The vanishing of currency puzzles is a puzzle too[1]

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Abstract

In recent years, there has been a reversal of several long-standing currency puzzles, such as the forward premium puzzle, carry trade profitability, and the exchange rate "disconnect." This paper proposes a unified framework to understand these reversals, which is based on the structural breaks identified in currency returns in 2005 and a simultaneous shift in the relative importance of global and local currency risk factors. This shift is attributed to the growth of the U.S. oil sector, a stronger impact of the oil price on U.S. inflation, and a weaker link between real interest rates in the U.S. and other advanced economies since 2005.

KEY WORDS: currency puzzles, oil price, structural breaks, global risk factors

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1. Introduction

Several salient changes in the currency market have been documented recently, including (i) declining profitability of the currency carry trade (Ready et al. (2017)), (ii) reversal of the forward premium puzzle (Bussiere et al. (2018)), (iii) increased correlations between exchange rates and other macro and risk variables, which likely overturn the classical "currency disconnect" (Lilley et al. (2019)), (iv) the rise of new currency risk factors (Shin (2016)). These changes concern some of the longest-standing and most widely studied currency puzzles, and are thus essential for understanding the recent developments in the currency market. Yet, these changes have not been incorporated into extant international finance models, which primarily focus on resolving puzzles established in earlier periods (e.g., see Itskhoki and Mukhin (2021) and references therein). Moreover, these changes have been so far analyzed separately, with individual explanations provided for each of them.[1]

But do these changes indeed represent different facets of the currency market? In this paper, we argue that these changes are interconnected and share a common root. We propose a common framework for their understanding and make a first step towards rigorous modeling that accounts *both* for the earlier puzzles and the recent changes. Central to this framework is the interplay between global and local currency risk factors, with the observed changes reflecting a shift in the relative importance of these factors. We attribute this shift to developments in the oil market, and particularly the substantial growth of the U.S. oil sector since 2005. We show that the relations between exchange rates and the oil price, as well as inflation, real interest rates and economic growth all change around the end of 2005. Our findings suggest that the observed changes in multiple currency market puzzles stem from a concurrent realignment of various macroeconomic variables across economies.

At the heart of our analysis is the precise dating of the changes in the currency market that we aim to explain. Using testing procedures as in Bai and Perron (1998, 2003), we find statistically significant structural breaks in various currency returns and their relations with other macro variables, all occurring

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[1] For example, Bussiere et al. (2018) show that the traditionally negative slope in uncovered interest rate parity (UIP) regressions (which represents the forward premium puzzle) has now turned too positive, and interpret this in terms of the co-movement of expectation errors and interest rate differentials. Ready et al. (2017) explain the lost carry trade profitability with the highly variable costs of international trade due to the slow adjustment of capacity in the shipping sector. Lilley et al. (2019) show that a number of global risk variables now co-move (i.e., "re-connect") with exchange rates, and attribute this to foreign bond purchases by U.S. investors. Shin (2016) argues that in the recent years the U.S. dollar has emerged as a new global risk factor (replacing the VIX), driven by dollar cross-border capital flows and their close link to the leverage decisions of global banks.

towards the end of 2005. This finding distinguishes our paper from previous studies that typically see the global financial crisis of 2008 as the watershed event. Therefore, the breaks we uncover in 2005 are novel and pose a new challenge to currency research.

Figure 1 illustrates these breaks, where Panel A in plots the cumulative returns of a carry trade constructed from the G-10 currencies. Notably, these returns exhibit a distinct flattening starting at the end of 2005. Panel B provides further detail by separately plotting the components of this trade derived from currencies with extreme (high or low) interest rates, and those with intermediate interest rates. This plot clearly shows that the change in overall carry trade returns is driven by the currencies with intermediate rates, as their returns experience significant growth before 2005 but turn negative on average thereafter.[2]

[Figure 1 about here]

Furthermore, Panels C and D in Figure 1 demonstrate a sharp reversal in the U.S. oil sector, also occurring at the end of 2005. This reversal is particularly evident in the U.S. exports of oil and petroleum products, which remain persistently low (about 5% of the U.S. consumption of petroleum products) until 2005, but subsequently undergo a dramatic and sustained increase (reaching about 40% of consumption). The main theme of this paper is the close linkage between the observed patterns in the currency and oil markets depicted in Figure 1, which can also help explain the changes in other currency puzzles mentioned earlier.

Importantly, we stress that our primary focus is on the differences between the pre- and post-2005 periods (which we refer to as the “early” and “later” periods). While we do not establish causal statistical evidence for the impact of the oil price on other variables, we acknowledge the inherent ambiguity of causality in international finance. In particular, previous studies of the interactions between exchange rates, interest rates, oil price, inflation rates, etc. often find that causality runs in all directions (see Kilian and Zhou (2020), among others.) Therefore, we concentrate on the *change* in the contemporaneous relations between variables across different markets around the end of 2005.

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[2] Panel B in Figure 1 is also informative with respect to the relation between carry trades and the forward premium puzzle (or the violation of UIP). On one hand, it is seen in Panel B that the carry trade returns due to the currencies with extreme interest rates remain positive after 2005. On the other hand, we show in Section 2 that the slope coefficient in a UIP regression for these currencies changes sign in 2005, and hence the classic violation of UIP no longer holds in the recent period, consistent with Bussiere et al. (2018). Combined, these two facts imply that carry trade profitability and UIP violation are *distinct* puzzles. While this distinction was established in Colacito et al. (2018) and Hassan and Mano (2019), among others, is most clearly manifested after 2005, and mostly for the currencies with extreme interest rates.

