European Commission

ISSN 2443-8030 (online)

Euro-US Dollar Exchange Rate Dynamics at the Effective Lower Bound

Eric McCoy

ECONOMIC BRIEF 055 | JULY 2020

EUROPEAN ECONOMY

Economic and Financial Affairs

European Economy Economic Briefs are written by the staff of the European Commission's Directorate-General for Economic and Financial Affairs to inform discussion on economic policy and to stimulate debate.

Authorised for publication by Declan Costello, Deputy Director-General for Economic and Financial Affairs.

This paper exists in English only and can be downloaded from https://ec.europa.eu/info/publications/economic-and-financial-affairs-publications_en.

Luxembourg: Publications Office of the European Union, 2020

PDF ISBN 978-92-79-77384-6 ISSN 2443-8022 doi:10.2765/372 KC-BE-18-023-EN-N

European Commission
Directorate-General for Economic and Financial Affairs

Euro-US Dollar Exchange Rate Dynamics at the Effective Lower Bound

By Eric McCoy

Abstract

In the aftermath of the Global Financial Crisis (GFC), central bank policy rates edged closer to their effective lower bound – the point beyond which central banks cannot or do not want to lower rates further due to economic reasons or institutional constraints. Central banks therefore had to move beyond conventional policy instruments and instead resort to using unconventional tools such as large-scale asset purchase programs. With policy rates stuck at their effective lower bound for an extended period of time, central bankers and academics started to investigate the channels linking central bank unconventional monetary policy decisions to exchange rate movements. As will be discussed in this paper, extracting the expected policy rate and the term premium components of interest rates using a term structure model contributes to a better understanding of the channels through which the introduction of unconventional monetary policy measures have affected the dynamics of the euro – US dollar (EUR/USD) exchange rate. Empirical evidence is presented showing that the term premium component started to play a predominant role in anchoring EUR/USD developments to unconventional monetary policy, which first began in the US with the US Federal Reserve's (Fed) QE1 in 2008 and which was later followed in the euro area by the onset of the ECB's large-scale asset purchase program (APP) in 2015. The ECB's APP, by compressing the term premium component, has likely triggered portfolio rebalancing and the ensuing cross-border capital flows have exerted a downwards pressure on the EUR/USD. Last but not least, the paper also presents empirical evidence demonstrating that incorporating non-monetary policy variables (relative stock market performance, a measure of domestic sovereign credit risk, as well as relative long-term inflation expectations and oil prices) into the analytical framework enhances significantly the understanding and analysis of EUR/USD developments.

Acknowledgements: I would like to thank Bogdan Bogdanov, Maja Ferjancic, Wolfgang Lemke (*), Eric Ruscher, Matteo Salto, Lucio Pench, and Vaclav Zdarek for their helpful comments and feedback on the paper.
(*) Adviser, European Central Bank, Capital Markets/Financial Structure Division

Contact: Eric McCoy, European Commission, Directorate-General for Economic and Financial Affairs, eric.mccoy@ec.europa.eu.

INTRODUCTION

Prior to the Global Financial Crisis (GFC), central banks typically steered broader financial conditions and, ultimately, inflation developments by setting short-term key policy interest rates. In such a traditional monetary policy context (i.e. conducted far away from the effective lower bound), the signalling effects implicit in a central bank's policy rate decisions help to shape expectations about the future course of short-term rates. Under the "asset market approach" to exchange rate determination, movements in exchange rates reflect essentially current and expected future short-term interest rate developments in the domestic and foreign countries and consequently exchange rates are impacted by central bank policy rate decisions.

As policy rates of major central banks approached their effective lower bound (ELB) in the aftermath of the GFC, their ability to provide the necessary degree of monetary stimulus using conventional policy measures (i.e. by setting short-term key policy rates) became increasingly limited. In this particular context, central banks had to move beyond conventional policy instruments and instead deploy a set of unconventional tools (such as large-scale asset purchase programs amongst others) which resulted in significant expansions of their balance sheets. In ensuing discussions relating to the effects, transmission channels and spill-overs of these unconventional monetary policy measures, the issue of exchange rate dynamics at the effective lower bound has attracted the attention of both central bankers and academics.

Based on the so-called asset market approach to exchange rate determination, movements in the exchange rate between two countries are essentially determined by changes in the expected path of the interest rate differential between the respective countries - see for instance Engel (2014) for an exhaustive survey. Due to the influence of central banks on short-term interest rates, under these assumptions then, monetary policy divergence should in theory be one of the most important drivers of exchange rate dynamics. In fact, research has shown that in the past there has always been a rather strong positive correlation between short-term EA-US interest rate differentials, in particular bond yields with a maturity of two years, and short-term movements in the EUR/USD.

This paper will focus on the euro – US dollar (EUR/USD) exchange rate, as the ECB and the US Federal Reserve (Fed) have been carrying out the largest quantitative easing programmes after the GFC[1], and as this is the world's most liquid currency pair. The paper is divided into two sections. Section I analyses the traditional link between exchange rates and interest rate differentials. As will be discussed in this section, breaking down interest rates into their two main components – the expected path of the future policy rate and the term premium – helps to fine-tune the understanding of the channels through which unconventional monetary policy measures have affected short-term EUR/USD exchange rate dynamics. The empirical evidence presented in this section supports the view that the term premium component of interest rates started to play a predominant role in anchoring EUR/USD developments to unconventional monetary policy, which began in the US with the Fed's QE1 in 2008 and which was later on followed in the euro area by the onset in 2015 of the ECB's large-scale APP. Section II of the paper further enhances the analytical framework developed in section I, providing further empirical evidence showing that incorporating non-monetary policy variables (relative stock market performance, a measure of domestic sovereign credit risk, as well as relative long-term inflation expectations and oil prices) into the analytical framework enhances significantly the understanding and analysis of EUR/USD dynamics.

SECTION I

I.1 Theoretical foundations - the asset market approach to exchange rates

The starting point is the "asset market approach" to exchange rates, which considers exchange rates just as any other financial asset, and as such exchange rates should therefore fully reflect today's market expectations about the future, just as today's stock prices reflect the expected discounted stream of future dividend earnings and other relevant market information. Obstfeld and Rogoff (1996, p. 529) state that "one very important and quite robust insight is that the nominal exchange rate must be viewed as an asset price. Like other assets, the exchange rate depends on expectations of future variables".

