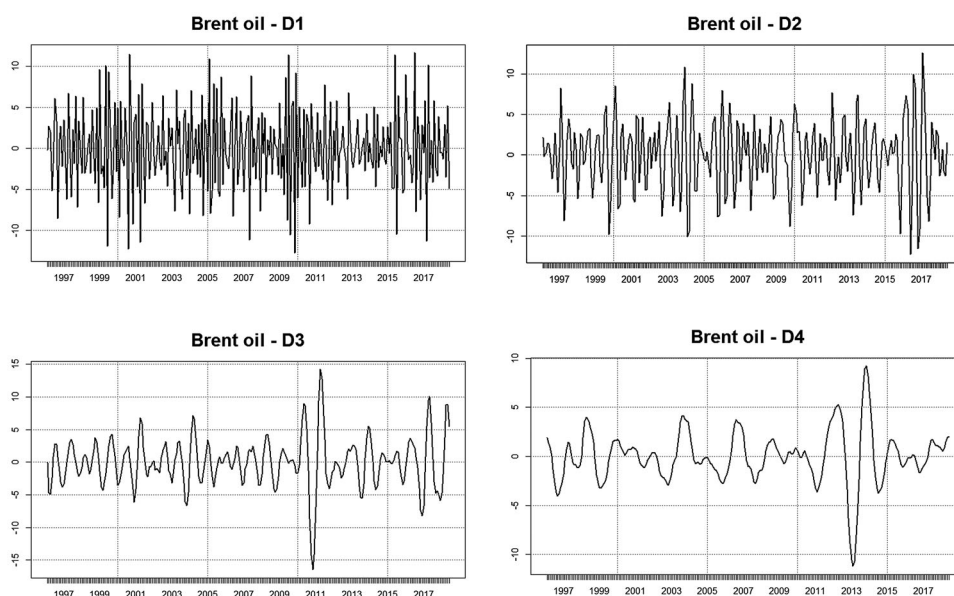
**Figure 1.** Empirical dynamics of Brent oil price changes and inflation rates in the eleven selected countries.

inflation rates are also the most volatile. It should be noted that majority of the kurtosis values are higher than 3, which is the reference value of the normal distribution, while in some cases the kurtosis values are very high (Bulgaria, Romania, Slovakia and the Czech Republic). These findings suggest the presence of extreme values and outliers, and as such, justify the usage of wavelet methodology, because the wavelet signal-decomposing technique can handle outliers, but can also remove noises in the original data (see Tabak & Feitosa, 2009). The Jarque-Bera test indicates nonnormality for the majority of the inflation time-series. We do not calculate unit root tests, since we work with the wavelet-transformed series, which are stationary by default (Dewandaru, Rizvi, Masih, Masih, & Alhabshi, 2014). In order to save space, we show four wavelet details of Brent oil price changes in Figure 2, while the wavelet decomposition plots of the inflation time-series can be obtained by request.

## 4. Empirical results

### 4.1. Regime switching results when Brent oil is expressed in the US dollars

This section provides an answer about the extent of oil shock transmission to inflation in the selected CEECs, when the oil price changes are expressed in the US dollars. In this way,



**Figure 2.** Four wavelet details of Brent oil price changes.

we can single out only the effect of oil shocks on the national inflations, assuming different time-horizons and two different state regimes. However, this approach neglects exchange rate changes, which is also an important factor to consider, because if national currencies depreciate *via-a-vis* USD it raises the price of Brent oil and eventually these higher oil prices spillover on inflation. This issue will be addressed in the next subsection.

Table 2 contains the regime-dependent parameters, regime probabilities, expected durations and regime-specific error variances, across four wavelet details. It is obvious that the regime parameters are heterogeneous across the regimes, wavelet scales and the selected countries, which provides justification for the usage of wavelet-based regime-switching methodology. In addition, it is immediately evident that the regime-dependent  $\alpha$  parameters are positive, but relatively low, while some of them are not statistically significant.

The results in the first wavelet scale show that most of estimated  $\alpha$  parameters are not statistically significant, indicating that shock transmission from oil to inflation does not occur in very short time-horizons in most of the selected CEECs. The only countries in which we detect the shock spillover effect are the Czech Republic, Slovakia, Lithuania and Slovenia. In the cases of the Czech Republic and Slovakia, when the oil price increases 100%, then the average extent of the spillover effect is 4.5% and 6.1%, respectively, and it occurs only in the second regime, which depicts lower inflationary pressure. For Lithuania and Slovenia, this impact is lower in comparison to the Czech and Slovakian cases, but it occurs in higher inflation regimes (first regime). For these four countries, the probabilities of staying in the first regime are higher in comparison to the second regime, which means that the first regime lasts longer in comparison to the second one. In particular, Lithuania has the highest average duration of the first regime, while Slovakia and the Czech Republic follows. Slovenia has very low probabilities for both regimes, which implies that changes

**Table 2.** Regime switching spillover effect from Brent oil price changes to national inflation rates, when the Brent oil price is expressed in USD.