Regarding the shift in the oil market, we attribute it to long-term economic developments. One potential long-term driver is the oil price target bands maintained by OPEC throughout most of the 1980's and 1990's. These bands were finally suspended in 2005, during the significant increase in oil prices that disrupted the previous period of relative stability (as shown in Panel E of Figure 1) and lasted until mid-2008. Another factor could be the build-up of the U.S. current account deficit, which reached a record high of 6.3% of GDP at the end of 2005 and then dropped substantially (as shown in Panel F of Figure 1). Net oil imports accounted for a significant portion (around 40% in 2005) of this deficit, making them a primary target for policy makers' deficit reduction efforts.[3]

This paper makes three contributions that rationalize the evidence from different markets. First, we demonstrate that the observed changes in the currency market can be reproduced within a reduced-form model by altering the relative importance of local and global risks. Second, we provide evidence that the oil price is uniquely suited to represent one of these risks, considering the structural breaks in the relationship between exchange rates and the oil price that we find at the end of 2005. Third, we document additional concurrent breaks in the relations between several global macro variables, indicating that the changes in various currency market puzzles reflect deeper shifts in the global economy that occurred around the same time. These shifts preceded the global financial crisis of 2008 by at least two years, presenting a novel and challenging stylized fact.

Our model-based insights are derived from a version of the currency market model in Lustig, Roussanov, and Verdelhan (2014) (the "LRV model"), which explicitly accounts for currency risk premia, carry trade returns and violations of uncovered interest rate parity (UIP). In Section 3, we elaborate on the key features that allow this model to capture the empirical differences between the pre- and post-2005 periods. These features can be qualitatively derived even before calibrating the model with our data, establishing general requirements for any international finance model consistent with this data.

However, the LRV model is in reduced form and does not name the specific risks involved. To address

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[3] This unprecedented deficit was vigorously discussed before 2005, with concerns that it is unsustainable and will entail a painful adjustment and dramatic U.S. dollar depreciation (e.g., Obstfeld and Rogoff (2001, 2005) and Blanchard et al. (2005)). The policies toward addressing this issue included a comprehensive energy bill passed by the U.S. Congress in mid-2005. Specifically, the Economic Policy Act of 2005 held a number of authorizations for energy efficiency, and also cleared the way for the use of hydraulic fracking and hence the subsequent shale oil boom in the U.S. In retrospect, this Act triggered the dramatic turn in U.S. oil production and exports in 2005 that is seen in Panels C and D of Figure 1.

this limitation, in Section 4 we examine a wide range of risk variables to identify those that align with the model's predictions for the early and later periods. Surprisingly, the standard risk variables commonly used in the currency literature *cannot* serve as risk factors in our context:

Firstly, they are not suitable for the role of a global factor, as the model implies a lower correlation between global factors and exchange rates in the later period, whereas these variables exhibit higher correlations (consistent with findings in Lilley et al. (2020)). Secondly, the LRV model predicts the prominence of certain local risks in the later period, which again rules out the standard risk variables, because they are widely considered to be global in nature. Finally, most of these variables tend to exhibit structural breaks in their relationship with currency returns somewhere in 2008, providing further empirical ground to exclude them.

The notable exception is the oil price – we find strong evidence from several perspectives that it can play the role of a U.S.-specific (local) factor emerging precisely after 2005. Additionally, the break in currency returns around the end of 2005 can be traced to a sharp increase in the sensitivity of these returns specifically to *down*-moves in the oil price, and this asymmetry can be naturally connected to the resurgence in U.S. oil production exports after 2005 (as observed in Panels C and D in Figure 1). In Section 5 we also show that this asymmetry is crucial in understanding the changing relationships between exchange rates and other macro variables in the later period.

One important caveat to our results is that the changes in the currency market that we aim to explain are concentrated in the last few months of 2005, rather than sharing an *exact* common timing. Nevertheless, the confluence of these changes within a relatively short period around the end of 2005 provides strong evidence for a common underlying economic mechanism.

Our main finding that 2005 was a significant turning point in the currency market calls for reconsidering some previous results. For instance, carry risk appears to have lost its risk premium for over a decade now (as noticed previously in Ready et al. (2017)), even though carry risk factors are often employed in recent studies of the currency market. Similarly, our results indicate significant changes in the risks associated with the U.S. dollar, occurring at least two years prior to the global financial crisis, and thus have implications for understanding the special role of the dollar as a dominant currency. in general, the traditional unconditional approach to studying currency returns and risks does not seem justified, and the existence of at least two major regimes over the last three decades should be taken into account, contrasting with the prevailing practice in empirical and theoretical currency research.

Finally, we acknowledge that alternative interpretations of the changes in the currency market studied in this paper may exist, which do not involve the oil price. In fact, such interpretations will be necessary for a more complete understanding of the currency market in the recent years, especially the increased correlations between exchange rates and other risk variables (such as equity index returns) observed since the global financial crisis. However, these alternative interpretations can still benefit from our empirical and model-based insights into the potential common roots of various recent developments in the currency market, as well as the documented structural changes that have previously gone unnoticed in the currency literature. As indicated by the paper's title, we propose a new currency puzzle and suggest one direction for its resolution.