It is worthwhile at this point to provide a brief reminder of the theoretical framework introduced by Engel (2014) and in particular to highlight the equation below[2] which defines the relationship between exchange rates and interest rates:

$$(1) \quad s_t = -\sum_{j=0}^{\infty} E_t\left(i_{t+j} - i_{t+j}^*\right) + \lim_{j\to\infty} E_t s_{t+j+1}$$

where s_t is the nominal spot exchange rate (the price of the foreign currency in units of the domestic currency), i_{t+j} is the nominal interest rate on a riskless deposit held in the domestic currency over period j, i_{t+j}^* is the interest rate for a foreign-currency deposit over the same period j, and $\lim_{j\to\infty} E_t s_{t+j+1}$ denotes the expected long-run equilibrium nominal exchange rate.

Under this framework, holding the expected long-run equilibrium nominal exchange rate constant, short-run movements in the spot exchange rate should in theory depend only on the dynamics of current and expected future interest rates in the domestic and foreign countries. For example, if domestic interest rates are expected to fall in the future (due to the implementation of the domestic central bank's quantitative easing measures for instance), the domestic currency is, ceteris paribus, expected to depreciate. What can be inferred from this succinct recap of the underlying theoretical framework is that monetary policy divergence should in theory be one of the most important drivers of exchange rate dynamics.

I.2 The traditional link between exchange rates and interest rates – empirical evidence

Research has shown that in the past there has always been a rather strong positive correlation between short-term EA-US interest rate differentials, in particular bond yields with a maturity of two years, and short-term movements in the EUR/USD. For instance, Cahill (2017) provides empirical evidence that the two-year interest rate differential (in comparison to other maturities) turns out to be the strongest driver of the US dollar. Table 1 (the "baseline regression") in Annex 1 presents empirical results that further corroborate this claim. The left-hand column of Table 1 shows the results of regressing the monthly change in the EUR/USD against the two-year government bond yield differential (calculated as the difference between the euro area[3] minus the US). The regression coefficient on the two-year interest rate differential variable is statistically relevant (p-value less than the 5% threshold) across the entire sample period which runs from August-2004 to December-2019[4].

In order to gauge the behaviour of the regression coefficient (linking the change in EUR/USD to the change in the two-year differential) across time, dummy variables were utilised de facto dividing the sample period (covering August-2004 to December-2019) into three sub-periods: August-2004 to October-2008, November-2008 to February-2015, and March-2015 to December-2019. The first sub-period, covering August-2004 to October-2008, corresponds to the pre-GFC period where traditional monetary policy (i.e. far away from the effective lower bound) was being conducted by central banks. The second sub-period, covering November-2008 to Februay-2015, is primarily characterised by the onset of unconventional monetary policy in the US, which first began with the US Fed's announcement of QE-1 on November 25-2008[5]. It is during the third sub-period, covering March-2015 to December-2019, that the ECB implemented its large-scale asset purchase program (APP)[6]. It is also worth highlighting the increasingly divergent monetary policies of the US Fed and the ECB during this third sub-period, as the Fed pursued the normalisation of its monetary policy. This being said, it is interesting to note that the regression coefficient on the 2-year interest rate differential variable has remained statistically relevant across all three sub-periods, implying that short-term rate differentials remained pertinent during periods of conventional as well as unconventional monetary policy. The picture is quite different, however, when one looks at the link between exchange rates and longer-term interest rate dynamics.

The right-hand column of Table 1 shows the results of regressing the monthly change in the EUR/USD against the 10-year government bond yield differential (calculated as the difference between the euro area minus the US). The regression coefficient on the 10-year interest rate differential variable becomes statistically significant (i.e. less than the standard 5% threshold of statistical significance) as from the second sub-period only. This would seem to suggest that since the onset of the unconventional monetary policy (which first began in November-2008 with US Fed's QE1) the traditional channel through which monetary policy used to affect exchange rates (i.e. based on short-term interest rate differentials) might have evolved. This observation could indicate that short-term EUR/USD dynamics might reflect additional information, not sufficiently embedded in the 2-year rate differential, possibly coming from the longer-end of the yield curve (i.e. the 10-year rate differential)[7]. This is where it becomes useful to break down interest rates into their two main components.

I.3 Decomposing interest rates into their expected policy rate and term premia components

Breaking down interest rates into their two main components - the expected path of the short-term policy rate and the term premium – sheds more light on the question of why the 10-year rate differential has also become a statistically relevant driver of short-term EUR/USD movements (in addition to the 2-year rate differential) since the onset of unconventional monetary policy (from November 2008 onwards). Table 2 (the "extended regression") of Annex 1 presents the results of regressing the monthly change in the EUR/USD on the policy rate and term premium components[8], in addition to a number of non-monetary policy variables: relative stock market performance, a measure of domestic sovereign credit risk, as well as relative long-term inflation expectations and oil prices. This section will focus on the monetary policy variables (i.e. the first two explanatory variables).

Before turning to a discussion of the regression results, a few words on what is meant by the term premium component of interest rates is useful. The term premium reflects the excess return that an investor demands as compensation for holding a bond with a long maturity (for example a bond maturing in 10 years) relative to rolling over a short-term bond until this long-dated maturity[9]. Locking into a long-dated fixed income investment for a specific holding period is not equivalent to rolling over a short-term investment for the same holding period, because holding the long-dated bond exposes the investor to the risk that interest rates may increase unexpectedly during the holding period. An unexpected increase in interest rates causes a market loss on investment positions in these long-dated fixed-rate securities; consequently, the term premium component compensates risk averse investors for taking on such interest rate or duration risk[10].