		CZE	POL	HUN	SLK	LIT	LAT	EST	ROM	BUL	SLO	CRO
D1	$\alpha_1$	0.004	0.002	0.006	0.001	0.016***	0.003	0.008**	0.006*	0.011*	0.015***	-0.003
	$\alpha_2$	0.045***	0.011	-0.003	0.061***	0.019**	0.019	0.008	-0.006	-0.286	0.010***	0.011***
	P11	0.90	0.99	0.95	0.92	0.99	0.99	0.95	0.94	0.99	0.30	0.83
	P22	0.68	0.98	0.89	0.77	0.98	0.97	0.96	0.82	0.96	0.22	0.84
	ED regime 1	9.9	98.1	18.6	13.0	80.5	79.9	17.2	17.9	458.1	1.4	6.1
	ED regime 2	3.1	56.3	8.9	4.5	50.0	31.2	25.8	5.8	29.1	1.3	6.4
	$\sigma_1^2$	-1.71***	-1.99***	-1.62***	-1.96***	-1.50***	-1.29***	-1.76***	-1.60***	-0.71***	-1.47***	-0.99***
D2	$\sigma_2^2$	-0.54***	-1.05***	-0.73***	-0.22**	-0.88***	-0.79***	-1.51***	-0.58***	3.43***	-1.59***	-1.18***
	$\alpha_1$	0.003	0.017***	-0.002	0.009***	-0.011**	0.043***	0.011***	0.006	0.019***	0.036***	0.022***
	$\alpha_2$	-0.020	0.002	0.018***	0.034**	0.051***	-0.004	0.010	-0.097	-2.245	0.015***	0.006
	P11	0.99	0.94	0.94	0.97	0.93	0.94	0.99	0.99	0.99	0.99	0.98
	P22	0.96	0.97	0.98	0.92	0.92	0.99	0.91	0.97	0.95	0.99	0.96
	ED regime 1	82.9	16.4	15.9	30.6	14.4	16.6	79.0	234.1	254.6	253.8	43.0
	ED regime 2	27.1	33.6	57.6	13.1	13.1	98.9	11.7	34.5	19.8	200.3	26.8
D3	$\sigma_1^2$	-1.76***	-2.44***	-1.02***	-2.15***	-1.61***	-2.05***	-1.78***	-1.38***	-0.82***	-0.99***	-0.99***
	$\sigma_2^2$	-0.82***	-1.32***	-1.65***	-0.50***	-1.26***	-1.34***	-1.01***	-0.84***	3.24***	-1.58***	-1.77***
	$\alpha_1$	0.012***	0.020***	0.037***	0.017***	0.018**	0.009***	0.042***	-0.004	0.031	-0.043***	-0.118***
	$\alpha_2$	0.012**	-0.021	-0.014***	-0.004	-0.009	0.004	-0.011*	-0.668	-0.848	0.041***	0.020***
	P11	0.86	0.99	0.99	0.98	0.98	0.85	0.97	0.99	0.99	0.95	0.91
	P22	0.78	0.97	0.97	0.98	0.96	0.82	0.96	0.94	0.96	0.97	0.98
	ED regime 1	6.9	106.8	221.6	56.6	60.3	6.5	34.4	121.2	230.8	21.2	11.5
D4	ED regime 2	4.5	31.9	29.3	66.1	24.9	5.7	26.9	16.3	23.7	42.3	46.8
	$\sigma_1^2$	-2.21***	-2.01***	-1.50***	-2.76***	-1.94***	-2.02***	-2.03***	-1.47***	-0.68***	-1.53***	-1.55***
	$\sigma_2^2$	-2.04***	-1.06***	-0.90***	-1.13***	-1.21***	-2.04***	-1.26***	-0.96***	2.53***	-1.91***	-1.79***
	$\alpha_1$	0.010***	0.015***	0.014***	0.000	-0.009***	0.040***	0.018***	-0.001	0.008	0.018***	0.014***
	$\alpha_2$	0.017***	0.004	0.018***	0.032***	0.020***	-0.001	0.011*	0.079	-0.390	0.020***	0.009***
	P11	0.91	0.95	0.88	0.96	0.94	0.90	0.97	0.99	0.99	0.86	0.89
	P22	0.91	0.95	0.90	0.95	0.88	0.95	0.95	0.98	0.97	0.93	0.91
ED regime 1	11.6	20.7	8.3	24.9	15.9	10.1	33.5	252.5	135.0	7.1	9.2	
ED regime 2	11.1	18.8	10.5	19.4	8.2	21.0	20.8	44.7	34.3	13.8	11.3	
$\sigma_1^2$	-2.61***	-3.41***	-2.53***	-3.01***	-2.45***	-3.27***	-2.78***	-2.00***	-1.48***	-2.83***	-2.58***	
$\sigma_2^2$	-2.51***	-1.81***	-2.35***	-1.60***	-2.69***	-1.80***	-1.46***	-1.68***	2.25***	-2.75***	-2.74***	

Notes: ED stands for expected duration. P11 and P22 are the probabilities of staying in each regime.  $\sigma_1^2$  and  $\sigma_2^2$  are regime-specific error variances.

