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The relationship between oil prices and exchange rates: Revisiting theory and evidence☆,☆☆

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ABSTRACT

This paper reviews existing theoretical and empirical research on the relationship between oil prices and exchange rates. We start with theoretical transmission channels—which point to bi-directional causality. Empirical research is classified and shows that the evidence varies substantially depending on sample, country choice and empirical method. Yet there are some common patterns: (i) strong links between exchange rates and oil prices are frequently observed over the long-run; and (ii) either exchange rates or oil prices are a potentially useful predictor of the other variable in the short-run, but the effects are strongly time-varying. We also identify some important avenues for future research.

1. Introduction

Policymakers, academics and journalists have frequently discussed the link between oil prices and exchange rates in recent years—particularly the idea that an appreciation of the US dollar triggers a dip in oil prices. Empirical research is not clear on the direction of causation, as there is evidence for bi-directional causality. Some studies find that an increase in the real oil price actually results in a real appreciation of the US dollar (Amano and Van Norden, 1998a), while others show that a nominal appreciation of the US dollar triggers decreases in the oil price (Akram, 2009).

Fig. 1 illustrates the potential link between the nominal West Texas Intermediate (WTI) crude oil price and the effective US dollar exchange rate index relative to its main seven trading partners. The two-way causality between both variables results in the need to carefully distinguish between the apparent co-movement between both variables and the underlying causality (Kilian and Zhou, 2019).

This survey paper takes a closer look at the research dealing with the relationship between oil prices and exchange rates. After a brief review of theoretical transmission channels, we focus on a comprehensive and critical evaluation of empirical studies surrounding this research area. The idea is to summarize the most important contributions based on their impact on the empirical and the theoretical literature and their policy relevance. The growing relevance of the relationship between oil prices and exchange rates is illustrated in Fig. 2, which shows the number of articles published in economics journals including the terms "exchange rate" and "oil price" in title, abstract or keywords over the last decades. The amount of articles is clearly increasing since the early 2000s.

We identify four major issues that need to be addressed in order to classify the oil price/exchange rate relationship. The first is to disentangle a backward ("in-sample") and a forward-looking ("out-of-sample") empirical analysis. The second challenge is to disentangle

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☆☆ The analysis and conclusions expressed here are those of the authors and not necessarily those of the U.S. Energy Information Administration.

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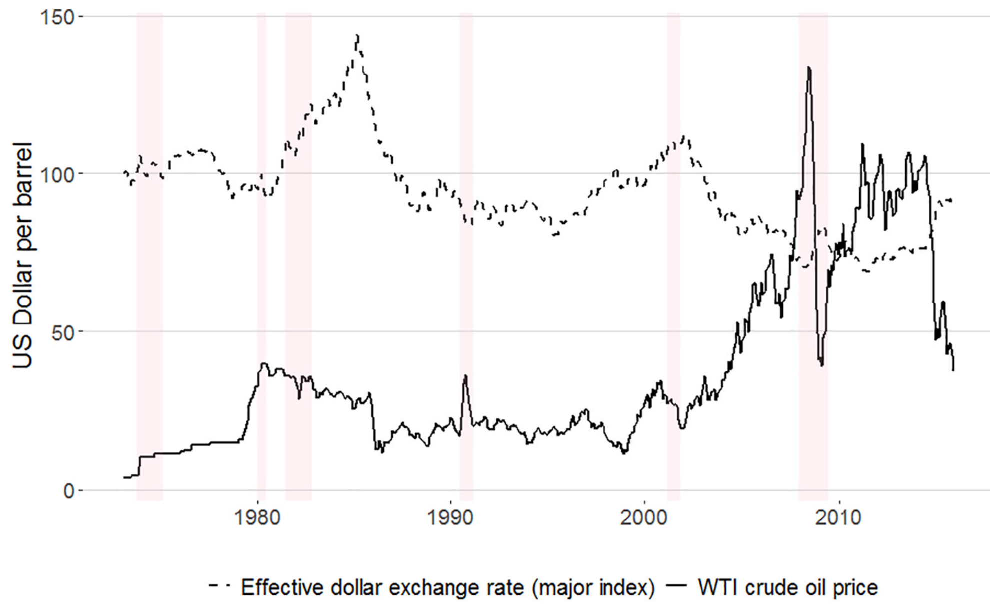

Fig. 1. Time series pattern of the oil price and the major US dollar index.
Source: own illustration, data taken from Federal Reserve Economic Data. The pink shaded areas represent US recession periods according to the National Bureau of Economic Research.

direct and indirect transmission channels. The third major task is to address the role of time-variation and nonlinearity. A final issue is related to policy implications and open research questions.

The rest of this paper is organized as follows. Section 2 provides some helpful definitions. Section 3 briefly summarizes various theoretical transmission channels, which link oil prices and exchange rates. Sections 4 and 5 focus on in-sample validity of the identified transmission channels by reviewing empirical evidence over the long-run and over the short-run, respectively. The question of predictability between oil prices and exchange rates is considered in Section 6. Section 7 addresses the role of the exchange rate regime for the link between oil prices and exchange rates. The final two sections focus on policy recommendations and conclusions.

2. Definitions

The distinction between real and nominal measures is important when assessing the relationship between oil prices and exchange rates. The nominal spot exchange rate at a specific point in time (s_t) is expressed as domestic currency per US dollar, implying that an increase

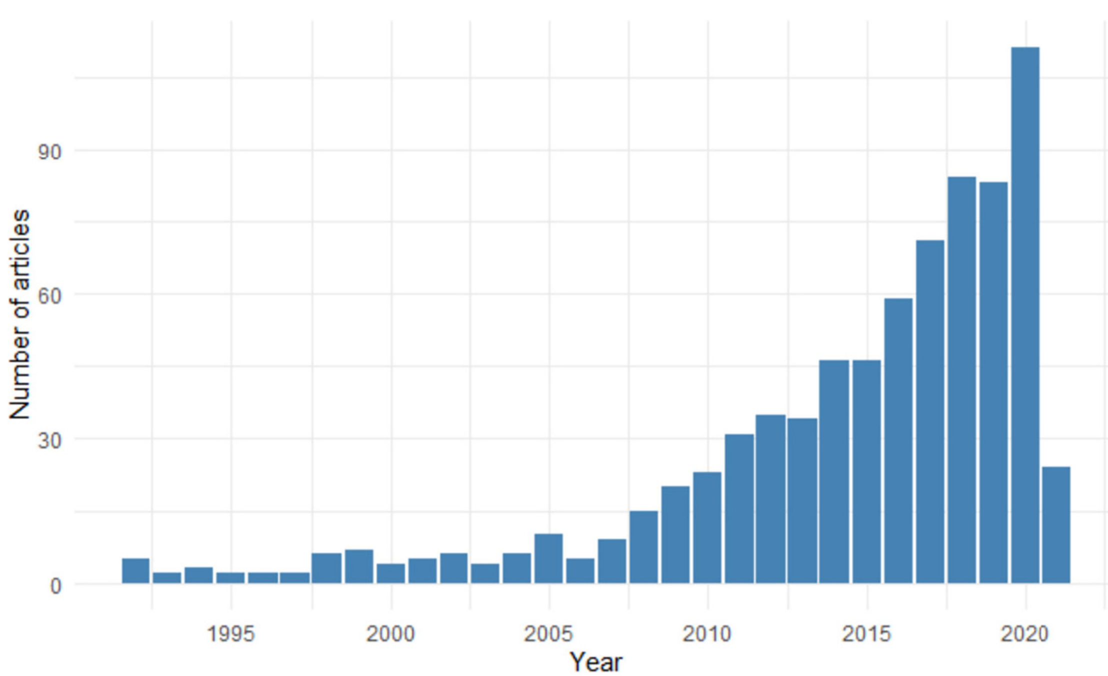

Fig. 2. Number of articles published including the terms “exchange rate” and “oil price” in title, abstract or keywords.
Source: own illustration, data taken from Scopus. We have conducted a Scopus search for the words “exchange rate” and “oil price” in title, abstract or keywords of all articles published within the subject area “Economics, Econometrics and Finance”.

reflects a nominal appreciation of the US dollar,

$$s_t = \frac{domestic\ currency_t}{US\ dollar_t}. \tag{1}$$

The real exchange rate (q_t) also includes price indices for both countries, and reflects the basket of domestic goods that can be purchased with one basket of US goods. This can be expressed as $q_t = s_t \frac{p_{t^*}}{P_t}$ where p_t and p_{t^*} denote domestic and foreign (i.e. US) price levels, usually approximated through consumer or producer prices. An increase is a real appreciation of the US dollar because the real purchasing power of US goods increases. This definition corresponds to the real exchange rate in external terms. Some studies consider the ratio between the prices of tradable and non-tradable goods; this is called the real exchange rate in internal terms or the terms of trade, and a relative increase in the price of tradable goods corresponds to a real depreciation.