Turning now to the extended regression, the left hand column of Table 2 shows the regression involving the breakdown of the 2-year rates into their two components while the right hand column displays regression results using instead the breakdown of the 10-year rates. The first two variables correspond to the monetary policy variables. The first is the differential, between the euro area and the US, of the policy rate expectations component while the second monetary policy variable relates to the differential in the term premium component. Moreover, using dummy variables in order to split these two monetary policy variables across the three sub-periods allows one to gauge the statistical pertinence of the variables during periods of conventional and unconventional monetary policy. A few key takeaways are worth highlighting in relation to these regression results.

First, breaking down the 2-year rate differential into its two components reveals that the relevance of the "traditional" short-term interest rate differential (i.e. from the baseline regression) in explaining monthly EUR/USD variations stems essentially from its policy rate component. Indeed, the term premium component turns out to be statistically insignificant except for the third sub-period (March-2015 to December-2019) during which the ECB implemented its large-scale APP. This is not surprising, as one would expect the term premium component to be rather contained at shorter horizons (see Box 1 for a more enhanced discussion of the term structure of the term premia).

Second, breaking down the 10-year rate differential into its two components helps to shed more light on the reason why the 10-year rate differential (i.e. from the baseline regression) started to become a statistically relevant driver of the EUR/USD since the onset of unconventional monetary policy (which started with the US QE 1 program in November 2008). The 10-year term premium differential variable becomes statistically relevant across the second and third sub-periods (from November 2008 to December 2019) and the coefficient increases sizeably (from 0.07 to 0.12) from the second to the third sub-period. This noticeable increase in the coefficient's value in the third-sub period coincides with increasingly divergent monetary policies between the US Fed (which pursued a course of monetary policy normalisation) and the ECB (which implemented its large-scale APP). The empirical evidence thus seems to support the view that it is in fact the term premium component of interest rates which began to play a predominant role in anchoring EUR/USD developments to increasingly divergent (unconventional) monetary policies in the euro area and the US.

Third, it is useful to mention that the coefficient on the 10-year expected policy rate differential variable is higher compared to its 2-year counterpart across the two sub-periods when unconventional monetary policy was at play (i.e. as from November 2008 onwards). With policy rates stuck at their effective lower bound in the post-GFC era, the weight that market participants attached to the expected path of the policy rate in the more distant future (i.e. up to the 10-year horizon) may have increased. This would seem to suggest that EUR/USD dynamics were incorporating additional information not sufficiently embedded in the 2-year rate differential but rather reflected in yields at the longer-end of the curve.

These empirical results appear to suggest that the term premium component started to play a predominant role in anchoring EUR/USD developments to monetary policy during periods when it was conducted at or close to its effective lower bound but not before (i.e. in the pre-GFC era when traditional monetary policy was being conducted away from the effective lower bound). The behaviour of coefficient on the term premium component, as estimated across the three different sub-periods, provides empirical evidence to support this claim. In light of these observations, what remains to be understood then is the channel through which the term premium component is affecting exchange rates.

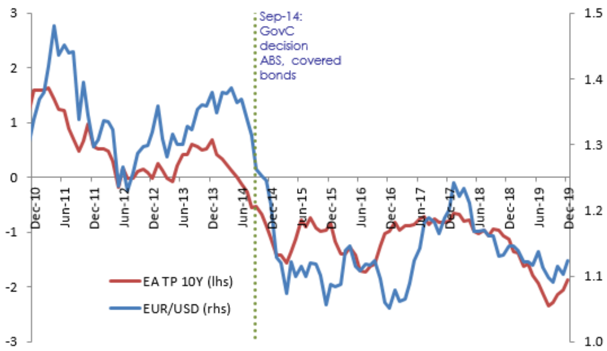
I.4 The portfolio rebalancing channel

Central bank quantitative easing (QE) programs, by compressing the term premium component of domestic bond yields, encouraged investors to rebalance their portfolios towards foreign, higher yielding assets. The induced capital outflows from euro-denominated securities and bonds have reached historical dimensions in the case of the ECB's APP[11] and have likely exerted a downwards pressure on the EUR/USD.

The positive coefficient on the 10-year term premium differential variable (see Table 2 in Annex 1) can be interpreted as follows: expectations of a reduction in the euro area 10-year term premium (induced by the ECB's APP) should, ceteris paribus, lead to a depreciation of the euro versus the US dollar via the portfolio rebalancing channel and the associated cross-border capital outflows which exert a selling pressure on the euro.

For example, the rather large depreciation of the EUR/USD in the second half of 2014 serves as a case in point. The EUR/USD started to decrease substantially once market expectations regarding ECB asset purchases gained a strong tailwind in the course of the second half of 2014. As is visible in Graph 1 below, the EUR/USD lost nearly 10% of its value in a couple of months (from August to December 2014), coinciding, amongst others[12], with the ECB's announcement in September 2014 of its purchase program targeting ABS and covered bonds. Empirical analysis carried out by the ECB, using the Diebold-Yilmaz methodology, on the direction of international spill-overs in bond markets corroborates this view and finds that spill overs from euro area to US bond markets spiked sharply in mid-2014[13].

Graph 1: **EUR/USD and the portfolio rebalancing channel**



Source: Bloomberg, ECFIN estimates.

Graph 1 also shows the existence of a positive correlation, albeit not perfect, between the EUR/USD and the 10-year euro area term premium since 2012 when policy rates were approaching their effective lower bound and when the ECB was switching to unconventional policy tools. In fact, the ECB’s APP has had the effect reducing aggregate duration risk and this lower aggregate duration risk has increased the risk-bearing capacity of price-sensitive bond market participants, which in turn has contributed to decreasing their required risk compensation per unit of risk exposure (the so-called "market price of risk"), and hence also the term premium component[14].

The ECB’s APP, by compressing the term premium component of interest rates, has prompted private investors to rebalance portfolios into higher yielding alternative investments (including abroad such as in the US) exerting a downwards pressure on the EUR/USD. The pattern observed in Graph 1 further supports the claim that portfolio rebalancing induced by the ECB's compression of the euro area term premium (due to the APP) was one of the dominant channels driving EUR/USD dynamics.