\*\*\* $p < .01$ ; \*\* $p < .05$ ; \* $p < .1$ .

Source: Authors' calculation.

between regimes occur relatively frequently. As for the other countries, it can be seen that in the Estonian and Romanian cases, the  $\alpha_1$  parameters are statistically significant in the first regime, but of no economic importance as they are very low. The same applies for Croatian  $\alpha_2$  parameter.

These findings coincide very well with other studies which found relatively low level of the spillover effect. For example, Choi et al. (2018) stipulated that a 10% increase in global oil prices increases domestic inflation, on average, by about 0.4 percentage points. Álvarez et al. (2011) found that oil price changes impact inflation by 2% on average both in Spain and in the euro area. The same authors also listed several reasons why the inflationary impact of oil price shocks decreased in recent years. They argued that the reasons could be the higher energy efficiency of production processes, the declining share of oil in the economy since the 1970s, and the adoption of more or less explicit inflation targeting strategies by monetary authorities.

Looking at a somewhat longer time-horizon (D2 wavelet scale), an increase in the number of the statistically significant parameters may be observed. At the same time, these parameters are also economically significant, which means that they are not too small. Regarding the first regime, which depicts higher inflationary pressure, we find that 100% rise in the prices of Brent oil impact inflation by 1.7% in Poland, 4.3% in Latvia, 1.1% in Estonia, 1.9% in Bulgaria, 3.6% in Slovenia and 2.2% in Croatia. As for the second regime, Hungarian inflation is affected by 1.8%, Slovakian by 3.4%, Lithuanian by 5.1% and Slovenian by 1.5%. It is interesting to note that in longer time-horizon, which is D2 scale, the selected inflations generally experience higher spillover effect, than in the first wavelet scale. As we said earlier, the direct effect occurs in very short time-spans, which is reflected in the transfer of rising oil prices to the prices of refined oil products. Since this expenditure is not too high in comparison to total expenditure of households, this impact is relatively small or even non-existent in very short time-frame. Our results are in line with this theoretical contention. On the other hand, in somewhat longer time-horizon (e.g. 4 months), which is portrayed by the second wavelet scale, the indirect effect comes to the fore, and it is reflected in the price changes of goods and services, which use oil or oil products as inputs in the production process. Due to the fact that indirect effect impacts a wider range of goods and services in the consumer basket, this effect is higher in the longer time horizon. Our results concur very well with this assertion, since in almost all countries we find statistically and economically significant parameters. Only in the Czech and Romanian cases, the oil shock spillover effect is not found at all, regarding the both regimes. As for the regime probabilities in the second wavelet scale, they are heterogeneous. In the cases of Poland and Lithuania, they are lower in both regimes, comparing to the D1 scale, while in Slovenia and Croatia they are higher in both regimes, comparing to the first wavelet scale.

Observing the midterm horizon, we can notice the presence of relatively high, positive and statistically significant switching parameters in both regimes in almost all the countries. Only in the case of Romania, the transmission effect is not found. In midterm horizon (8 months), the same logic applies as in somewhat shorter time-horizon (4 months). This means that indirect spillover effect is more dominant than the direct effect in this time-horizon, which imply that regime-switching spillover parameters are higher than their counterparts in the first wavelet scale. Table 2 confirms this assertion. In particular, we report that Czech, Hungarian, Estonian, Slovenian and Croatian inflation

suffers oil shock transmission in both regimes. However, it is evident that in both regimes in the Czech case and in the second regime in the Estonian and Hungarian cases, these effects are really small. On the contrary, Hungary and Estonia experience a relatively high impact in a high-inflation regime, with 3.7% and 4.2%, respectively, when oil price increases 100%. It is worth mentioning that oil-price shocks have a relatively modest impact on Polish, Slovakian and Lithuanian inflation in the midterm, amounting to 2%, 1.7% and 1.8%, respectively. Although the transmission effect is higher in both the second and third wavelet scales than in the first wavelet scale, its magnitude is relatively modest. These findings are in line with the assertion of De Gregorio et al. (2007), who found evidence of an important decline during recent decades in the pass-through from the price of oil to inflation.