Related literature

This paper is related first to the extensive literature on various puzzles in the currency market such as the forward premium puzzle, uncovered interest rate parity puzzle, and other anomalies (e.g., Lewis (1995), Engel (2014), Engel and Zhu (2018), and references therein). However, our focus is specifically on the significant changes (reversals) in some of these puzzles around the end of 2005 and their common drivers. We do not delve into other developments in the currency market that occurred after 2005, such as deviations from covered interest rate parity, or those related to non-conventional monetary policies or the zero-lower bound, which are also of a later vintage.

Our key finding regarding the important recent link between the U.S. dollar and the oil price also relates this paper to a large body of literature on the impact of the oil price on the currency market, and on financial markets and the economy in general (e.g., Krugman (1983), Golub (1983), Hamilton (1996), Backus and Crucini (2000), Barsky and Kilian (2004), Kilian (2009), among others). Building upon the insights about the asymmetric impact of oil price movements on GDP, as discussed in Mork (1989) and Hamilton (2003), we contribute a novel finding that a similar asymmetry characterizes the oil-dollar relationship in our sample.

Additionally, our paper is related to studies examining the global role of the U.S. dollar (e.g., Gourinchas et al. (2019) and Gopinath et al. (2020), and references therein). In particular, our empirical evidence suggests a *diminished* global risk premium embedded in the U.S. dollar in recent years. This conclusion is drawn from our analysis of currency returns and the distinction between global and local currency risk factors.

Lastly, our focus on the shift in exposures to oil-related risks, inflation and interest rates aligns this paper with strands of literature that investigate the changing global impact of oil prices (e.g., Blanchard and Riggi (2013), among others) or regime changes in U.S. monetary policy (e.g., Bianchi (2013)). Other related studies, such as Ready (2018) and Fang et al. (2021), find important shifts in the links between oil prices and economic growth, inflation, and risk premia across various markets during the early 2000's. It is worth noting that formalizing these diverse relationships among multiple macro variables in a rigorous model poses a non trivial challenge, particularly in endogenizing the simultaneous changes in various risk exposures and risk premia, which remains a subject for future research.

2. Empirical evidence

In this section, we present summary statistics derived from a range of currency trades that are constructed from the G-10 currencies – the most actively traded and liquid currencies that have been widely utilized in currency research. These currencies are the New Zealand dollar (NZD), Australian dollar (AUD), British pound (GBP), Norwegian krone (NOK), Swedish krona (SEK), Canadian dollar (CAD), U.S. dollar (USD), euro (EUR), Swiss franc (CHF), and Japanese yen (JPY), whereby the German mark is used prior to 1999 instead of the euro. The data is sourced from Barclays Bank, accessed through Datastream, and from Bloomberg.

2.1. Currency returns in two periods

The U.S dollar-based carry trade involves taking long (short) positions in all currencies that have a positive (negative) forward differential against the U.S. dollar. This trade has been examined in Burnside et al. (2011) and Daniel et al. (2017), among others. Rebalancing occurs at the end of each month, and transaction costs are ignored. To ensure robustness, a currency is excluded from the trade if its forward differential is too small (less than two basis points in magnitude), although the results remain unchanged even without this constraint.

Similar to Figure 1, we consider separately the two components of this dollar-based trade. The "static" component comes from the two currencies with the highest interest rates on average (AUD and NZD) and the two currencies with the lowest rates (JPY and CHF). Conversely, the "dynamic" component comes from the remaining five currencies. These two components sum up to the returns of the dollar-based trade at each time. The rationale behind this labeling is that the "static" currencies generally maintain their position in the trade (on the long and short sides, respectively), whereas the "dynamic" currencies tend to change their position more frequently (similar terminology is employed in Hassan and Mano (2019)).

The insert below displays the average returns of the static and dynamic components before and after 2005 (annualized and in percent, and in the columns labeled STA and DYN, respectively). The p-values for the difference between the averages of the early and later periods are shown in square brackets in the third row. The last two rows show similar averages and p-values after excluding the global financial crisis (which we take to be from 03/2018 to 03/2019).

	STA	DYN	AFD	FX	var_{DOL}	UIP slope	SC	SR_{SC}
early	1.8	2.9	1.1	1.6	0.45	1.8	3.0	0.7
later	0.4	-0.6	0.2	-0.4	0.6	-2.4	0.4	0.1
	[0.11]	[0.00]	[0.00]	[0.34]	[0.10]	[0.06]	[0.09]	
later (ex-FC)	0.7	-0.5	0.1	0.7	0.5	-1.9	1.0	0.3
	[0.24]	[0.00]	[0.00]	[0.77]	[0.66]	[0.10]	[0.21]	

In addition to the U.S. dollar-based carry trade shown in Figure 1, we also examine an unconditional trade (denoted DOL) that simply holds long all G-10 currencies against the U.S. dollar with equal weights. DOL is closely related to the dollar index DXY, whereby their return correlation is –0.94 (DXY holds the U.S. dollar long, while DOL holds it short and increases when the dollar depreciates, hence the negative correlation). The carry and foreign exchange components of DOL can be conveniently modeled, which we exploit in our analysis. In the previous table insert's third and fourth columns, AFD (the average forward differential) is the carry component of DOL's return, while FX is the remaining portion resulting from changes in exchange rates against the U.S. dollar.