The coefficient on the 10-year term premium differential variable in the Nov-08 to Feb-15 period is smaller than the corresponding one in the Mar-15 to Dec-19 period (i.e. 0.07 vs 0.12 respectively). Although the portfolio rebalancing argument seems to hold across both sub-periods, the smaller coefficient in the Nov-08 to Feb-15 sub-period could possibly suggest that spill over effects (capital outflows from the US) were somewhat weaker due to the safe-haven status of the US.

Moreover, the fact that the term premium differential variable is statistically insignificant in the Aug-04 to Oct-08 period (i.e. pre-GFC), when monetary policy was conducted far away from its effective lower bound, could indicate that the expected policy rates channel was the dominant driver of exchange rates as opposed to the term premium-linked portfolio rebalancing channel[15]. This could simply reflect the fact that in the pre-GFC period, the term premium component was, in the absence of central bank intervention affecting it directly, performing its normal role of rewarding risk efficiently in both the euro area and the US[16].

SECTION II

Incorporating non-monetary policy variables into the analytical framework

According to the academic literature, developments in interest rate differentials explain only a relatively small fraction of EUR/USD developments. This is also confirmed by the empirical results presented in Table 1: the baseline regression with 2-year rates has an R^2 of only 21.1%. Therefore, in order to be able to explain a larger share of EUR/USD variations, other types of variables (i.e. non-monetary policy) need to be considered. The discussion which follows will focus on the "extended regression" presented in the right-hand column of Table 2 of Annex 1.

The extended regression framework incorporates non-monetary policy variables (i.e. the last four variables), some of which have already been identified in the literature as being relevant drivers of the EUR/USD: relative stock market performance, a measure of domestic sovereign credit risk, oil prices, as well as relative long-term inflation expectations[17]. All of these non-monetary policy variables turn out to be statistically relevant (all bearing p-values under the 5% significance threshold).

The first explanatory variable, relative stock market performance, is constructed using the Europe STOXX 600 and US S&P 500 equity indices as they provide a broad market coverage representing large, mid and small capitalisation companies across all sectors of the economy. The coefficient on this variable is negative (-0.52), implying that a relative over performance of European equities versus the US leads to a depreciation of the EUR/USD. It is worthwhile further discussing in more detail the possible justifications underlying this negative relationship between relative equity returns and the exchange rate.

Recent academic theory (see Hau and Rey 2006 for instance) advocates that the observed negative correlation between foreign exchange and equity market returns is related to the effects of cross-border portfolio rebalancing induced by the relative performance of equity markets in the two countries concerned. To understand better this argument, it is useful at this stage to introduce the uncovered equity parity (UEP) condition, whose empirical validity has already been assessed in various studies (see for instance Hau and Rey 2006, Melvis and Prins 2015).

The main idea underlying UEP is portfolio rebalancing: when foreign equity holdings outperform domestic holdings, domestic investors face higher exchange rate exposure and hence in order to reduce this additional exchange rate risk (i.e. hedging their incremental foreign exchange exposure in order to match the benchmark for their fund) they rebalance back into domestic holdings. By doing so, they sell the foreign currency which leads to a foreign currency depreciation. Hau and Rey (2006) provide supporting evidence on the observed negative correlation between relative equity market performance and exchange rates over short-term horizons for 17 OECD countries vis-à-vis the US dollar.

More recently, Curcuru, Thomas, Warnock and Wongswan (2014) provide further evidence that investors reallocate away from equity markets that recently outperformed, thus corroborating the rebalancing argument inherent in UEP. Moreover, they provide an alternative and substantiated argument behind portfolio rebalancing: domestic investors may be exploiting mean reversion in underlying equity markets, rebalancing away from equity markets that recently performed well (i.e. as these should tend to revert back down to their longer-term mean). In this case, the cross-border reallocations relate to investors whose primary motivation is to maximise overall portfolio returns; however, this does not preclude that at the same time investor behaviour is also driven by the need to reduce foreign exchange risk exposure (see Hau and Rey 2006 and others). It is interesting to note that this mean-reversion hypothesis seems to be consistent with the introductory proposition (drawn from Obstfeld and Rogoff) that the exchange rate "must be viewed as an asset price. Like other assets, the exchange rate depends on expectations of future variables".

The second explanatory variable is a measure of domestic sovereign credit risk, which corresponds to a GDP weighted-average of the 10-year sovereign bond yield spreads between some euro area Member States[18] and Germany. As illustrated in Table 2, the estimated regression coefficient on this variable carries a negative sign (-0.054), suggesting that an increase in the average euro area credit risk yield spread tends to depreciate the euro against the US dollar, which is consistent with the acknowledged safe haven role of the US dollar.

The extended regression model also incorporates the differential in long-term inflation expectations, which is calculated as the difference between the 30-year euro area inflation swap rate and the 30-year US inflation swap rate. The variable's coefficient carries a negative sign (-0.04), implying that a relative increase in long-term inflation expectations in the euro area relative to the US will likely lead to a depreciation of the euro against the US dollar. One possible interpretation of the meaningfulness of this variable is in relation to the purchasing power theory (PPP), which states that the long-run equilibrium exchange rate should adjust in order to equalise the long-run purchasing power in both countries.

Finally, the last variable, the US dollar price of Brent crude oil, turns out to be statistically significant and was thus included in the extended regression as it contributes to increasing its explanatory power (i.e. the regression's R^2). The relationship between oil prices and exchange rates has attracted considerable attention in the academic literature and it appears that there are several possible channels through which changes in oil prices may affect the exchange rate of oil-importing countries.

For instance, an oil price increase should weigh negatively on the currency of an oil-importing country due to a worsening macroeconomic outlook. However, an oil price increase could also put upward pressures on the currency of an oil-importing country if this currency plays a significant role as an international reserve asset and to the extent that oil-producers recycle their oil revenues in this reserve asset (see Golub 1983 and Krugman 1983).

The extended regression framework presented in Table 2 seems to corroborate this second channel, as the regression coefficient carries a positive sign. Nevertheless, one needs to remain cautious, as both the direction and the sign of the causality between oil price and exchange rate movements remain unclear in the literature (see Coudert and Mignon 2016 for a detailed survey). In particular, it is also possible that the causality also runs from the dollar exchange rate to oil prices[19], which would lead to an upward bias in the estimated coefficient.