The results in the longest time-horizon (D4 scale) of the oil-inflation pass-through effect do not differ greatly from those in the second and third wavelet scales. In other words, it is apparent that the majority of spillover parameters are relatively high and statistically significant, which favours the indirect transmission effect. More specifically, we find that Brent oil impacts inflation in both regimes in the Czech Republic, Hungary, Lithuania and Estonia. It is apparent that the spillover effect is stronger in the second regime in the Czech Republic, Hungary and Lithuania, whereby Lithuanian inflation endures the highest impact from oil in the long-run (2%). Hungary and the Czech Republic follow with 1.8% and 1.7%, respectively. Estonian inflation suffers a stronger effect in the first regime, which amounts to 1.8%. Latvian inflation experiences the strongest shock from oil in the long-run in the first regime (4%), while Slovakian inflation follows with 3.2% in the second regime. We do not record any spillover effect in the cases of Romania and Bulgaria in long-run. Our findings concur with the assertion of Salisu et al. (2017), who also investigated the long-run pass-through effect and found a significant long-run positive relationship between oil price and inflation, emphasizing that the oil price-inflation relation tends to change over time.

If we want to single out those countries that are most affected by oil shocks (when oil price is expressed in USD), regarding all the wavelet scales, then Slovakia and Lithuania stand out as the countries with the highest switching spillover parameters throughout the wavelet scales. More specifically, Slovakian inflation endures a 6.1% pass-through effect in the first wavelet scale in a lower inflation regime, while the magnitude for Lithuania is 5.1% in the second wavelet scale, also in a lower inflation regime. A possible rationale for these results is the fact that Lithuania and Slovakia have a relatively high percent of oil import *vis-à-vis* GDP (see Table 3). Slovenia and Latvia also have high share of oil *vis-à-vis* GDP, amounting 2.86% and 2%, respectively. Table 2 confirms that these countries also have high  $\alpha_1$  parameters in the third and second wavelet scales, respectively, at around 4%.

As for the regime-specific error variances, it can be noticed that all the sigma parameters have negative signs, but since the variances are shown in quadratic form, they should be observed in absolute values. The regime-specific error variances refer to the standard deviation of each regime, indicating the magnitude of the volatility of each regime. Table 2 suggests that, in all the countries except in Bulgaria, Slovenia and Croatia, observing all the wavelet scales, the sigma coefficients in high-inflation regimes are larger than their counterparts in low-inflation regimes.

**Table 3.** Oil import, GDP and oil import/GDP ratio in 2017.

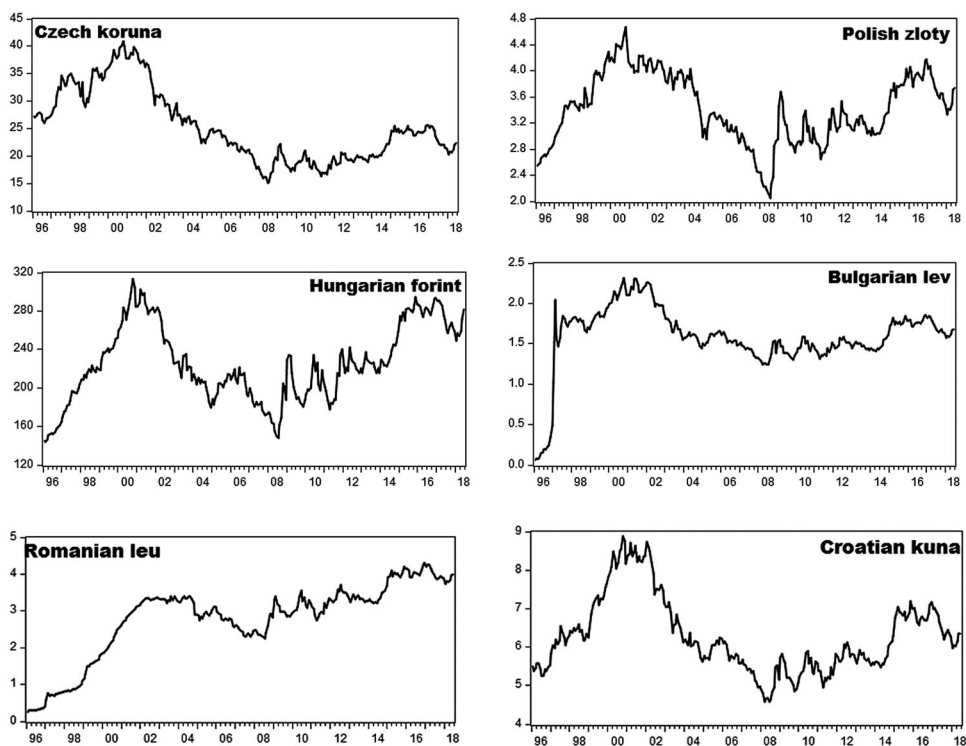
	Oil import in billions of \$ <sup>a</sup>	GDP in billions of \$ <sup>b</sup>	Oil import / GDP in %
The Czech Republic	3.2	216	1.48
Poland	9	525	1.71
Hungary	2.3	139	1.65
Slovakia	2.1	96	2.19
Lithuania	4.1	47	8.72
Latvia	0.6	30	2
Estonia	0.016	26	0.06
Romania	3	212	1.41
Bulgaria	2.6	57	4.56
Slovenia	1.4	49	2.86
Croatia	1.1	55	2

<sup>a</sup><http://www.worldstopexports.com/crude-oil-imports-by-country/>

<sup>b</sup>IMF World Economic Outlook database.