Furthermore, var_{DOL} is the variance of DOL returns (again annualized and in percent) – it corresponds to annualized volatility of 7–8%, which is typical for currency returns. The "UIP slope" column displays the slope coefficients from univariate regressions (with a constant) of FX on AFD – these are analogues to the Fama regressions used to test the UIP hypothesis, but are applied to the DOL trade, rather than to individual exchange rates (see also Lustig et al. (2014, Section 3)).

Lastly, we also consider a "standard" carry trade (denoted SC). In this trade the G-10 currencies are sorted according to their forward differentials against the U.S. dollar at the end of each month. Then the top (bottom) three currencies in the ranking are held long (short) against the U.S. dollar, with equal weights. As in various investable currency indexes, these positions depend only on the ranking of differentials and not on the level of the U.S. interest rate. The insert above shows the average returns of this trade and its Sharpe ratio.

In contrast to the U.S. dollar-based trade, the standard carry trade is neutral with respect to the base currency. At the same time, it is worth noting that the currencies involved in both trades tend to have the same positions (long or short), because the U.S. dollar typically has an intermediate interest rate. Therefore, the returns of the two trades exhibit high correlation (0.80 in our sample). Our primary focus is on the former trade, which has a higher annualized Sharpe ratio (0.70 vs. 0.47) throughout the full sample period. Additionally, the dollar-based trade offers greater analytical tractability.

The reported statistics confirm that the two periods differ sharply, especially with respect to the average return of the dynamic component of the dollar-based carry trade. Pre-2005, this return is about 50% higher than that of the static component but later becomes negative. The static component maintains a slightly positive average return post-2005. The averages for AFD and FX also vary across the two periods, even though the difference is not statistically significant for FX. The DOL return variance is higher in the later period, and this difference is marginally significant when we do not exclude the financial crisis.

Moreover, the UIP slope coefficient reverses its sign in the later period (similar to results in Bussiere et al. (2018)). Under the UIP hypothesis, the slope coefficient should be equal to –1, while in our sample it stands at 1.80 in the early period and drops below –2 in the later period. We find a similar sign reversal also in separate UIP regressions for the static and dynamic components of DOL (post-2005 the slope coefficients are –1.76 and –2.17, respectively).

Importantly, the static component in the later period exhibits both a positive return and a UIP slope coefficient below –1, which shows clearly that carry trade profitability does *not* imply the forward premium puzzle. This is a simple demonstration of the point made previously in Colacito et al. (2018) and Hassan and Mano (2019), and confirms the need to treat the two puzzles as separate phenomena.

Lastly, it is worth noting that the standard carry trade is significantly more profitable in the early period, with a Sharpe ratio of 0.70 compared to an average of 0.20 in the later period). Panels A and B in Figure 2 show that the cumulative returns and components of this trade exhibit similar patterns to those in Figure 1 for the dollar-based trade. In particular, the standard carry trade returns due to the dynamic currencies also start declining after 2005 and this similarity implies that the two carry trades have common drivers.[4]

[Figure 2 about here]

For comparison, Panels C and D in Figure 2 present cumulative returns for the DOL trade and its components. There is no clear difference between the returns of the static and dynamic components of DOL, which implies that the interest rate signals used by the (dynamically rebalanced) carry trades allow us to detect a data feature that remains hidden when looking at the unconditional DOL trade. Our focus on carry trades is thus similar to Verdelhan (2018), who uses various carry-based portfolios as test assets to identify different risk factors in the currency market.

2.2. *Further confirmation of the empirical patterns*

To verify that the patterns in the static and dynamic components of the U.S. dollar-based carry trade are *not* driven by some isolated currency, Figure 3 plots the cumulative returns that each individual currency contributes to this carry trade. These are the returns of separate carry trades that are implemented with each currency against the U.S. dollar. In each plot, the thin (thick) portions of a line represent returns in periods when the respective currency has higher (lower) interest rate than the U.S. dollar, and hence is held long (short) in such a bilateral trade. As previously, a currency does not enter a trade in a given month (and hence the corresponding return is zero) when its interest rate differential with the U.S. dollar is less than two basis points in magnitude.

[Figure 3 about here]

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[4] Panel B in Figure 2 shows that the vanishing profitability of the standard carry trade in the recent years is due to the currencies in the dynamic component, whereas the static component continues to grow overall. This observation casts doubt on explanations of the diminishing carry trade returns that focus on the typical carry trade currencies like the AUD or JPY, because such currencies belong in fact to the static component of the trade. Other examples showing that the typical carry currencies may not be the most relevant for understanding carry trade profitability are provided in Bekaert and Panayotov (2020).

The plots in Figure 3 are ordered starting from the NZD (highest average interest rate) in the top-left corner and ending with the JPY (lowest rate) in the bottom-right corner. Therefore, there are just few months in the first few plots with thick line portions, because those currencies typically have higher interest rates than the U.S. dollar and are held long. In contrast, the last few plots have mostly a thick line, as they refer to currencies with typically low interest rates that are held short against the dollar.