Overall, incorporating these additional non-monetary policy variables results in a significant increase in the explanatory power of the regression framework leading to a regression R^2 of 61.5%[20]. In general, modelling currency dynamics is known to be notoriously difficult (see Meese and Rogoff 1983; Cheung, Chinn and Pascual 2005). Despite this, the empirical results obtained in this paper, which account for close to two-thirds of short-term movements in the EUR/USD, are rather encouraging. This being said, more than one-third of exchange rate fluctuations still remains unexplained, which merits further investigation.

CONCLUSION

In the past, there has always been a rather strong positive correlation between short-term euro area - US interest rate differentials (i.e. in particular yields with a maturity of two years) and short-term movements in the EUR/USD and the empirical results presented in this paper corroborate this claim. Moreover, the analysis presented in this paper also shows that since the onset of the unconventional monetary policy (which first began in November-2008 with the US Fed's QE 1 program) the traditional channel through which monetary policy used to affect exchange rates (i.e. based on short-term interest rate differentials) may have evolved. In fact, the empirical results presented support the claim that short-term

EUR/USD dynamics likely reflect additional information – namely the term premium component - not sufficiently embedded in the 2-year interest rates, and coming mainly from the longer-end of the yield curve (i.e. the 10-year interest rates).

Extracting the expected policy rate and the term premium components of interest rates using a term structure model contributes to a better understanding of the channels through which the introduction of unconventional monetary policy measures have affected the dynamics of the EUR/USD. In particular, the ECB's APP, by compressing the term premium component, has triggered portfolio rebalancing and the ensuing cross-border capital flows have likely exerted a downwards pressure on the EUR/USD exchange rate.

Last but not least, the extended regression presented in the paper also integrates non-monetary policy variables (relative stock market performance, a measure of domestic sovereign credit risk, as well as relative long-term inflation expectations and oil prices) which contribute to increasing the overall explanatory power of the regression framework (R^2 of 62%). Nevertheless, more than one-third of the short-term variations in the EUR/USD remains unexplained, which might suggest that the explanatory variables chosen in this particular econometric model may not fully capture the full effects of factors like political uncertainty.

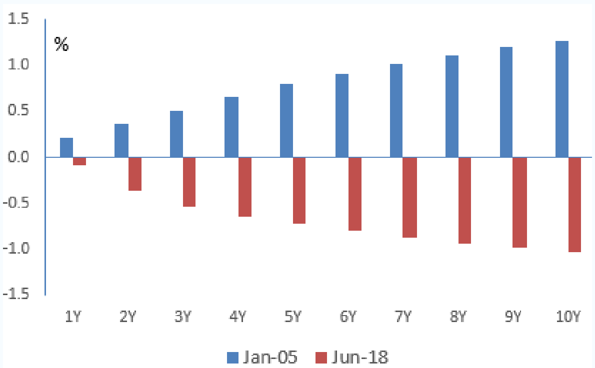
Future research work could possibly explore the pertinence of alternative drivers such as political uncertainty indices, the impact of the relative euro area – US shadow short rate[21], or even test other types of quantitative models which go beyond ordinary least-squares regression and which are better suited to capture possible non-linear effects.

Box 1: **THE TERM STRUCTURE OF TERM PREMIA**

The yield curve can be a valuable source of information for central bankers as it helps in assessing the impacts of central bank policy decisions. A proper interpretation of yield curve information, especially in times when a central bank implements unconventional monetary policy measures (such as large-scale asset purchase programs), requires separating expectations of future short-term policy rates from the so-called "term premium" component embedded in interest rates. The term premium reflects the excess return that an investor demands as compensation for holding a bond with a long maturity relative to rolling over a short-term bond until this long-dated maturity. The 2-year and 10-year term premium estimates used in the regressions (as explanatory variables) displayed in Table 2 of Annex 1 were extracted from historical yield curve data using a Gaussian affine term structure model (GATSM).

In an affine term structure model, yield curve dynamics are typically captured by two or three unobservable factors. Such term structure models compress a large amount of cross-sectional and time series yield information into the behaviour of these latent factors. The dynamics of these factors determine the shape of the yield curve at each point in time (i.e. the cross-sectional dimension) as well as through time (the times series dimension). "Affine" means that bond yields depend linearly on the risk factors. Although the assumption of linearity may appear simplistic at first sight, when the risk factors are defined as unobserved (statistical) variables, such a specification can accommodate a rich array of possible term structure models (such as the Nelson Siegel family of yield curve models). "Gaussian" refers to the distributional assumption for the risk factors, which also helps to simplify the mathematical derivation of yield dynamics considerably. To be more specific, the term premium estimates employed in the regressions shown in Table 2 were extracted from historical yield curve information using a two-factor arbitrage-free Nelson Siegel model (for a more detailed discussion see ECFIN Discussion Paper 110 "A Calibration of the Term Premia to the Euro Area", Eric McCoy, September 2019). In order to decompose interest rates into their two components (i.e. the expectations and term premium components), in addition to extracting the latent factors, term structure models also need to calculate the "market price of risk".

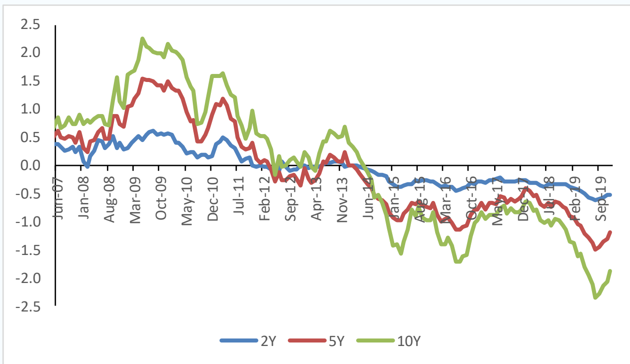
Graph 2: **Term structure of the euro area term premia.**



Note: German govt. yields were used as a proxy for risk-free euro area govt. yields.

Source: ECFIN.

Graph 3: **Evolution of the 2Y, 5Y and 10Y euro area term premia.**



Note: German govt. yields were used as a proxy for risk-free euro area govt. yields.