#### 4.2. Regime switching results when Brent oil is expressed in the national currencies

The previous subsection has focused on the isolated effect of oil shocks on the national inflation rates, but this approach does not address the factor of exchange rate changes, which is also very important, since all oil purchases are carried out in USD. Therefore, this raises the question of exchange rate stability against the US dollar. As already mentioned in Section 3, we conduct this analysis only in those CEECs which have retained



**Figure 3.** Empirical dynamics of selected exchange rates *vis-à-vis* USD.

national currencies as a means of payment in their systems. Those countries are the Czech Republic, Poland, Hungary, Romania, Bulgaria and Croatia. Figure 3 presents the empirical dynamics of the exchange rates of these six countries against USD, and it is evident that all these currencies are quite volatile, whereby some currencies depreciated significantly against USD at some point in time. For instance, the Bulgarian lev and the Romanian leu suffered the highest depreciation. The Bulgarian lev depreciated more than 2800% in the period from January 1996 – February 1997, while the Romanian leu lost almost 1200% of its value against USD in the period from January 1996 to April 2002. These cases of high depreciation are probably the main culprit for the very high inflation rates, which we have found in these two countries in these particular periods (see Figure 1). Therefore, it is quite justifiable to suspect that exchange rate instability contributes to the volatility of oil prices when they are expressed in domestic currencies, which ultimately reflects on national inflation. Hence, this subsection presents the results of the transmission effect when the price of Brent oil is expressed in domestic currencies, and Table 4 shows these results.

The results in Table 4 are not very different from those in Table 2 for the Czech Republic, Poland, Hungary and Croatia. This means that exchange rate instability *vis-à-vis* USD is not a major factor affecting inflation in these countries. However, for Bulgaria and Romania,

**Table 4.** Regime switching spillover effect from Brent oil price changes to inflation when the Brent oil price is expressed in national currencies

		CZE	POL	HUN	ROM	BUL	CRO	
D1	$\alpha_1$	0.038***	-0.001	-0.004	-0.079***	1.169*	0.006	
	$\alpha_2$	0.003	0.012	0.006*	0.008***	0.009	0.004	
	P11	0.69	0.99	0.86	0.83	0.90	0.85	
	P22	0.89	0.98	0.94	0.94	0.99	0.95	
	ED regime 1	3.2	99.2	7.19	5.95	10.4	6.6	
	ED regime 2	9.7	56.5	18.0	18.28	255.7	19.9	
	$\sigma_1^2$	-0.56***	-1.98***	-0.69***	0.53***	3.67	-0.83***	
	$\sigma_2^2$	-1.72***	-1.05***	-1.60***	-1.60***	-0.702	-1.51***	
	D2	$\alpha_1$	-0.021	0.016***	0.020***	-0.023	0.811***	0.024***
		$\alpha_2$	0.005*	0.001	0.001	0.005	0.018***	0.001
P11		0.96	0.93	0.97	0.98	0.95	0.97	
P22		0.98	0.97	0.92	0.99	0.99	0.96	
ED regime 1		26.8	15.1	33.7	46.0	19.1	40.3	
ED regime 2		85.9	30.2	12.3	196.9	242.5	25.6	
$\sigma_1^2$		-0.81***	-2.49***	-1.74***	0.85***	3.12***	-1.00***	
$\sigma_2^2$		-1.76***	-1.31***	-1.07***	-1.38***	-0.81***	-1.75***	
D3		$\alpha_1$	0.016***	0.022***	0.041***	-0.006	1.033***	0.025***
		$\alpha_2$	0.014***	-0.006	-0.117***	0.165	-0.014	-0.120***
	P11	0.87	0.98	0.99	0.99	0.96	0.98	
	P22	0.76	0.97	0.96	0.94	0.99	0.91	
	ED regime 1	7.6	74.7	168.5	122.1	25.2	47.1	
	ED regime 2	4.2	41.6	24.9	16.5	240.3	11.7	
	$\sigma_1^2$	-2.20***	-2.21***	-1.50***	-1.47***	2.44***	-1.83***	
	$\sigma_2^2$	-2.05***	-1.17***	-0.82***	1.12***	-0.69***	-1.52***	
	D4	$\alpha_1$	-0.001	0.016***	0.011***	0.004	1.167***	0.013***
		$\alpha_2$	0.030***	0.006	0.023***	0.429***	0.014**	0.016***
P11		0.92	0.94	0.88	0.99	0.97	0.91	
P22		0.91	0.94	0.92	0.98	0.99	0.90	
ED regime 1		12.8	16.2	8.2	251.8	41.6	11.5	
ED regime 2		11.5	16.8	12.9	44.8	167.9	9.66	
$\sigma_1^2$		-1.97***	-3.37***	-2.56	-2.01***	1.58***	-2.78***	
$\sigma_2^2$		-3.12***	-1.83***	-2.35	0.30***	-1.49***	-2.57***	