The nominal oil price is usually measured in US dollar per barrel, as shown in Fig. 1. The real oil price is calculated by adjusting the nominal oil price for any changes in the US price level (usually based on the US consumer price index (CPI)). Both nominal and real exchange rates can be expressed as a geometric or arithmetic trade weighted index between multiple countries, rather than just between two countries. Such effective exchange rates reflect overall external competiveness for an economy. Instead of analyzing current or spot price dynamics, another alternative is to focus on futures price dynamics, as these also reflect expectations.

3. Theoretical transmission mechanisms

Before we turn to the empirical evidence, it is important to identify theoretical links between oil prices and exchange rates. The various transmission channels are summarized in Fig. 3. The terms of trade channel mostly focuses on real oil prices and exchange rates, while the wealth and portfolio channels propose an effect from the nominal exchange rate to the nominal oil price. The expectations channel allows for nominal causalities in both directions. Overall, it is important to highlight that both oil price and exchange rate dynamics are driven by several factors and are notoriously difficult to predict. The unstable link between exchange rates and macroeconomic fundamentals is reflected in the exchange rate disconnect puzzle (Sarno, 2005), while understanding cycles in oil price fluctuations is often complicated by identifying the underlying source of demand and supply shocks (Baumeister and Kilian, 2016).

3.1. The impact of oil prices on exchange rates

The literature considers three direct transmission channels of oil prices to exchange rates: the terms of trade channel, the wealth effect channel and the portfolio reallocation channel (Buetzer et al., 2016).

The terms of trade channel was introduced by Amano and Van Norden (1998a, 1998b) and mainly reflects relative price dynamics. The underlying idea is to link the price of oil to the price level, which affects the real exchange rate (Bénassy-Quéré et al., 2007). Consider two economies A and B with the production of the former more dependent on oil compared to the latter. If the non-tradable sector of a country A is more energy intensive than the tradable one, the output price of this sector will increase relative to the output price of country B in case of an increasing price of oil. This implies that the currency of country A experiences a real appreciation due to higher inflation (Chen and Chen, 2007 Buetzer et al., 2016).

Effects on the nominal exchange rate arise if the price of tradable goods is no longer assumed to be internationally fixed. In this case, inflation and nominal exchange rate dynamics are related via purchasing power parity (PPP). If the price of oil increases, we expect currencies of countries with large oil dependence in the tradable sector to depreciate due to higher inflation for the reason outlined above. The response of the real exchange rate then depends on how the nominal exchange rate changes, but relative to the impact of any changes in the price of tradable (and non-tradable) goods described above. Overall, causality embedded in the terms of trade channel potentially holds over different horizons depending on the adjustment of prices.

Portfolio and wealth channel, introduced by Krugman (1983) and Golub (1983) focus on nominal exchange rate dynamics. The underlying framework is based on a three country framework and has been reconsidered by Bodenstein et al. (2011). The basic idea is that oil-exporting countries experience a wealth transfer if the oil price rises (Bénassy-Quéré et al., 2007). The wealth channel reflects the resulting short-run effect, while the portfolio channel assesses medium- and long-run impacts. When oil prices rise, wealth is transferred to oil-exporting countries (in US dollar terms) and is reflected as an improvement in exports and the current account balance in domestic currency terms. For this reason, we expect currencies of oil-exporting countries to appreciate and currencies of oil-importers to depreciate in effective

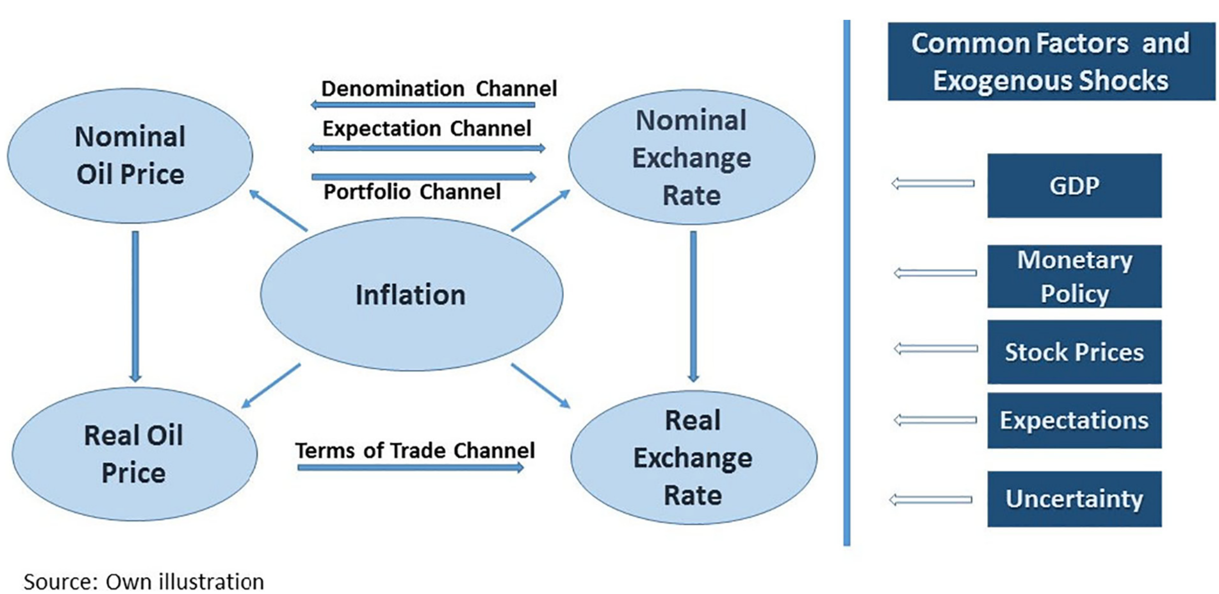

Fig. 3. Interdependence between oil prices, exchange rates and other factors.

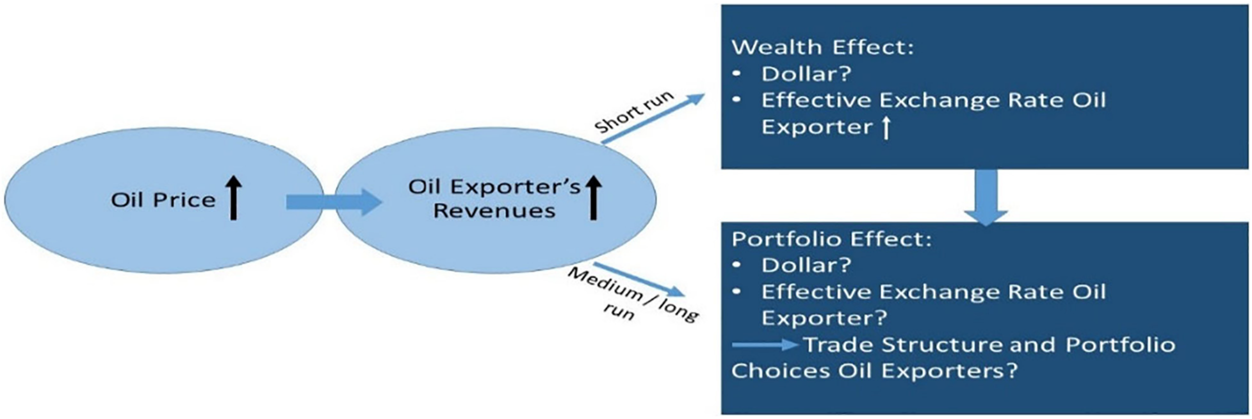

Fig. 4. Wealth and portfolio channel.
Source: own illustration.

terms after a rise in oil prices (Beckmann and Czudaj, 2013b). There is also the possibility that the US dollar appreciates in the short-run because of the wealth effect—if oil-exporting countries reinvest their revenues in US dollar assets.