Source: ECFIN.

The market price of risk, which varies over time and is typically specified as a linear function of the factors, captures the market's required risk compensation per unit of interest rate risk. In essence, the term premium is a function of both the amount of risk as well as the market price per unit of risk. The longer the horizon, the greater is the uncertainty surrounding the expected short rate (this makes sense intuitively, as it is more difficult to forecast today where the short rate will be in 10 years from now compared to where it will stand in 1 year from now). This increasing uncertainty in function of maturity, combined with a market price of risk parameter consistent with risk-averse investors, gives rise to an upward sloping term structure of term premia, which was the case for example in January 2005 (see the blue-coloured bars depicted in Graph 2). One can observe from term structure of term premia in January 2005 that the term premium at the 2-year horizon is much smaller than the corresponding one at the 10-year horizon. This further helps to justify why the 2-year term premium variable turned out to be statistically weaker in the regression results presented in Table 2 of Annex 1; indeed, the term premium component is typically more contained at shorter horizons and less responsive to unconventional monetary policy events.

On the other hand, as is discernible in Graph 2, the term structure of term premia in June 2018 (see red-coloured bars) was inverted and increasingly negative with maturity. What can explain this? Before attempting to answer this question, it is worthwhile further discussing the "market price of risk" parameter embedded in Gaussian affine term structure models. Ahmad R and Wilmott P (Wilmott magazine, January 2007) are amongst the few who devote an entire article on this concept, which one typically finds in models of incomplete markets. In a nutshell, if a market is "incomplete" and risk cannot be fully hedged away, then in order to value a tradeable bond for instance, one must specify how this risk is being priced by the market. This amounts to modelling how much extra expected return is required for a "unit" amount of interest-rate risk. Once this is specified then one can use the 'market price of risk' parameter to price all fixed-income instruments (i.e. bonds with different maturities) in a consistent way. As these authors explain, investors are typically risk-averse and require extra compensation for bearing interest rate risk (i.e. on long-dated bonds for example) which they refer as market "fear". This thus provides an explanation for the upward sloping term structure of term premia under normal economic times. However, these same authors also show that there are periods of time characterised by market "greed" whereby investors are even willing to pay to take on more interest rate risk. One such example is for example local pension funds constrained to invest in euro area bonds even when the ECB's APP compressed the term premia and pushed down bond yields. This change in the sign of the "market price of risk" parameter is what enables one to obtain the inverted and negatively sloping term structure of term premia.

So what can explain the inverted and negative term structure of term premia in Graph 2? The ECB's implementation of the large-scale asset purchase program (APP) since 2015 has had the effect reducing aggregate duration risk. This lower aggregate duration risk has increased the risk-bearing capacity of price-sensitive bond market participants, which in turn has contributed to decreasing their required risk compensation per unit of risk exposure (see Eser, Lemke, Nyholm, Radde and Vladu 2019 for more details). In other words, it is the change in the market price of risk which drives the negative term premia observed in June 2018. The ECB's APP, by reducing the overall duration risk borne by price-sensitive investors, has compressed term premia across maturities, with a proportionally greater compression for longer maturities. Graph 3 illustrates the evolution of the 2-year, 5-year and 10-year euro area term premia over time and here too one can observe the compression (into negative territory) of the term premia since 2015. The graph also shows that the compression of the 10-year term premium has been significantly more pronounced in comparison to the compression of the 2-year term premium, as was picked up by the regression in Table 2. To conclude, further research could investigate whether or not the relative change in the slope of the term structure of term premia (between the euro area and the US) bears any impact on short-term EUR/USD dynamics.

Annex 1: The Regression Framework

Table 1: **Baseline Regression**

Dependent variable: EUR/USD	Analysis with 2Y rates	Analysis with 10Y rates
	Coeff.	Coeff.
Govt bond yield (EA-US):		
Sub-period: Aug04-Oct08	0.07 *(*)*	0.07 *(ns)*
Sub-period: Nov08-Feb15	0.13 *(***)*	0.07 *(*)*
Sub-period: Mar15-Dec19	0.06 *(**)*	0.10 *(***)*
R-squared	**21.1%**	**10.6%**

ns P-value > 0.05, * P-value < 0.05, ** P-value <0.01, *** P-value < 0.001

Sample: 2004M08 to 2019M12 (185 obs.) with Huber-White standard errors.

Source: ECFIN.

Table 2: **Extended Regression**

Dependent variable: EUR/USD	Analysis with 2Y rates	Analysis with 10Y rates	
	Coeff.	Coeff.	
Policy rate component (EA-US):			MP Variables
Sub-period: Aug04-Oct08	0.04 *(*)*	0.04 *(ns)*	
Sub-period: Nov08-Feb15	0.12 *(***)*	0.15 *(***)*	
Sub-period: Mar15-Dec19	0.06 *(**)*	0.10 *(***)*	
Term premia component (EA-US):			
Sub-period: Aug04-Oct08	0.05 *(ns)*	0.01 *(ns)*	
Sub-period: Nov08-Feb15	0.01 *(ns)*	0.07 *(**)*	
Sub-period: Mar15-Dec19	0.12 *(*)*	0.12 *(***)*	
Stock market perf. (Europe vs US)	-0.5427 *(***)*	-0.5169 *(***)*	Non-MP Variables
Avg 10Y govt spread (vs Bund)	-0.0494 *(***)*	-0.0543 *(***)*	
30Y inflation expectations (EA-US)	-0.0442 *(*)*	-0.0400 *(*)*	
Brent (in US $)	0.0016 *(***)*	0.0019 *(***)*	
R-squared	**60.5%**	**61.5%**	

ns P-value > 0.05, * P-value < 0.05, ** P-value <0.01, *** P-value < 0.001

Sample: 2004M08 to 2019M12 (185 obs.) with Huber-White standard errors.

Source: ECFIN.

<u>Technical notes</u>:

1. The sample period covers August-2008 to December-2019. Datasets are of a monthly frequency and all of the variables are expressed as first differences to ensure that the series are stationary. By construction, the regression captures the contemporaneous relationship between the monthly change in the EUR/USD and the various explanatory variables. Given the high-frequency behaviour of exchange rates and the explanatory variables (i.e. all are market based), the justification for this modelling assumption rests upon the fact that the length of the observation interval is long enough to allow behavioural adjustments to take place.