The key observation from this figure is that for each "dynamic" currency (i.e., NOK, GBP, SEK, CAD and EUR) the cumulative returns reach a maximum around the end of 2005 and then flatten out or decline over the rest of the sample. In contrast, the plots for the currencies in the static component show no specific pattern in 2005: the returns of the NZD and AUD trades continue to grow until about 2012, only briefly interrupted by the global financial crisis; the plot for CHF reaches a maximum around 2001 and then trends down; for JPY there is a local maximum in 2008, which is exceeded in 2015. Overall, *each* currency in the dynamic component contributes to the reversal in its returns in 2005, while no such reversal is observed at that time for any of the currencies in the static component.

2.3. Structural break tests

For statistical confirmation of these observations, we run tests for a structural break in the returns of various carry trades. The tests for the null of no break are based on the supF statistics, as in Bai and Perron (1998), who generalize a similar test developed in Andrews (1993). We test for one versus zero breaks, and if the test does not reject at the 10% confidence level, we also test for two versus zero breaks. These tests are run separately for the static and dynamic components of the U.S. dollar-based carry trade and also for each of the nine individual carry trades against the U.S. dollar from Figure 3.

For the static component, the test shows one break in 07/2007, but with a supF statistics of only 3.5 (whereas the critical values for rejecting the null at the 10%, 5%, 2.5%, and 1% levels are 7.04, 8.58, 10.18, and 12.29, respectively). Testing for two breaks does not bring up the significance either, and hence there is no evidence for a break in this component of the dollar-based trade. On the other hand, the test identifies a break in 11/2005 for the dynamic component, with a supF statistic of 11.74, and thus rejects the null at the 2.5% confidence level.

Moving to the individual trades, we find marginally significant breaks for the NZD and AUD, but only in the second half of 2011. For CHF a marginally significant break is found in 2001, while the null cannot be rejected for JPY, with very low values of the test statistic. Therefore, the individual currencies in the static component also do not exhibit a consistent pattern with respect to structural breaks in their returns.

In contrast, the currencies in the dynamic component yield stronger statistical results. For NOK, SEK, and CAD the test identifies breaks in 02/2006, 10/2005 and 05/2005, respectively, with significance at the 2.5% level for SEK and CAD. For GBP, the break is in 03/2005, but not significant. The EUR exhibits a break in 11/2005, significant at the 10% level. The results from the individual dynamic currencies thus indicate that the dynamic component of the dollar-based trade captures a common phenomenon that represents a major change in the currency market towards the end of 2005.

Next we run a similar test for the UIP slopes and regress FX on AFD, mimicking the classic UIP regressions, but for the DOL trade. The test for a single break yields an insignificant supF statistic (3.94, whereas in this case the critical value at the 10% confidence level is 9.81). With the test for two breaks, however, this statistic is 16.29, and thus shows significance at the 1% level. The test identifies a break in 11/2005, exactly as for the dynamic component of the dollar-based carry trade. This confirms that the classic UIP relation has changed significantly in the recent period, but with an earlier estimated break than that adopted in Bussiere et al. (2018).

In sum, the carry trade returns exhibit clear patterns both in the time dimension (early vs. later period) and cross-sectionally (static vs. dynamic component). In particular, the dynamic component of the U.S. dollar-based trade provides strong evidence for the structural changes that motivate this paper.

3. Rationalizing the empirical evidence

This section first presents general requirements for any model of the currency market that can reproduce the patterns observed in the data and then examines one specific model that satisfies these requirements.

The statistics reported in the previous section imply that a suitable model should be able to:

A. distinguish between currencies with extreme (high or low) interest rates and those with intermediate interest rates (as in the “static” and “dynamic” components of the U.S. dollar-based carry trade),

B. generate different signs of the slope coefficients in UIP regressions (as in the early and later periods),

C. break the link between UIP violations and carry trade profitability (they reflect different puzzles),

D. generate carry trade returns that are either consistently positive or consistently negative (as for the dynamic component of the carry trade),

E. accommodate a higher variance of DOL when its average return decreases (as in the later period).

The above requirements are clearly not trivial and pose a significant challenge to any model of the currency market. More precisely, point A. is not consistent with typical two-country models with symmetric economies. Regarding point B., Engel (2016) observes that extant international finance models are often hard-wired to reproduce certain stylized facts and hence may be inherently inflexible. The distinction in point C. between the two puzzles has been only recently emphasized, and not internalized in most models. Point D. is new, given that the main focus of prior work was to explain the positive carry returns.

A model's task is further complicated by the need to reproduce at the *same* time (i) negative returns for some carry trades and (ii) positive returns for others (as observed for the dynamic vs. static components in the later period). Point E. (together with point D.) indicates the presence of multiple risk factors, with different risk compensations and changing exposures over time, which rules out risk-based models that focus on a single (possibly global) risk priced in currency returns.

As we show next, these multiple requirements can all be satisfied by the model in Lustig et al. (2014) (the LRV model), after certain modifications. The model can meet this high bar due to its inherent flexibility – being in reduced form it does not predefine the risk factors that drive currency returns. On the other hand, such flexibility also limits the economic insights offered by models of this type (see also Backus et al. (2013)), and our subsequent discussion aims to overcome this limitation.