The medium- and long-run effects on the US dollar relative to currencies of oil-exporters will depend on two factors according to the portfolio effect. The first is the dependence of the United States on oil-imports relative to the share of US exports to oil-producing countries. This will determine whether trade effects tend to appreciate (if the demand for US goods dominates) or depreciate (if the US demand for oil dominates) the US dollar relative to currencies of oil-producing countries. The second is oil exporters' relative preferences for US dollar assets which affects the financial demand for US dollar as outlined above (Bénassy-Quéré et al., 2007 Coudert et al., 2008 Buetzer et al., 2016). Fig. 4 summarizes the wealth and portfolio channels.

3.2. The impact of exchange rates on oil prices

The theoretical starting point for causality from exchange rates to oil prices is the fact that the oil price is denominated in US dollar. Abstracting from transaction costs, consider the following relationship between the logarithms of the oil price denominated in a local currency (o_t^*) and the US dollar (o_t) based on the law of one price

$$o_t^* = s_t * o_t. \tag{2}$$

Following this equation, an appreciation of the US dollar (a rise in s_t) increases the price of oil measured in terms of the domestic currency, and this lowers demand for oil outside the US, resulting in a drop in the oil price (Bloomberg and Harris, 1995 Akram, 2009).

Effects on the supply side are potentially relevant but less frequently discussed, mainly because they are subject to several other factors affecting price setting and production. Positive supply responses may stem from a rise in the oil price due to a US dollar appreciation if drilling activity and/or production capacity increases (Coudert et al., 2008). Oil-exporting companies or countries might also decide to adjust oil prices or supply as a response to exchange rate changes depending on their price strategy (Yousefi and Wirjanto, 2004). In case of a partial or full exchange rate pass-through, foreign oil-producers potentially increase the price of oil, or cut supply, if the US dollar depreciates—and vice versa (Fratzscher et al., 2014). If following a pricing to market strategy, they may hold the oil price in US dollars fixed instead, even if the valuation of the dollar is changing. In this case no supply effects emerge as a result of exchange rate changes. Another important factor is the amount of US dollar debt in case of state owned oil companies. Dollar appreciations increase debt denominated in domestic currencies, which could trigger incentives for an oil price increase in case of an appreciation.

The denomination channel is also related to expectation effects. Market participants might for example expect that an appreciation of the dollar immediately triggers a decrease in the price of oil. This can also lead to movements in future markets if oil futures are considered as a good hedge against an expected dollar depreciation (Fratzscher et al., 2014). If both exchange rates and oil prices are viewed as asset prices, the fact that both are jointly determined in equilibrium complicates the identification of (one-sided) clear causality (Chen et al., 2010).[1]

3.3. Common factors driving oil prices and exchange rates

Having already explained the role of inflation, Fig. 3 incorporates other common factors including GDP, interest rates, stock prices and uncertainty (see e.g. Baumeister and Kilian, 2016 Degiannakis et al., 2018 Kilian and Zhou, 2019). A full analysis of all possible linkages and other potential factors is beyond the scope of this paper, but a few important channels are worth mentioning.[2]

GDP and interest rates both affect exchange rates and oil prices and are also interrelated: Monetary policy reacts to GDP growth fluctuations[3] while interest rate changes affect GDP through total investment and total spending. An increase in GDP of a large economy, all else equal, results in an increase in the oil price. Effects on exchange rates are less clear for both interest rates and GDP. A relative increase in domestic interest rates should for example depreciate the domestic currency according to uncovered interest rate parity. However, exchange rate overshooting models in the spirit of Dornbusch (1976) predict an appreciation in the short-run and the empirical evidence has also demonstrated that an appreciation is frequently observed, reflecting the notorious forward premium puzzle.[4] Another major influence on both the macroeconomic environment and exchange rate dynamics is the degree of uncertainty. A domestic appreciation of the exchange rate might

[1] Whether or not the oil price should be considered a forward-looking asset price is debated, but recent studies by Kilian and Vega (2011) and Fratzscher et al. (2014) provide evidence for the view that oil prices react to changes in other financial assets.

[2] In addition, crude oil prices might also have an indirect effect on exchange rates through sovereign credit risk since there is also some evidence that oil price shocks affect the perception of sovereign credit risk (Wegener et al., 2016; Bouri et al., 2020) and the latter is linked to exchange rate fluctuations (Augustin et al., 2020).

[3] A central bank adjusts interest rates according to deviations of inflation and GDP from specific targets according to the Taylor rule principle.

[4] It is also worth mentioning that the intensity of the link between oil prices and exchange rates is of potential relevance for monetary policymakers. A central bank which aims at price stability will react less to inflationary effects stemming from oil prices which are at least partially offset by a change in domestic currency value. Central banks which adopt exchange rate targeting will also take such linkages into account (Reboredo, 2012; Beckmann and Czudaj, 2013a).

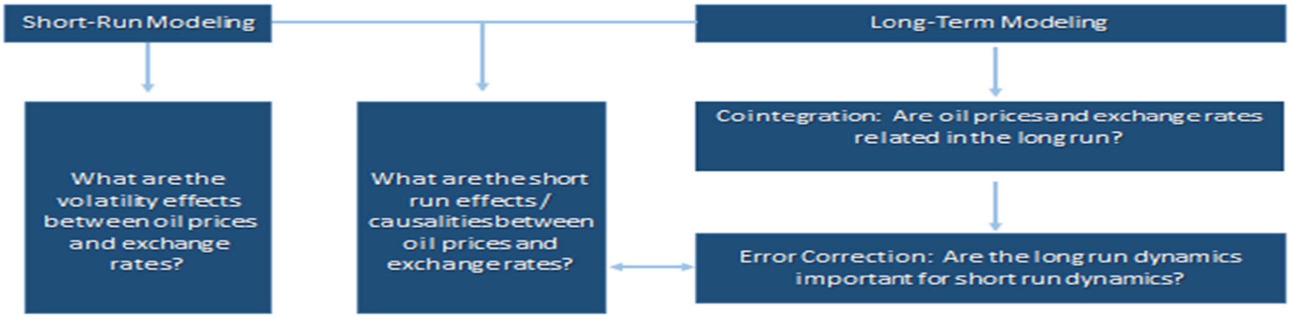

Fig. 5. Long-run vs. short-run dynamics between oil prices and exchange rates.
Source: own illustration.