2. The variable representing the relative stock market performance is calculated based on the difference between the Europe STOXX 600 and S&P 500 stock market indices. A logarithmic transformation is applied to each of the stock market indices.

3. The following variables are expressed in relative terms (i.e. defined as euro area minus the US): expected policy rate, term premium, stock market index, and 30Y inflation expectations.

4. A Chow breakpoint test was performed to assess the statistical relevance of the two breakpoints: November-2008 and March–2015. The Chow breakpoint test confirms (at the 5% threshold level) the statistical relevance of these two breakpoints.

5. To overcome the presence of heteroscedasticity detected in the residuals of the OLS regression, which is typical for regressions involving exchange rates, all of the regressions were estimated using Huber-White heteroscedasticity-consistent standard errors.

6. The residuals of the extended regression show no significant serial autocorrelation as evidenced by the Durbin-Watson statistic of 1.9 (i.e. it is close to the benchmark value of 2). Moreover, all of the other regressions presented in Tables 1 and 2 have a Durbin-Watson statistic which is also close to 2.

References

Ahmad, R. and Wilmott, P., (2007) "The Market Price of Interest-rate Risk: Measuring and Modelling Fear and Greed in the Fixed-income Markets", Wilmott Magazine, pp. 64-70.

Brainard, L., (2017) "Cross border spillovers of balance sheet normalization", Speech at the National Bureau of Economic Research's Monetary Economics Summer Institute, Cambridge, Massachusetts.

Breitenfellner, A., J.C. Cuaresma (2008), "Crude oil prices and the USD/EUR exchange rate, Monetary Policy and the Economy, Austrian Central Bank, Issue 4, pp. 102-121.

Cahill, M., (2017) "Global Markets Daily: Rate differentials still driving the Dollar" Goldman Sachs Economic Research, March.

Chernov, M. and Creal, D., (2018) "International Yield Curves and Currency Puzzles", NBER Working Paper No. 25206, November 2018.

Cheung W., Chinn M., and Pascual G. (2005), "Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?", Journal of International Money and Finance, Volume 24, Issue 7, November 2005, Pages 1150-1175.

Coeuré, B. (2017), "The international dimension of the ECB's asset purchase programme", speech at the ECB's Foreign Exchange Contact Group meeting.

Coeuré, B. (2017), "Monetary policy, exchange rates and capital flows", speech at the 18th Jacques Polak Annual Research Conference, Washington D.C.

Courdert, V, and Mignon, V., (2016) "Reassessing the empirical relationship between the oil price and the dollar" Energy Policy 95, pp: 147-157

Curcuru S., Thomas C., Warnock F., and Wongswan J. (2014), "Uncovered Equity Parity and Rebalancing in International Portfolios", Federal Reserve System International Finance Discussion Paper 1103, May 2014.

Diebold, F.X. and K. Yilmaz (2012), "Better to Give than to Receive: Predictive Directional Measurement of Volatility Spillovers", International Journal of Forecasting, 28, pp. 57-66.

Engel, C., (2014) "Exchange rates and interest rates parity" in Gopinath, G., Helpman, E, and Rogoff, K., (eds) Handbook of International Economics, vol. 4 Amsterdam: North Holland, pp: 453-522

Eser F., Lemke W., Nyholm K., Radde S., and Vladu A.L., "Tracing the impact of the ECB's asset purchase programme on the yield curve", ECB Working Paper Series, No 2293, July 2019.

Fama, E., (1984) "Forward and spot exchange rates" Journal of Monetary Economics 14: 319–338.

Fratzscher M., Schneider D., and Van Robays I. (2014) "Oil Prices, Exchange Rates and Asset Prices" ECB Working Paper Series N° 1689 / July 2014.

Golub (1983) "Oil prices and exchange rates" Economic Journal 93: 576–593.

Hau H. and Rey H. (2006), "Exchange Rates, Equity Prices, and Capital Flows", The Review of Financial Studies, Vol 19 No 1, pp. 273-317.

Krugman, P., (1983) "Oil and the dollar" in: Bhandari, J., Putnam, B. (eds.), Economic Interdependence and Flexible Exchange Rates. MIT Press.

McCoy, E., Clemens, U., (2017) "A Calibration of the Shadow Rate to the Euro Area using Genetic Algorithms", ECFIN Discussion Paper 51 (July 2017).

McCoy, E., (2019) “A Calibration of the Term Premia to the Euro Area”, ECFIN Discussion Paper 110 (September 2019).

Meese R., and Rogoff K. (1983), “Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample?”, Journal of International Economics, 14, pp. 3-24.

Melvin M. and Prins J. (2015), “Equity hedging and exchange rates at the London 4 p.m. fix”, Journal of Financial Markets, 22, pp. 50-72.

Meese, R.A., and Rogoff, K., (1983): “Empirical exchange rate models of the seventies: do they fit out of sample?” Journal of International Economics 14, 3–24.

Stavrakeva V., and Tang J. (2016) “Exchange Rates and the Yield Curve”, Working Paper No. 16-21, Federal Reserve Bank of Boston.

Vayanos D., and Vilas J., (2009), “A Preferred-Habitat Model of the Term Structure of Interest Rates”, NBER Working Paper No. 15487, November 2009.

[1] A number of other major industrialised countries had policy rates hovering around their effective lower bound after the GFC and they also implemented quantitative easing programs. However, some of these engaged in active currency intervention, complicating the analysis even further (beyond the scope of this paper) and hence the focus of the paper is on the euro area and the US.

[2] See Engel (2014), equation 4 on page 454, "Exchange rates and interest rates parity".

[3] Throughout the paper, German government bond yields are used as a proxy for euro area risk-free interest rates. German government bonds are typically considered as a good proxy for euro area risk-free interest rates as German government credit/default risk is considered minimal.