3.1. The LRV model

The LRV model adapts the affine framework of term structure models of interest rates to the currency market, in the spirit of Backus, Foresi, and Telmer (2001). In the model, markets are complete, currency returns are driven by real variables, and inflation risk is not priced. The model features two global risk factors that affect all pricing kernels and exchange rates among the economies, as well as local risks that are specific to each economy.

Even though the model is in reduced form and leaves the risks unspecified, it still imposes important constraints on the variables involved in it and disciplines the possible interpretations. Details of the model are shown in the Appendix.

In this model, the interest rate differential rd_t^i, spot exchange rate changes sx_{t+1}^i, and currency excess returns rx_{t+1}^i (of currency i against the U.S. dollar, and in log form) are given by:

$$\begin{aligned}
rd_t^i &= -\frac{1}{2}\left(\delta^i-\delta\right)z_t^w-\left(\frac{1}{2}(\gamma+\kappa)-\chi\right)(z_t^i-z_t) &(1)\\
sx_{t+1}^i &= -\chi(z_t^i-z_t)\\
&\quad -\sqrt{\gamma}\left(\sqrt{z_t^i}u_{t+1}^i-\sqrt{z_t}u_{t+1}\right)-\left(\sqrt{\delta^i}-\sqrt{\delta}\right)\sqrt{z_t^w}u_{t+1}^w-\sqrt{\kappa}\left(\sqrt{z_t^i}-\sqrt{z_t}\right)u_{t+1}^g &(2)\\
rx_{t+1}^i &= rd_t^i+sx_{t+1}^i=-\frac{1}{2}(\delta^i-\delta)z_t^w-\frac{1}{2}(\gamma+\kappa)(z_t^i-z_t)\\
&\quad -\sqrt{\gamma}\left(\sqrt{z_t^i}u_{t+1}^i-\sqrt{z_t}u_{t+1}\right)-\left(\sqrt{\delta^i}-\sqrt{\delta}\right)\sqrt{z_t^w}u_{t+1}^w-\sqrt{\kappa}\left(\sqrt{z_t^i}-\sqrt{z_t}\right)u_{t+1}^g. &(3)
\end{aligned}$$

A superscript i here denotes variables for different economies, except for the respective U.S. variables, which have no superscript. The global shocks (or risks), u^w and u^g, and the economy-specific shocks, u^i and u, are all independent standard normal variables. In addition, z^i and z are economy-specific state variables (for economy i and the U.S., respectively), and z^w is a global state variable. The parameter δ for the U.S. takes the average value of the δ^i's for the remaining economies.

Most important in our setting are the parameter κ which reflects exposure to the global risk u^g, the parameters χ and γ which reflect exposure to economy-specific risks, as well as the long-term mean of the U.S. state variable z, which can differ from that of the remaining z^i's. Changes in these parameters allow the LRV model to reproduce the key stylized facts that motivate this paper.

3.2. Model-based qualitative insights

This section discusses the model's ability to meet the model requirements A. to E., stated above. It offers some qualitative implications of the LRV model, showing that it contains just the sufficient number of factors that allow it to match the empirical evidence.

A. The distinction between currencies with extreme (high or low) interest rates and those with intermediate interest rates is built in the LRV model, which postulates that economies have persistently different exposures to the global risk factor u^w, whereby an economy with a small (large) δ^i tends to have persistently large (small) interest rate. Such a distinction is specific to the LRV model, in contrast to the two-economy models that are used traditionally for studying carry trades (see also Colacito et al. (2018, Section 2)).

B. The UIP regression slope coefficient can be derived in the LRV model as:

$$\text{UIP slope} = \frac{\chi}{(\gamma+\kappa)/2-\chi}. \tag{4}$$

This expression is positive for large κ and/or small χ and can be made negative for smaller κ and/or larger χ. (While γ can also affect the UIP slope coefficient, its role here is negligible, as it is much smaller in magnitude than κ. See also Section 3.3.)

C. The LRV model can break the link between UIP violations and carry trade profitability, because the UIP slope coefficient in this model is associated only with the second term in the interest rate differential $rd_t^i = -\frac{1}{2}\left(\delta^i - \delta\right) z_t^w - ((\gamma+\kappa)/2-\chi)\left(z_t^i - z_t\right)$. If this second term is on average smaller in magnitude than the first term (which is more likely to hold for the "static" currencies that have either the highest or lowest δ^i), then, regardless of the sign of the UIP slope in equation (4), the position of the respective currency in the carry trade (long or short) and its contribution to the trade's returns will tend to be determined by the first term in the interest rate differential.

   For the currencies with the lowest δ^i, the term rd_t^i tends to be positive, so they are held long against the U.S. dollar and contribute the (large) positive term $-z_t^w(\delta^i - \delta)/2$ to the return of the dollar-based carry trade, as seen from equation (3). Similarly, the currencies with the highest δ^i tend to be held short in the trade and again contribute a (large) positive term to the trade's return.

   Such positive contributions can result in overall positive carry trade returns even when the UIP slope coefficient is negative and the UIP is not violated, precisely as observed in the data for the static component of the U.S. dollar-based carry trade in the later period (and to some extent for the standard carry trade from Figure 2 as well, which is dominated by the static currencies).