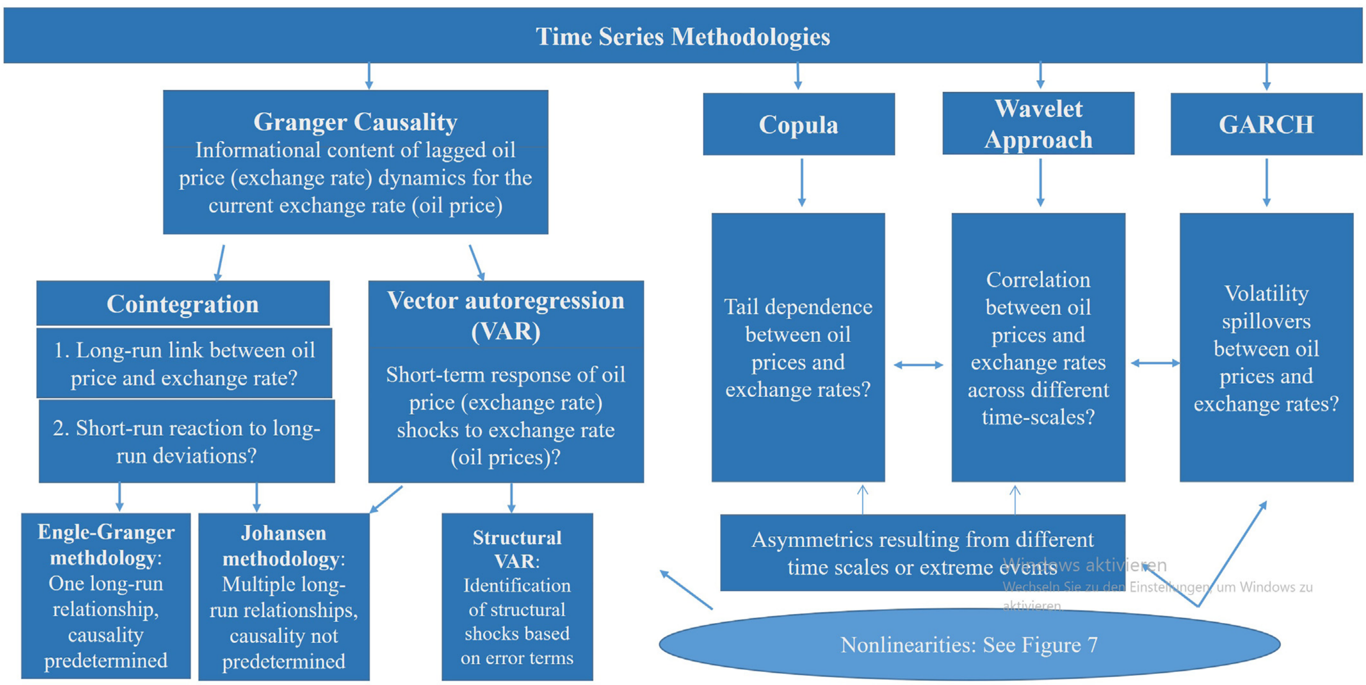

Fig. 6. Overview of different empirical approaches modeling the relationship between oil prices and exchanges rates.
Source: own illustration.

result from uncertainty, if participants expect a currency to act as a safe haven (Beckmann and Czudaj, 2017).[5]

4. Long-run in-sample evidence between exchange rates and oil prices

4.1. General classification of empirical methods and data used

As mentioned in the introduction, in-sample estimates consider the historical relationship between the price of oil and exchange rates, while out-of-sample analyses use information up to a point t to make predictions about time $t + h$. The term "pseudo out-of-sample" corresponds to a forecasting model which uses only the portion of historical data that would have been available up to a pre-specified point in time. A crucial question that arises when studying historical relationships is whether knowledge about the past is important when making predictions for the future. Empirical studies usually address two different issues: The causality between oil prices and exchange rates, and/or the intensity of the link between them.

Fig. 5 provides a distinction between long-run and short-run analysis. The underlying concept of cointegration relies on the idea of a stable long-run equilibrium with short-run deviations above and below it that are corrected over time. If exchange rates and oil prices share a long-run (cointegrating) relationship, they (potentially) still deviate from this relationship in the short-run. The long-run coefficient characterizes the connection between both variables in equilibrium. The so-called error correction mechanism captures 1.) the speed with which deviations from a long-run equilibrium are corrected; and 2.) the variables responsible for such corrections.

The classification of empirical evidence shown in Fig. 6 also reflects the distinction between short-run and long-run dynamics and provides a good guideline for the discussion of empirical results.

The simplest measure corresponds to Granger causality, which analyzes whether past oil prices or exchange rates help explain the current value of the other variable. In the context of vector autoregressive (VAR) models, another frequently adopted technique is the consideration of impulse response functions. They measure the reaction of one variable to a shock of another variable. The general advantage of VAR models is that oil and exchange rate dynamics can be assessed without any assumptions related to causalities. Structural vector autoregressive (SVAR) models additionally include some theory-guided restrictions

5 A possible explanation is that market participants consider news about a weakening of the US economy to have even worse effects for other countries (Fratzscher, 2009).

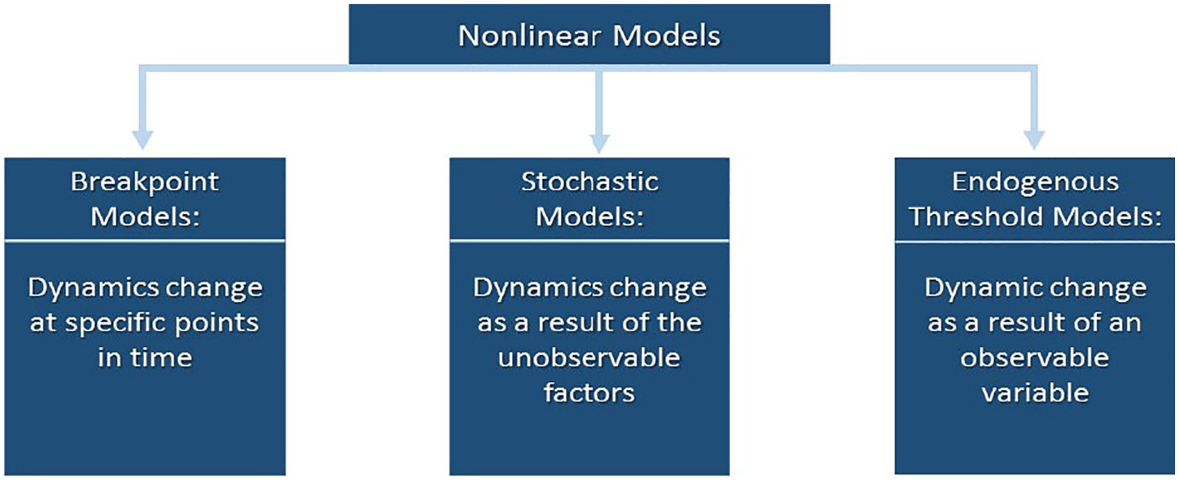

Fig. 7. Modeling nonlinearities.
Source: own illustration.

when shocks are implemented. Such a proceeding allows for a distinction between supply and demand shocks in the context of oil prices.

When conducting cointegration analysis, the long-run coefficient reflects the direction and intensity of the long-run relationship between the nominal oil price and exchange rates. The error correction coefficients measure the speed of adjustment to long-run deviations for each variable. If, as an example, only the oil price (but not the exchange rate) adjusts to long-run equilibrium, the causality essentially runs from exchange rates to oil prices. Two different frameworks are considered in the context of cointegration: The Engle and Granger (1987) two-step methodology adopts single equation estimates, where one variable is assumed to be the dependent variable, and tests these for stationarity. The multivariate Johansen (1988) methodology essentially resembles a VAR model which incorporates long-run dynamics and allows for the simultaneous estimation of several long-run relationships, if detected.

Short-run dynamics often focus on contemporaneous correlations or spillovers rather than lead-lag relationships. Generalized autoregressive conditional heteroscedasticity (GARCH) models are the most common framework to assess short-run volatility spillovers. Recent studies also consider copula and wavelet approaches (Beckmann et al., 2016). Such frameworks can be extended in various directions. Copula frameworks are able to assess and compare relationships in turbulent and normal times by allowing for tail dependency, i.e. dependency in the tails of both distributions. Wavelet approaches are adopted to compare dependencies between oil price and exchange rates over different frequencies. Essentially, both wavelet and copulas reflect specific forms of asymmetry or nonlinearity by accounting for different relationships across frequencies (wavelet) or between normal and turbulent times (copulas). Approaches which account for nonlinearities and different forecast evaluation methods will be discussed after the next section.