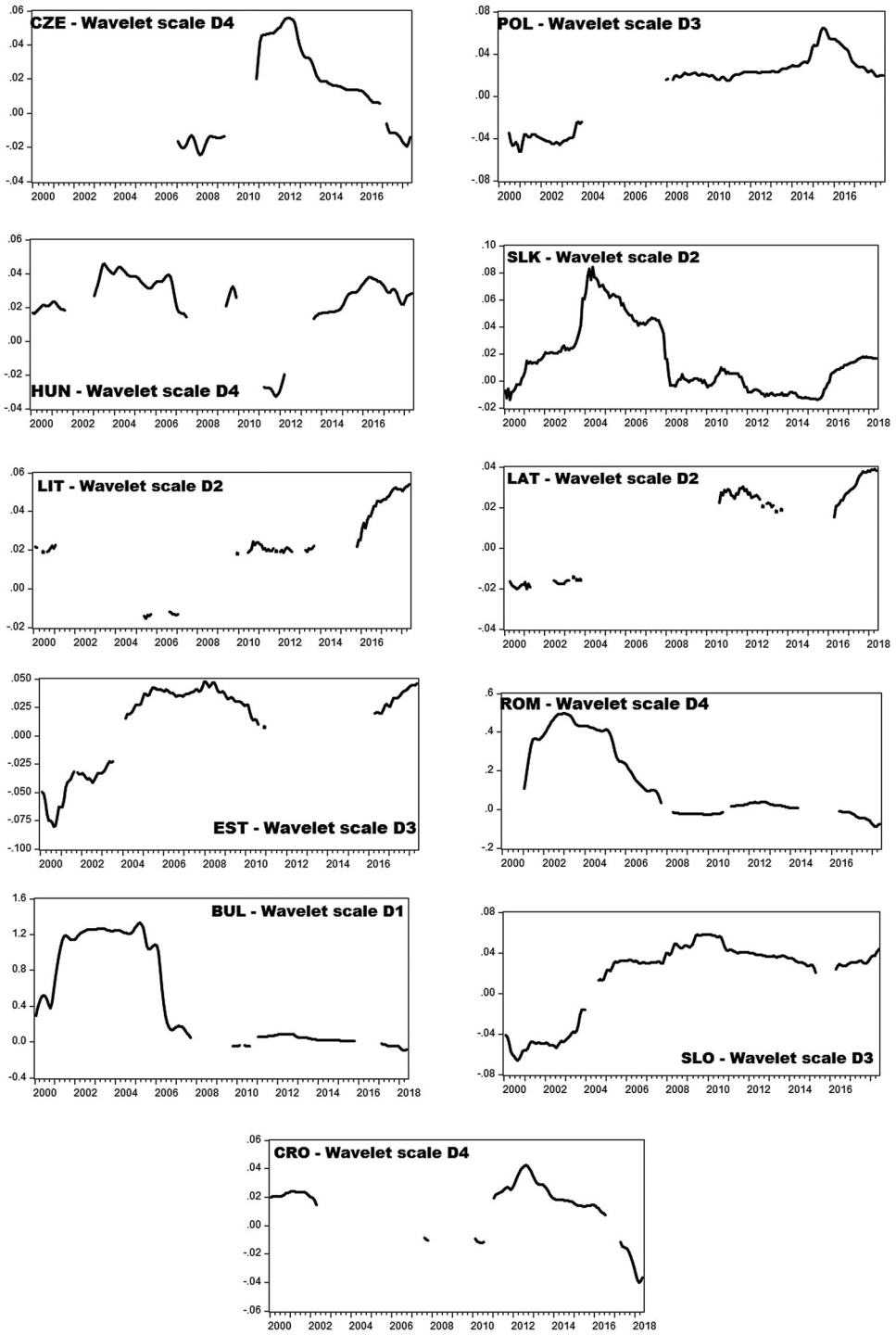
the difference is obvious. In [Table 2](#), we have seen that Bulgarian inflation suffered very little effect from Brent oil in all the wavelet scales, while for the Romanian case this effect is non-existent. However, when oil prices are expressed in the national currencies of these two countries, the difference is huge. For instance, we find that the oil price has a tremendous impact on Bulgarian inflation in all the wavelet scales. This impact is present in the first regime, which is related to higher inflationary pressure. For example, in the very short time-horizon (D1 scale), the 100% oil price increase affects a 117% rise in Bulgarian inflation. In the somewhat longer time horizon (D2 scale), it is 81%, while in the third and fourth wavelet scales this impact is even higher, amounting to 103% and 117% respectively.