D. The model can also generate negative expected carry trade returns if the second term in the interest rate differential is negative and larger in magnitude than the first term (which is more likely for the "dynamic" currencies). In particular, if χ is large enough relative to κ, the interest differential will be giving the "wrong" signals to the carry trade – it will hold long (short) currencies with negative (positive) expected return, which happens because χ does not enter the return in equation (3).

E. The LRV model incorporates multiple sources of risk, both local and global. It can reproduce the simultaneous decrease in DOL's expected returns and increase in its returns variance in the later period, if the exposure to local risks (with no risk compensation) increases, whereas the exposure to global risks (with risk compensation) decreases in this period.

Note that all factors in the LRV model are necessary to explain the stylized facts that we focus on in this paper – the *two* global factors are needed to reproduce the difference in returns between the static and dynamic carry components in the later period, while local factors and state variables are needed to generate the switch in the UIP slope and the higher currency volatility in this period.

Even if the discussion of the model has been only qualitative so far, it already highlights an interplay between global and local factors, which is key to understanding the economic drivers of the currency market changes documented in this paper. In particular, the importance of the local state variables z^i and z increases in the later period (because χ likely increases, as per point B.). At the same time, the overall exposure to the global risk u^g is reduced, given a lower κ. Since the variance of DOL increases in the later period, a lower κ would also imply a higher exposure γ to the local risks u^i and u.

Note that point B. alone does not guarantee that the κ parameter *must* decline in the later period – a negative slope can also be achieved for a larger κ and an even larger χ. However, a large κ is not likely in the later period, whihc can be seen as follows: Consider the bilateral carry trade of currency *i* against the U.S. dollar, as in Figure 3. Let $(\gamma+\kappa)/2 < \chi$ (i.e., negative UIP slope) and $\delta^i < \delta$ (an analogous argument applies for $\delta^i > \delta$). From equations (1) and (3), the interest rate differential and expected carry trade return at time t each has a term with z_t^w and a second one with $(z_t^i - z_t)$. The signs of these terms, depending on the relation between z_t^i and z_t, are:

	$z_t^i << z_t$		$z_t^i < z_t$		$z_t^i > z_t$	
	z_t^w	$(z_t^i - z_t)$	z_t^w	$(z_t^i - z_t)$	z_t^w	$(z_t^i - z_t)$
interest rate differential (rd_t^i)	+	–	+	–	+	+
expected carry return	–	–	+	+	+	–

When z_t^i is much smaller than z_t, the interest rate differential in equation (1) is negative and currency *i* is shorted against the U.S. dollar. Both terms in the expected return on this trade are negative, as per equation (3). When $z_t^i - z_t$ is negative but not extreme, currency i is held long, and both terms in the expected return are positive. Finally, when z_t^i is larger than z_t, currency i is still held long, but the $(z_t^i - z_t)$ term has a negative contribution to the expected return, which can again turn negative for a sufficiently large z_t^i.

Therefore, the term with $(z_t^i - z_t)$ has a predominantly negative contribution to the carry trade return, and a larger κ will exacerbate this effect. While the magnitude of κ is an empirical issue that can be resolved ultimately by taking the model to data, the above argument indicates that a high value of κ in the later period is not likely, given that the static component of the trade is on average positive in this period.

3.3. Model calibration

Next we calibrate the model to the statistics reported in Section 2.1, after averaging the values for the later period with and without the financial crisis. Since the standard carry trade (SC) is less tractable, it is *not* used in the calibration, but the respective results are still reported. Further details are in the Appendix.

The critical parameters κ, χ, and γ are estimated separately for each period. We also estimate one long-run mean (θ^n) of the non-U.S. state variables z^i for both periods, a separate mean (θ) for the U.S. state variable z for the early period. For the later period we assume $\theta = \theta^n$. The results are not too sensitive to the remaining model parameters, and hence their original values as in Lustig et al. (2014) are kept unchanged.

Panel A in Table 1 shows the estimated parameters. Confirming our conjecture, the parameter κ decreases significantly in the later period (1.4 vs. 3.7), indicating a lower exposure of all economies to the global risk u^g. As per point B. in our model requirements, the parameter χ increases (1.3 vs. 1.2). Given the lower κ, it is now necessary for γ to increase (2.4% vs. 0.4%) to ensure that the variance of DOL returns increases in the later period. Finally, in the early period θ is somewhat higher than θ^n (1.66% vs. 1.53%), allowing the model to reproduce the large positive averages of AFD and FX in that period. (A higher θ corresponds to a relatively lower U.S. interest rate, and is consistent with a premium/privilege enjoyed by the U.S. A smaller average AFD observed in the later period implies a reduction of this privilege.)

[Table 1 about here]

Panel B in Table 1 shows the moments to which the model is calibrated, as well as the average value for each moment obtained from 1,000 simulations that use the estimated parameters. These averages are typically very close to the target, confirming the accuracy of the approximations used in the calibration.[5] A large discrepancy is obtained only for the average returns of the standard carry trade SC (5.1 vs. 3.0 and 0.8 vs. 0.5), which however were not used as targets in the calibration. At the same time, the Sharpe ratios of SC from simulations are still very close to the observed ones on average.