4.2. Empirical results

4.2.1. Long-run linkages

The long-run relationship between the price of oil and exchange rates has been analyzed for several countries in a range of studies. These cover various spans of data and use both effective and bilateral exchange rates, as well as nominal and real oil prices.[15]

[15] A table summarizing most important papers is provided in the Appendix of the working paper version. See https://www.eia.gov/workingpapers/pdf/oil_exchangerates_61317.pdf

The bottom line is that several studies have provided evidence for a long-run relationship between exchange rates and oil prices. One type of study has focused on the link between the real oil price and real US dollar exchange rates. Many authors have identified a long-run relationship between both, suggesting that a real effective appreciation of the US dollar coincides with an increase in the real oil price over the long-run (Amano and Van Norden, 1998a; Coudert et al., 2008 Bénassy-Quéré et al., 2007 Beckmann and Czudaj, 2013b).

Similar findings have been obtained for bilateral real exchange rates. Clostermann and Schnatz (2000) establish a long-term link between the real US dollar-euro exchange rate and the oil price, while Chaudhuri and Daniel (1998) assess real US dollar exchange rates for 16 OECD countries and detect a cointegrating relationship between most of them. Chen and Chen (2007) use a panel of G7 countries and find that real oil prices have significantly contributed to real exchange rate movements.

In line with the terms of trade channel discussed in Section 3, most studies find that the price of oil affects the exchange rate, but not vice versa. However, it is important to emphasize that the existence of a long-term relationship does not necessarily imply strong linkages in the short-run. In the case of linear models, the adjustment to restore disequilibria in many cases is estimated to be higher than 5 years, calling into question any practical relevance. There are also several studies which fail to establish a cointegrating relationship between exchange rates and the price of oil.

4.2.2. Oil-importing countries vs. oil-exporting countries and the importance of sample choices

The terms of trade channel discussed in Section 3 has inspired several authors to focus on effective exchange rates of oil-importers and oil-exporters. The findings differ remarkably across studies and countries. The link between nominal exchange rates and price differentials (reflecting the validity of purchasing power parity (PPP), which constitutes a part of the terms-of-trade channel) is characterized by several nonlinearities. PPP is for example more relevant over the long-run and in the case of high inflation differentials (Taylor et al., 2001 Kilian and Taylor, 2003 Sarno, 2005).

Many studies provide country-specific results. Habib and Kalamova (2007) do not find a long-run relationship between real effective exchange rates and the oil price for Norway and Saudi Arabia, but report evidence for a long-run real appreciation in Russia if the oil price rises. On the other hand, Al-Mulali (2010) provides evidence for a real effective appreciation of Norway in the case of an increase in the real oil price. Camarero and Tamarit (2002) find that real oil prices explain the real exchange rate for the Spanish peseta, while Huang and Guo (2007) show that real oil price shocks imply an appreciation of the real exchange rate for China based on a structural VAR.

On the other hand, the findings of three recent studies which analyze a richer dataset clearly show that there is no unique link between the real oil price and real effective exchange rates of oil-exporters and oil-importers. Buetzer et al. (2016) identify various shocks to real oil prices in a structural VAR and find no systematic evidence that the exchange rates of oil-exporters appreciate against those of oil-importers (for a set of 43 countries). One explanation for the missing link is that countries with a higher oil surplus intervene in the foreign exchange rate market to prevent appreciation pressures.

Beckmann and Czudaj (2013b) analyze a group of 10 economies and find that the results differ not only between, but also within the group of oil-exporters and oil-importers. They find that changes in nominal oil prices trigger real exchange rate effects through the nominal exchange rate and price differentials. Nominal appreciation against the US dollar is mainly observed for oil-exporting countries, while nominal depreciation is detected for importing and exporting countries. They also find reverse causality, in the sense that nominal exchange rates influence nominal oil prices in some cases. The more general evidence on commodity producing countries also suggests a strong link between real exchange rate appreciations and an increase in commodity prices. Bodart et al. (2012) analyze 68 economies and find that such an effect is observed if the dominant commodity accounts for at least 20% of total exports. Overall, there is clear evidence that sample selection strongly affects empirical results.

4.2.3. Time-varying relationships

The previous section has illustrated that the empirical findings differ over time, suggesting that instabilities are a key ingredient for understanding the oil price-exchange rate link. Fig. 7 summarizes different kinds of nonlinearities, which are relevant over different frequencies. The first possibility is that the relationship between the price of oil and exchange rates changes at a specific point in time due to a structural break. Two different ideas for identifying regime changes can be distinguished. One possibility is to identify a variable, which is responsible for such changes, for example a specific threshold of an observed variable.[6] Such models are easy to handle in terms of interpretation and are well suited to capture the underlying dynamics if the data is primarily generated by market forces (Balke and Fomby, 1997). However, if exogenous factors such as policy interventions or abnormal global economic crises affect the data, a stochastic framework, which does not require a transition variable, such as a Markov-switching approach is better suited.

Several authors have adopted nonlinear frameworks when assessing the link between oil prices and exchange rates. Akram (2004) introduced nonlinear dynamics into the literature on oil prices and exchange rates. He identifies a negative nonlinear relationship between the value of the Norwegian krone and crude oil prices based on a threshold model where the change of the oil price determines the underlying dynamics. The intensity of the link depends on whether fluctuations are within or outside the normal range, and whether oil prices are falling or rising. Allowing for nonlinearities is also important when assessing a long-run relationship between oil prices and exchange rates. Several findings like the one obtained by Zhang (2013) show that oil price and exchange rate dynamics are subject to structural breaks.[7] Beckmann and Czudaj (2013b) rely on a Markov-switching vector error correction model (MS-VECM) and find that adjustment dynamics often differ significantly between regimes. For most countries oil prices how different adjustment speeds between regimes. Basher et al. (2016) also apply a Markov-switching approach and identify exchange rate appreciation pressures in oil-exporting economies after oil demand shocks, but find limited evidence that oil supply shocks display a similar effect on exchange rates. As discussed above, wavelet and copula approaches also capture nonlinear patterns in the short-run.

5. Short-run in-sample evidence between exchange rates and oil prices

5.1. Main empirical results

Several studies focusing on short-run dynamics between exchange rates and the price of oil point to a causal chain from the US dollar exchange rate to the nominal oil price. Short-term studies analyze both daily and monthly frequencies, and we begin by summarizing studies dealing with monthly data. The first empirical study related to empirical oil price-exchange rate dynamics was provided by Trehan (1986). He argues that the effect of oil price shocks on the US economy is likely to be exaggerated because the oil price is denominated in US dollars and should not be considered as exogenous. Since then, several authors have directly analyzed the effects of exchange rate changes on the price of oil. Among other, Cheng (2008) finds an increase in the real (nominal) oil price as a response to a real (nominal) effective US dollar appreciation.

Some studies have also focused on the response of oil demand and supply to exchange rate shocks. Yousefi and Wirjanto (2004) analyze five OPEC countries and provide evidence that crude oil export prices respond positively to US dollar depreciations. A recent study by De Schryder and Peersman (2015) offers an interesting perspective on the link between exchange rates and the oil demand of oil-importing countries. They identify a significant decline in the oil demand of 65 oil-importing countries as a result of an appreciation of the US dollar. Such demand effects are even stronger than exchange rate effects on the global price of crude oil. This pattern can potentially be explained by stronger pass-through of changes in the US dollar exchange rate to domestic end-user oil product prices.

There is also plenty of evidence based on structural VARs, which focuses on causality in the other direction, and distinguish between oil demand and supply shocks when analyzing exchange rate responses. Basher et al. (2012) focus on emerging markets and provide evidence for short-run effects of oil price shocks on exchange rates. The results of Basher et al. (2016), based on a similar methodology, show that oil demand shocks have stronger effects on oil-exporter exchange rates as compared to oil supply shocks.

A comprehensive study by Fratzscher et al. (2014) identifies bi-directional causality between the US dollar and oil prices since the early 2000s. They focus on daily data between January 2001 and 2012 and conclude that oil has become a global commodity whose price is driven not only by US-specific factors, but also financial ones (in particular asset prices). For the sample period they also find that a 10% increase in the price of oil leads to a depreciation of the US dollar effective exchange rate by 0.28%, while a 1% US dollar depreciation causes oil prices to rise by 0.73%.