In the case of Romania, we encounter a very strong impact only in the long-term horizon, where this impact is 43% when oil prices increase by 100%. This finding suggests that an indirect affect is dominant in the case of Romania. On the other hand, in the Bulgarian case, we find evidence of both direct and indirect effect, since very high spillover parameters are recorded in the short-term as well as in the midterm and long-term horizons.

However, it should be said that the results in [Table 4](#) present the average values of the spillover parameters, and it is unlikely that the Romanian and Bulgarian inflation rates suffered such a horrific impact from oil throughout the entire sample. Despite the huge price swings in Brent oil throughout the entire sample, the Bulgarian and Romanian inflation rates remained relatively stable for the majority of the selected period (see [Figure 1](#)). This means that the estimated average values of the switching parameters in the Romanian and Bulgarian cases in [Table 4](#) could be biased and misleading. In other words, such high estimated spillover parameters are most likely the aftermath of the very high currency depreciation, which these countries experienced in the second half of the nineties, whereby the heavy weight of these parameters in this period was transferred to the value of the switching parameters. Thus, the estimated average switching parameters most likely carry incorrect information, which requires an additional methodological approach. In that sense, the next section contains the results of the estimated rolling regression, which is time-varying, and which puts the exact weight on the rolling parameters, depending on the weight of the particular rolling sample.

## 5. Complementary analysis via rolling regression

In order to overcome the issue of biased average switching parameters, we apply a rolling regression methodology, which elegantly bypasses the problem of the heavy weight, which some parameters bear. The idea is borrowed from [Alper and Yilmaz \(2004\)](#), [Coudert, Hervé, and Mabilbe \(2015\)](#) and [Živkov, Njegić, and Pavlović \(2016\)](#). This particular methodology allows us to test whether the results are driven by a particular sample period. The size of the rolling window is set at four years, i.e. 48 monthly observations. Accordingly, the number of consecutively calculated rolling spillover parameters is 221 for each country. The decision on which particular wavelet scale would be observed was made on the size of the previously calculated switching parameters as presented in both [Tables 3](#) and [4](#). In other words, the wavelet scale in which the switching parameters are the highest was considered for rolling regression estimation. Also, we gave priority to those scales in which both switching parameters are statistically significant. [Figure 4](#)



**Figure 4.** Estimated rolling spillover parameters.

Note: The estimated rolling parameters are considered significant only if their  $p$ -value is less than 10%.

presents the estimated statistically significant rolling spillover parameters, and the label in each plot indicates which wavelet scale was taken into account. In order to avoid any possible spurious regression, we applied the generalized least square (GLS) approach to correct standard errors for autocorrelation, while we used the White method for heteroscedasticity proposed by MacKinnon and White (1985).

The rolling regression equation looks like as follows:

$$INF_t = c_t + \alpha_t OIL_t + \varepsilon_t; \quad \varepsilon_t \sim N(0, \sigma_t^2), \quad (6)$$

where  $INF_t$  represents the inflation rate, derived from the CPI index,  $OIL_t$  stands for Brent oil log returns,  $c_t$  is a time-varying constant and  $\alpha_t$  is time-varying spillover parameter. For the estimation of every rolling window, the normal distribution was assumed.

Figure 4 shows that the magnitude and statistical significance of the rolling parameters vary throughout the observed sample in all the countries, thus justifying the usage of this approach. The rolling parameters confirm our previous conclusion that oil price changes had a significant effect on the Slovakian inflation, since all the rolling parameters are statistically significant. However, it is also evident that this influence was considerably lower in the last ten years when compared to the period before 2007. In addition, oil price changes had a continuous and significant effect on Polish, Romanian, Bulgarian and Slovenian inflation rates, since the majority of the rolling parameters are statistically significant in these countries. However, this effect is interchangeable in the Czech Republic, Hungary, Croatia and Estonia. As for Latvia and Lithuania, relatively high and statistically significant rolling parameters were only found in the last two years.