[4] Note that in this "baseline" regression all variables are expressed as first-differences to ensure stationarity, and also the expected long-run equilibrium level of the nominal exchange rate from the Engel equation presented on page 2 is implicitly assumed to be held constant (i.e. disappears from the regression with first-differenced variables).

[5] In late November 2008, the Federal Reserve started buying $600 billion in mortgage-backed securities (QE-1). By March 2009, it held $1.75 trillion of bank debt, mortgage-backed securities, and Treasury notes; this amount reached a peak of $2.1 trillion in June 2010. In November 2010, the US Federal Reserve announced a second round of quantitative easing, QE-2, buying $600 billion of Treasury securities by the end of the second quarter of 2011. A third round of quantitative easing, QE-3, was announced on 13 September 2012.

[6] In January 2015, the ECB announced its large-scale asset purchase program (APP) by pledging the purchase of 60 billion euro of public and private sector securities per month from March 2015 until at least September 2016, thus amounting to 1.1 trillion euro. Successive rounds of APP recalibrations took place in December 2015, March 2016, December 2016, October 2017 and June 2018; these eventually brought the size of the portfolio to about 2.6 trillion euro by the end of net purchases in December 2018. Although the ECB stopped APP net purchases in Dec 2018, it resumed them again following the September 2019 Governing Council decision.

[7] For the interested reader, see also Chernov and Creal (2018) "International yield curves and currency puzzles" who study the links between exchange rates and yield curve differentials.

[8] The two components (expected policy rate and term premium) were extracted using a two-factor Gaussian affine term structure model (GATSM) which was calibrated to German and US historical government bond yield data. For more details, see ECFIN Discussion Paper 110 "A Calibration of the Term Premia to the Euro Area", Eric McCoy, September 2019.

[9] This definition of the term premium is commonly employed in the literature as well as in central bank speeches (see for example the ECB speech of Peter Praet "Maintaining price stability with unconventional monetary policy measures", MMF Monetary and Financial Policy Conference, London, October 2017).

[10] Duration risk refers to the risk associated with the sensitivity of a bond's price to a one percent change in interest rates. The higher a bond's duration, the greater its sensitivity to interest rates changes.

[11] See Coeuré, B., "The international dimension of the ECB's asset purchase programme", speech at the ECB's Foreign Exchange Contact Group meeting. Foreign Exchange Contact Group meeting, Frankfurt, Jul-17.

[12] It is worthwhile highlighting the increasingly divergent monetary policy context in the US (versus euro area), which in 2014 was characterised by growing market expectations of US monetary policy normalisation.

[13] See slide 4 of the speech by Benoît Cœuré (2017), "Monetary policy, exchange rates and capital flows". For more details on the methodology, see Diebold and Yilmaz (2012), "Better to Give than to Receive: Predictive Directional Measurement of Volatility Spillovers".

[14] Vayanos and Vila (2009) develop a model, featuring price-insensitive preferred-habitat investors and price-sensitive arbitrageurs, which links the term premium to the amount of duration risk to be absorbed by the arbitrageurs: lower aggregate duration risk increases the risk-bearing capacity of the arbitrageurs, thereby decreasing risk compensation per unit of risk exposure (i.e. the "price of risk") and hence the term premium.

[15] See for example the speech of Lael Brainard (2017) "Cross border spillovers of balance sheet normalisation" which mentions that before the GFC the impact of term premia on the exchange rate, although present, was rather small even at the long-end of the curve.

[16] For the interested reader, Box 1 discusses in further details how the term premium is linked to the so-called "market price of risk" parameter as well as how this parameter relates to the risk-aversion profile of investors.

[17] The assumption that the expected long-run equilibrium level of the nominal exchange rate is constant (see endnote 4) is somewhat (albeit loosely) relaxed in the "extended" regression as long-run inflation expectations are incorporated into the analytical framework, thus implying that the long-run real exchange rate is being held constant. This being said, a more comprehensive modelling of the dynamics of the long-run equilibrium exchange rate goes beyond the scope of this paper.

[18] Belgium, France, Greece, Italy, Ireland, Netherland, Portugal and Spain.

[19] Fratzscher, Schneider and Van Robays 2014 for instance find evidence for a bi-directional causality between the US dollar and oil prices since early 2000.

[20] For the extended regression involving the 10Y rates shown in Table 2 of Annex 1, the regression R^2 (which stands at 62%) drops to 25% when removing the non-monetary variables. However, this is still superior to the R^2 of 11% obtained when regressing on the 10Y yield differential in isolation (see baseline regression in Table 1) and it thus shows that decomposing interest rates into their two components (i.e. expected base rate and term premium) increases the explanatory power.

[21] For a more detailed discussion of how the shadow rate is calculated and how it is related to monetary policy stance, see ECFIN Discussion Paper 51, "A Calibration of the Shadow Rate to the Euro Area using Genetic Algorithms", McCoy, E., Clemens, U., July 2017.

EUROPEAN ECONOMY ECONOMIC BRIEFS

European Economy Economic Briefs can be accessed and downloaded free of charge from the following address:
https://ec.europa.eu/info/publications-0/economy-finance-and-euro-publications_en?field_eurovoc_taxonomy_target_id_selective=All&field_core_nal_countries_tid_selective=All&field_core_flex_publication_date[value][year]=All&field_core_tags_tid_i18n=22614.

Titles published before July 2015 can be accessed and downloaded free of charge from:

- http://ec.europa.eu/economy_finance/publications/economic_briefs/index_en.htm
  (ECFIN Economic Briefs)
- http://ec.europa.eu/economy_finance/publications/country_focus/index_en.htm
  (ECFIN Country Focus)

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct Information Centres. You can find the address of the centre nearest you at: http://europa.eu/contact.

On the phone or by e-mail

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696 or
- by electronic mail via: http://europa.eu/contact.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: http://europa.eu.

EU Publications

You can download or order free and priced EU publications from EU Bookshop at: http://publications.europa.eu/bookshop. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see http://europa.eu/contact).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu.

Open data from the EU

The EU Open Data Portal (http://data.europa.eu/euodp/en/data) provides access to datasets from the EU. Data can be downloaded and reused for free, both for commercial and non-commercial purposes.

Publications Office
of the European Union