Recent work by Kilian and Zhou (2019) has made a key contribution to the literature by extending the global oil market model of Kilian and Murphy (2014) to account for real exchange rate dynamics. Their identification approach also includes interest rates and is based on the assumption that there are no contemporaneous feedback effects from the real exchange rate to the oil market variables while the real exchange rate is allowed to respond contemporaneously to all structural shocks. An important conclusion from their work is that standard approaches for explaining the price of oil in principle remain valid. However, they also find that shocks to the real exchange rate can be an important source of real oil price fluctuations in some periods, reflecting the overall evidence of a time-varying relationship. They find for example that the real depreciation of the US dollar is the second important

[6] These effects can be formally derived in the context of international arbitrage costs (Taylor et al., 2001).
[7] A typical example is the breakpoint in 1986 shortly after the Plaza Agreement.

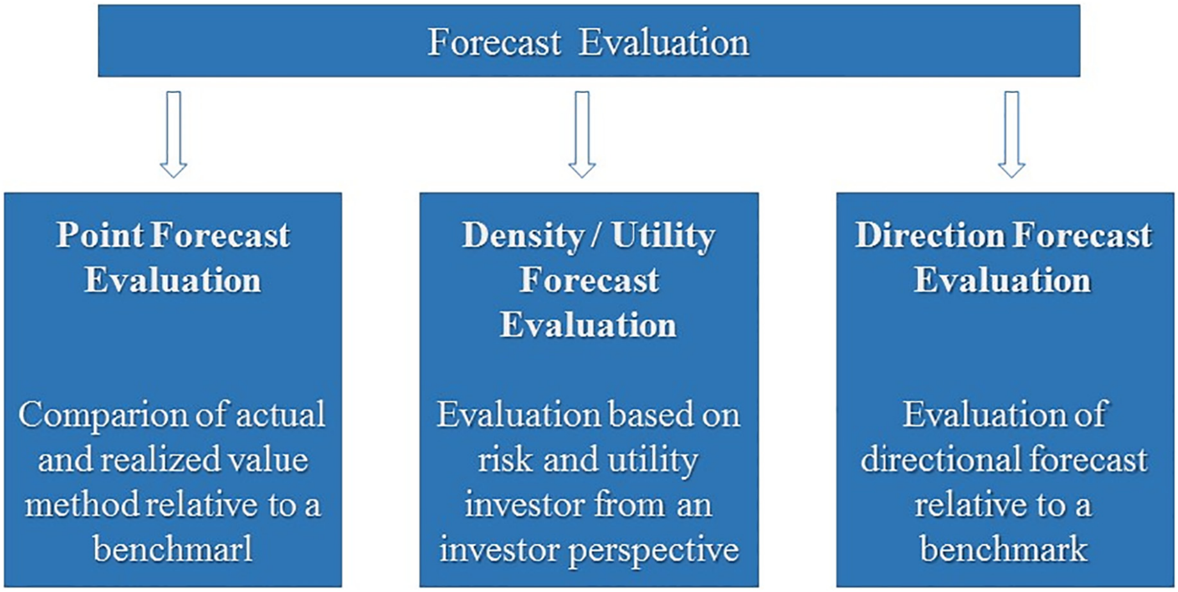

Fig. 8. Forecast evaluation approaches.
Source: own illustration.

factor for the increase in the real price of oil between 2003 and 2008 by transmitting the surge in flow demand caused by the economic boom in emerging economies.[8]

Studies dealing with volatility spillovers also find evidence for bi-directional causality over recent years. Ghosh (2011) focuses on the periods from 2007 until 2008 and finds that oil price increases depreciate the Indian rupee relative to the US dollar at a daily frequency. Tiwari and Albulescu (2016) confirm this finding for the period from 1980 to 2016 based on wavelet Granger causality tests. As discussed previously, possible explanations for the sample and currency-dependent findings include common factors and asymmetries.[9] Cifarelli and Paladino (2010) partly address the role of stock prices as a common factor. They focus on spillovers between oil prices, stock prices and US dollar exchange rates and find that oil price shifts are negatively related to exchange rate changes. Jiang and Gu (2016) analyze 13 currencies, 4 of them at a daily frequency, and find asymmetric correlations between oil prices and exchange rates—with more consistent correlations in case of small fluctuations.

Several studies also find short-run effects of oil price changes on exchange rates by comparing different frequencies. Benhmad (2012) conducts a wavelet analysis for real US dollar exchange rates and finds causality from oil prices to exchange rates over higher frequencies. The results over larger horizons point to bivariate causalities, but have potentially less explanatory power due to a smaller number of observations. Bouoiyour et al. (2015) also finds causality from oil price changes to the real exchange rate of Russia.

5.2. Time-varying relationships and evidence across different sample periods

There is also vast evidence that the main drivers of oil price changes are subject to structural breaks and can vary over time. Fan and Xu (2011) find that the price of oil has become more closely related to macroeconomic fundamentals and financial markets over time. Their findings are based on a wavelet approach that also suggests that the link between US dollar exchange rates and oil prices has intensified over time.

There is a strong consensus that the link between higher oil prices and US dollar depreciations has become stronger over recent years. An early study by Zhang et al. (2008), which analyzes the period between 2000 and 2005, finds a long-term equilibrium relationship between oil prices and euro/US dollar exchange rates, but reports little evidence for risk or volatility spillovers. This is in contrast to findings by Reboredo (2012) and Beckmann et al. (2016) which include the period after September 2008. Both studies rely on copula models and find that the intensity of the relationship between oil prices and US dollar exchange rates increased immediately after the onset of the financial crisis, and is stronger during extreme events. Reboredo (2012) additionally finds that the linkage turns out to be stronger for oil-exporters. The findings by Beckmann et al. (2016) also point to relevance of the wealth channel. They find that appreciations (depreciations) are positively correlated with an increase in oil prices for oil-exporters (oil-importers).

Reboredo and Rivera-Castro (2013) adopt a wavelet approach and also identify a much stronger relationship after the onset of the financial crisis. Turhan et al. (2014), based on dynamic conditional correlations, also find that the correlation has increased and become strongly negative over recent years. Jawadi et al. (2016) focus solely on the euro/US dollar exchange rate from 2014 and 2016, and find significant volatility spillovers from the exchange rate to oil prices using intraday data.

5.3. In-sample linkages: what have we learned?

The various short-run linkages identified in empirical studies confirm the importance of both the denomination and the portfolio channel. In the spirit of the denomination channel, long-run studies often focus on effective exchange rates, whereas short-run dynamics are mostly based on bilateral US dollar exchange rates. Several studies identify a bi-directional causality over both the short-run and the long-run.

[8] According to their results, real exchange rate shocks contribute to a cumulative increase of 50% in the real price of oil compared to demand shocks which account for a cumulative increase of 65%.

[9] The study by Bal and Rath (2015) identify statistically significant bi-directional nonlinear Granger causality between the real effective exchange rates of India and China and the real oil price. However, De Vita and Trachanas (2016) point to misspecifications in their study and come to different conclusions based on the same dataset.

The overall evidence suggests that exchange rate effects on oil prices materialize more frequently over the short-run.

At least the standard theoretical considerations do not offer any direct explanation for dynamics identified by wavelet and copula frameworks, such as changing dynamics between oil prices and exchange rates over time. Such changes are potentially driven by exogenous factors.

Many studies that have established a time-varying relationship between oil prices and exchange rates over time rely on copula or wavelet approaches. While both frameworks are quite useful and well suited to trace back such changes, they are rather descriptive and unable to establish causalities and/or consider common factors. The underlying question of why the link between the price of oil and exchange rates has become more time-varying has yet to be analyzed from either a theoretical or an empirical perspective. Obvious candidates include the changing stance of monetary policy and the financialization of commodity markets.