In addition, it can be seen that the size of the rolling parameters differentiates substantially only in the Romanian and Bulgarian plots. In particular, it can be seen that the initial rolling parameter estimates for these countries are much higher than the later ones. For instance, in the case of Bulgaria, these parameters are quite high in the initial six years, while the subsequent ones are considerably lower. The same applies for Romania. In other words, this confirms our assertion that the exchange rate depreciation, which occurred in these countries in the second half of the nineties, significantly affected national inflation rates. However, in the period which followed, this effect was considerably reduced, and the main reason was the stabilization of their exchange rates *vis-à-vis* USD (see Figure 3). Therefore, we can contend that the switching parameters of Bulgaria and Romania in Table 4 are heavily biased due to the strong currency depreciation, which occurred at some particular time-point in these countries. Nevertheless, if these extreme parameters are ignored, then the size of the spillover effect is not very different from other countries in the sample. In other words, this effect ranges up to 5% in normal occasions in these countries, when oil price changes reach 100%.

## 6. Conclusion

Oil serves as a major input in the economy, and this paper tries to quantify the impact of Brent oil price changes on the national inflation rates of the eleven CEECs. In an effort to do that, we assumed a non-linear relationship between these variables, but also, attempted to gauge how this impact varies across different time-horizons. Various time-horizons are considered because oil shocks can spillover to inflation directly and indirectly, whereby

the direct effect comes to the fore for shorter time-horizons, while the indirect effect is manifested for longer ones. Therefore, we used the wavelet-based Markov switching approach.

The calculated wavelet-based regime switching parameters are heterogeneous across the regimes and wavelet scales, thus justifying the usage of this methodology. We found that the transmission effect from oil price changes is relatively low in all the selected countries, meaning that a 100% rise in oil prices impacts the inflations in the range from 1% to 6% depending on the state regime and particular wavelet scale. These findings coincide very well with the results of other studies, reporting a low spillover effect from oil to inflation (see e.g. De Gregorio et al., 2007; Blanchard & Riggi, 2013; Álvarez et al., 2011; Choi et al., 2018). Such a relatively low pass-through effect from oil to inflation conveys an important message to international investors. Namely, since inflation is regarded as a very important indicator of macroeconomic stability, international investors can be confident that oil shocks cannot disrupt price stability in the selected CEECs, which is a positive feature of these countries.

Applying the wavelet approach, we found that the strongest oil impact on inflation is recorded in longer time-horizons in most of the selected countries. This means that the indirect effect is more prevalent than the direct one, which is expected since the indirect effect hits a wider range of goods and services and it comes to the fore for longer time-periods. However, we also found a high transmission effect in very short time-horizons, which favours the direct effect, but is limited to several countries such as the Czech Republic, Slovakia and to a certain extent Slovenia. In addition, it is interesting to note that the majority of high oil impacts occur in the second regime, when inflation is low. These results bring about another implication, in favour of central banks, indirectly speaking. In other words, low oil spillover effects in higher inflation regimes could mean that these economies conduct a reasonable and prudent monetary policy regarding the task of curbing inflation, regardless of from which source the inflationary shocks might stem. In other words, the estimated lower switching parameters in the first regime suggest that the monetary authorities of the CEECs are more dedicated to keeping inflation under control when inflationary pressure is stronger.

Expanding the analysis, we also express Brent oil in terms of national currencies for those CEECs which have not adopted the euro. The results suggest that the exchange rate is not a significant factor when oil shocks are transmitted towards inflation. However, when high depreciation occurs, then the exchange rate plays a major role in the pass-through from oil to inflation. This is evident in the Bulgarian and Romanian cases. In addition, rolling regression shows that oil spillover shocks are not linear and uniform, but are rather heterogeneous and time-varying. This means that the central banks of the CEECs need to recalculate the magnitude of these spillover shocks from time to time in order to maintain awareness of the possible changes in the level of oil shocks spillover towards inflation.

Observing all the results and all the selected countries, it can be inferred that Slovakia and Bulgaria are the countries which endure the highest and most consistent pass-through effect throughout all the wavelet scales in the observed time-sample. The rationale for this finding could lie in the fact that these countries are the most dependent on oil, that is, they have among the highest percentages of oil imports *vis-à-vis* GDP. Slovakian share of oil import in GDP is 2.19%, while Bulgarian is 4.56% in 2017. Lithuania also has

a very high percent of oil imports, but our rolling regression results reveal that oil shocks only had a serious impact on Lithuanian inflation in the last two years.

We believe that the results presented in this study could provide a useful base for understanding how oil shocks affect inflation rates in CEECs, and whether this impact requires a significant commitment from monetary authorities to cushion these shocks. Our results suggest that the inflation rates of the selected CEECs are rather resilient to oil price changes, which speaks indirectly in favour of the responsible monetary policy of these economies. The only exceptions are the periods when national currencies experience high depreciation. On these occasions oil spillover shocks towards inflation are exceptionally strong.

As for future research efforts, we can propose a few directions, which might be interesting. Firstly, future studies could broaden our baseline model, including some other macroeconomic aggregates, such as income. Also, it may be of interest to assess asymmetric oil impacts on inflation, whereby both positive and negative oil shocks would be addressed.

## Note

1. MODWT decomposition is done via 'waveslim' package in 'R' software.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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