6. Out-of-sample evidence between exchange rates and oil prices

6.1. Classification of empirical methods

The evidence considered so far focuses on in-sample evidence and is not necessarily related to out-of-sample predictability. The literature on forecasting oil prices based on exchange rates (or vice versa) starts around 1973, after the breakdown of Bretton Woods system of fixed exchange rates against the dollar. The literature on forecasting considers statistical and economic criteria for evaluating forecasts. Fig. 8 summarizes the different possibilities for assessing forecasts.

Statistical criteria usually compare the point prediction of a specific model to a simple benchmark. In many cases the random walk without drift is considered to be the toughest benchmark. In such a framework, the predicted change is zero, i.e. today's value is considered to be the best predictor for tomorrow. There are two alternative forecast evaluation methods, which have attracted less attention in the literature on oil prices and exchange rates. One is to focus on directional adequacy instead of analyzing point forecast adequacy. Another perspective is based on the economic value of forecasts, and considers utility measures based on dynamic asset allocation strategies.

6.2. Main empirical results

6.2.1. Predictive power of oil prices for exchange rates

The seminal work of Meese and Rogoff (1983)—showing that exchange rate models based on economic fundamentals are unable to outperform a simple random walk forecast—still constitutes a benchmark result in the international finance literature. The resulting exchange rate disconnect puzzle remains one of the most important topics in international economics (Sarno, 2005). In general, the forecasting performance of fundamental exchange rate models is highly sensitive to the selection of different currencies, sample periods and forecast horizons (Rossi, 2013). Similar to the in-sample evidence, country- and time-specific forecasting results should therefore be interpreted with caution.

Some papers have found evidence for improved exchange rate forecasts when including the price of oil. Lizardo and Mollick (2010) imbed the real oil price into a simple form of the monetary model of exchange rate determination and show that it improves exchange rate predictions for several bilateral currencies. However, the overall evidence suggests that this is not a systematic finding, nor is it robust to different time periods.

While one strand of the literature has focused on oil-exporting currencies, other authors have turned their attention to commodity exporters such as Canada or Chile. Ferraro et al. (2015) argue that commodity prices predict commodity exporters' exchange rates at a daily frequency, and this is not evident at quarterly or monthly frequencies. Kohlscheen et al. (2016) find that commodity price models dominate random walk forecasts in the case of exchange rates. However, their findings are obtained based on future values of commodity prices utilized as predictors. They point out that the evidence of out-of-sample predictability using only lagged predictors is clearly weaker, as a result of the fact that commodity prices are hard to predict. A reasonable conclusion is that the strong findings are mostly driven by the correlation between exchange rates and commodity prices.

Kohlscheen et al. (2016) also provide useful insights on the relationship between country specific commodity price measures and oil prices. Indices for Colombia and Mexico, for instance, are highly correlated with the price of oil (0.971), while commodity baskets of other countries such as Chile display a much lower correlation with the oil price. This suggests that the literature on commodity prices

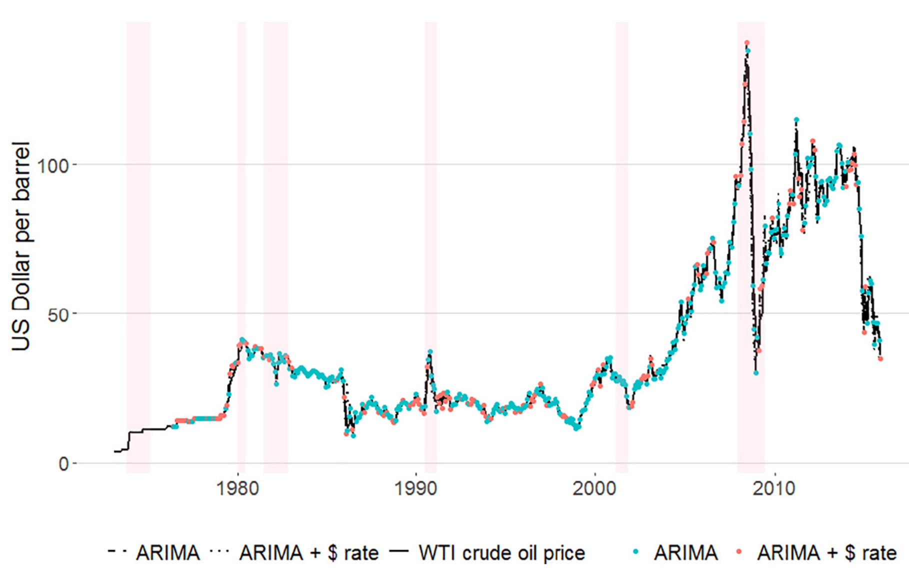

Fig. 9. One-month ahead ($h = 1$) oil price forecast based on the broad effective US dollar rate.
Source: own illustration, data taken from Federal Reserve Economic Data. The pink shaded areas represent US recession periods according to the National Bureau of Economic Research.

Table 1
Share of forecasting superiority of exchange rate models.

	$h = 1$	$h = 3$	$h = 6$	$h = 12$
Broad index	0.7004219	0.559322	0.5479744	0.5723542
Major index	0.6561181	0.5635593	0.5714286	0.5226782

Note: the table illustrates the share of forecasting superiority of exchange rate models against univariate models.

should be considered for a better understanding of exchange rate-oil price dynamics.

6.2.2. Predictive power of exchange rates for oil prices

Before we turn to the existing literature, we analyze the potential of exchange rates for forecasting the price of oil out-of-sample by comparing two rolling window forecast models. The first is a rolling window ARIMA model fitted based on the AIC as a simple benchmark and relies solely on information from the recent past (i.e. 40 observations) of the WTI crude oil price, while the second model also includes recent data on a US dollar exchange rate measure (i.e. the US effective dollar exchange rate broad index) as an additional predictor.[10] We use both models to forecast the price of oil for four different horizons: one-month-ahead ($h = 1$), three-months-ahead ($h = 3$), six-months-ahead ($h = 6$) and twelve-months-ahead ($h = 12$). Fig. 9 shows the corresponding results for $h = 1$ and reports the observed WTI crude oil price as well as the rolling window forecasts. The red dots reflect periods where the benchmark model is superior while the turquois dots represent a better performance of the exchange rate model. The exchange rate model outperforms the benchmark model over 50% of the time.

Table 1 summarizes results over the full sample for different forecasting horizons for the WTI oil price.[11]

The results look encouraging at first sight, and confirm the general result that exchange rates are more useful for forecasting oil prices over the short-run. The percentage of periods where effective exchange rate dynamics add information, as opposed to relying solely on past oil prices, does not exceed 60% over 3, 6 and 12 months—while results are more favorable over the short-run. These patterns are confirmed for common exchange rate expectation dynamics and the Australian dollar, where the percentage is close to 75% for a shorter sample period starting in 1995. This indicates that exchange rates exhibit at least some relevant information to predict oil prices. However, it is important to highlight that even these findings do not necessarily imply that exchange rate dynamics are useful for oil price predictions for a number of reasons. In terms of absolute differences, the exchange rate model does not outperform the simpler model by a large amount, while the simpler model in many cases outperforms the exchange rate model substantially. An example is the case where the simple model correctly proposes a constant oil price while the exchange rate model predicts changes which do not materialize.

Taking these findings into account, it is not surprising that there is little systematic evidence that exchange rates are directly useful for oil price predictions. Baumeister et al. (2015) show within a mixed frequency approach that high-frequency financial data are hardly helpful in forecasting the monthly real price of oil. The comprehensive survey by Alquist et al. (2013) concludes that neither short-term interest rates nor trade-weighted exchange rates have significant predictive power for the nominal price of oil in terms of point forecasts. However, they also argue that specific bilateral exchange rates might still be useful. They find that the Australian exchange rate has significant predictive power for the sign of the change in nominal oil prices over specific horizons.

Alquist et al. (2013) draw an important link to the study of Chen et al. (2010), which shows that exchange rates of commodity exporters ("commodity currencies") are helpful in forecasting country specific or aggregate commodity prices.[12] Their findings hold for Australia, Canada, Chile, New Zealand and South Africa where oil is not the primary exported commodity. Alquist et al. (2013) point to the strong link between other commodities and the price of oil, and argue that the predictive power of a commodity exporter's US dollar exchange rate might turn out be useful for oil price predictions via commodity prices. A related study by Groen and Pesenti (2011) analyzes a broad range of commodity prices and finds that exchange rates might be useful, but are not systematically more accurate predictors than simple benchmarks. Drachal (2016) addresses time variation in predictability by adopting a Dynamic Model Averaging framework for predicting the spot price of oil. He finds exchange rates to be important predictors between 1995 and 2000 and after 2005, while their relative importance diminishes between 2000 and 2005.

From an econometric perspective, the considerations so far have illustrated the issue of parameter and model uncertainty. On the one hand, all possible combinations of K potential explanatory variables for forecasting oil price or exchange rates result in 2^K different model specifications. A more common approach is to use Bayesian model averaging (BMA), which updates model weights and coefficient changes within a recursive learning scheme. These techniques are becoming more popular, and are increasingly used in the context of oil price and exchange rate predictions. Wright (2008), Della Corte et al. (2009) and Beckmann and Schüssler (2016) all adopt model averaging techniques in the context of exchange rate forecasting. When focusing on adequate oil price forecasts, Baumeister et al. (2014) and Baumeister and Kilian (2015) provide real-time out-of-sample evidence that the combination of forecasting models with equal weights dominates the approach of selecting one model and using it for all forecast horizons.

7. Exchange rate regimes and oil prices

Commodity exporters are usually strongly affected by fluctuations in global markets.[13] The choice of an exchange rate regime is of particular importance for emerging economies where oil companies are often state owned and contribute to a substantial portion of the government budget (Caruana, 2016). Unsurprisingly, many oil-exporting countries have opted for fixed exchange rates to protect domestic revenues against exchange rate fluctuations. The significant increase in dollar borrowing by oil firms in emerging countries constitutes an additional currency risk, which leads to a potential gain of a fixed exchange rate regime.

However, the recent episode of falling oil prices has revitalized this discussion because fixed exchange rates also do not allow for domestic depreciations if oil prices fall, a mechanism, which can absorb negative demand shocks. Fixed exchange rate regimes have also turned out to be costly for oil exports due to the need of interventions and the resulting loss of monetary policy independence. Governments that have not hedged oil revenues against the risk of lower oil prices underwent fiscal

[10] More precisely, in both cases we have estimated a rolling window ARIMA model with a window size of 40 months. In each single step (i.e. for each 40 months) we have selected the order p of the AR term, the order q of the MA term and the integration order d by minimizing the AIC. Therefore, the different lag orders differ over time. After each estimation step, we have used the corresponding model to forecast the oil price $t + h$-month-ahead. The only difference between both forecasting models is that the second model also includes one of the two US effective dollar exchange rate indexes as exogenous variable. We have also varied the window size and used other information criteria but our results turned out to be robust to these variations.

[11] We have also performed the same exercise using either the Australian dollar exchange rate (as a commodity currency) or a common factor across exchange rate expectations over the next month.

[12] Chen et al. (2014) find these results to be robust after the onset of the financial crisis.

[13] A related issue not discussed in this paper is the Dutch Disease scenario. This corresponds to a situation where increasing prices of key exported goods lead to an appreciation of the domestic currency which harms international competitiveness (Bodart et al., 2012).

retrenchment without monetary policy instruments as a shock absorber. Against this background, low oil prices and the need to prevail an exchange rate regime often resemble a negative demand shock (Husain et al., 2015). The case of Nigeria, where an unsuccessful attempt to defend a pegged exchange rate resulted in substantial exchange rate fluctuations and uncertainty, is used as a prime example in this regard. The (ex-post) optimal choice for oil-exporters is therefore a fixed exchange rate regime in case of increasing oil prices and a flexible regime in case of falling oil prices. Effects are also observed for oil-importing countries. Dollar appreciation coincides with negative effect on sovereign credit default swap (CDS) spreads of oil-importing countries (Caruana, 2016).

8. Areas for further research

From an econometric perspective, addressing time-varying predictability and sample choices is quite important since both exchange rates and oil prices are hard to predict. Relying on a data rich environment in a flexible econometric framework potentially addresses these issues but the rich toolset makes it difficult to identify one single adequate framework. The idea of averaging across models and discounting past information in a Bayesian framework outlined in the previous section is very appealing and should be considered against various benchmarks. Factor models offer an alternative possibility for dealing with rich datasets. A first important avenue for future research is a systematic extension of the study by Alquist et al. (2013) beyond 2009.

Another data issue is that many studies rely on aggregated market prices why little is known about the underlying drivers. In this spirit, disentangling oil supply and demand factors is also quite important since most studies analyze the relationship between the oil price and exchange rate without separating oil demand and supply factors. Such a distinction is of great importance for a theoretical underpinning of the transmission channels from exchange rates to oil prices. The work of Kilian and Zhou (2019) provides an excellent starting point for disentangling dynamics between exchange rates and oil prices within structural VAR models. The understanding of the exchange-rate pass-through of oil-exporters potentially explains the time-varying ties between exchange rates and oil prices via supply effects. Related to the issue of supply and demand, it also seems quite important to address the role of common factors, such as monetary policy drivers.[14] From a technical point of view, structural VAR models in the spirit of Baumeister and Hamilton (2015) allow for the identification of supply and demand shocks while allowing for common factors.

Assessing financial flows or expectation linkages between both markets offers another potential starting point for a disaggregated perspective on the oil price-exchange rate link. Preliminary evidence suggests that market expectations based on survey data take the oil price- exchange rate link into consideration. Relying on forward rates and trading volumes which has recently become available for several currencies constitutes alternative possibilities.

Finally, a critical evaluation of the economic value of predictions, for example in the spirit of Della Corte et al. (2009) for exchange rates or upside-downside risk for oil prices as outlined by Alquist et al. (2013), offers an interesting research avenue.

9. Conclusion and policy implications

This paper has addressed and summarized existing research on the link between oil prices and exchange rates. We have started by identifying different transmission channels, which provide simple theoretical underpinnings for the relationship between exchange rates and the price of oil.

The empirical evidence is strongly time-varying and suggests that past relationships do not necessarily hold in the future, and the link between in-sample and out-of-sample is often rather weak. A model which successfully explains past oil price changes based on exchange rates is not necessarily useful for forecasting the price of oil in the next period. This complicates the task of selecting an adequate forecasting model and constitutes an important research question.

There is strong evidence that oil prices and exchange rates are related over the long-run. There is also a fair amount of research showing various short-run linkages and spillovers between both markets at daily and monthly frequencies. The inverse causality from US dollar depreciations to increases in the price of oil often materializes at a daily frequency or over a few months.

A fair conclusion is that exchange rate movements are not a silver bullet for understanding or forecasting the price of oil—and vice versa —and neither is a substitute for supply or demand factors. The selective evidence partly provided in the literature is therefore potentially misleading. However, each contains potentially useful information for forecasting the other and should be taken into account, particularly over the short-run and in a broader modeling context. The oil price-exchange rate relationship is evolving over time and has recently become more volatile. The change in monetary policy and the financialization of commodity markets offer potential explanations for the intensified relationship. It remains to be seen whether the intensity of the link is affected by the exit of unconventional monetary policy. From a policy perspective, an important question besides assessing flexible exchange rates is whether oil-exporting or oil-importing countries should be in favor of fixed or flexible exchange rate arrangements.

CRediT authorship contribution statement

Joscha Beckmann: Conceptualization, Methodology, Software, Visualization, Investigation, Writing - original draft. **Robert L. Czudaj:** Conceptualization, Methodology, Software, Visualization, Investigation, Writing - original draft. **Vipin Arora:** Conceptualization, Writing - review & editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2020.104772.

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[14] Policy announcements have for example already been identified as a potential driver of exchange rate volatility (Conrad and Lamla, 2010) and exchange rate expectations (Beckmann and Czudaj, 2017), while there has been much less written about their effect on oil prices.

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