Note that the different parameter values in the early and later periods not only allow the model to perform well empirically, but are also informative about the underlying economic mechanism. In particular, the exposure to certain global risk (represented by u^g in the LRV model) has decreased in the later period, while the exposure to local risks (represented by u^i and u in the model) has increased. Both the lower value of the parameter κ and the higher values of χ and γ obtained for the later period translate into this conclusion. Note also that the lower value of θ in the later period points specifically to a U.S.-related change that accompanies the above moves in risk exposures.[6]

3.4. Non-parametric evidence

Local and global risks have in general different implications for the exchange rate moves across different currencies, regardless of the particular model used. A risk that is specific to only one currency affects all exchange rates of this currency in a similar way, all else being equal. In the LRV model, this is seen from equation (3), where the U.S.-specific risk u moves all U.S. dollar-based exchange rates in the same direction (and in fact by the *same* amount equal to $\sqrt{\gamma z_t} u_{t+1}$).

In contrast, a global risk affects different exchange rates differently, depending on their relative exposures to this risk. In the LRV model, this holds for the risk u^w, which moves in opposite directions the U.S. dollar-based exchange rates of currencies with parameters δ^i's that are higher or lower than the U.S.-specific parameter δ. It also holds for the risk u^g, which moves in opposite directions the exchange rates of currencies with state variables z^i that are conditionally higher or lower than the U.S. variable z.

Guided by this intuition, we examine the monthly returns in long positions of the G-10 currencies

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[5] The biggest discrepancy between target and model is observed in the early period for the average interest differential AFD (0.8 vs. 1.1), but this discrepancy can be expected even before any estimations and simulation – the model imposes a strict relation between the averages of AFD and FX on one hand and the UIP slope on the other, which does not hold among the respective empirical targets in the early period.

[6] Note further that the regime shift in carry trade returns is reproduced without *any* change related to the global factor u^w, which is intended to be the main driver of carry trade returns in the LRV model, since different economies have persistently different exposures to it. Similarly, we generate the UIP slope change even if it does not involve *any* parameters related to u^w. These findings call for reconsidering the role of global risks for carry trade returns.

against the U.S. dollar and simply count how many of them are of the same sign each month. If all or most of them are of the same sign, then it is likely that they are driven by a local (U.S.-specific) risk. Given nine such returns each month, there are five possibilities: five of these returns are of the same sign and four are of the opposite sign, then six are of the same sign and three of the opposite sign, then seven and two, eight and one, or all nine returns are of the same sign. Therefore, the respective absolute difference in the number of these signs can be one, three, five, seven, or nine.

We run a simple non-parametric test that compares the proportions of months in the early and later period that have each of these five possible absolute differences. The insert below shows in bold the number of such differences, then the corresponding proportions of months with each difference in the early and later period. The p-values for the χ^2 test that compares each pair of proportions are in square brackets:

	1	**3**	**5**	**7**	**9**
early	0.19	0.22	0.19	0.20	0.20
later	0.19	0.13	0.18	0.27	0.23
	[0.96]	[0.02]	[0.94]	[0.10]	[0.48]

In the later period there are fewer months with smaller differences (consistent with a lower importance of global risks) and more months with larger differences (i.e., more returns of the same sign, which indicates a higher importance of local risks). These differences in proportions are statistically significant in two cases, and thus support our conclusion of a larger impact of local risks in the later period.

An additional perspective on these proportions can be gained from the same test but performed on the simulated currency returns as in Table 1. In this case the simulations representing the later period again have lower (higher) proportions of months with fewer (more) returns with the same signs, although the differences in the respective proportions are only two or three percentage points in magnitude and never statistically significant. Therefore, the actual shift in the roles of global versus local risks may in fact be even stronger than that captured by the LRV model.

In sum, the results in this section indicate that a (likely U.S.-related) shift from global to local risks underlies the changes in the currency market that we aim to explain. Such a shift can help to reproduce the observed changes in carry trade returns and the forward premium puzzle. It also explicitly points to a stronger link in the later period between exchange rates and certain (local) risk factors and is thus related to a currency "re-connect" or rise of new factors, and can be consistent with recent studies of deglobalization trends in the international economy.

4. Identifying risk factors

Being a reduced-form pricing kernel model, the LRV model can conveniently capture certain key data features, but remains silent about the identity of the global and local risks involved. This section aims to overcome this limitation and attempts to identify some of the risk factors in the model. For this purpose we rely on the structural break found in the data, and use it to discriminate among risk factors. We seek factors that change their relation to currency returns precisely around the observed break at the end of 2005 and in a manner consistent with the model's predictions for the two periods.

4.1. Constraints on risk factors

The major model-based finding so far is that in the later period the exposure of all pricing kernels to some global risk diminishes (i.e., the parameter κ in the LRV model is lower), while the exposure to local risk increases (the parameters χ and λ are higher). These parameter changes translate into changing correlations between the corresponding risk factors and the model-based exchange rates.

To illustrate this point, next we use model simulations, as those in Table 1. For each simulation, we construct the DOL returns and regress them separately on the respective u^w, u^g, and u variables that represent the two global risks and the U.S.-specific risk in the model. The average slope coefficients β and adjusted R^2's from these regressions (both in %) are:

	β (u^w)	R^2 (u^w)	β (u^g)	R^2 (u^g)	β (u)	R^2 (u)
early	0.15	0.86	0.76	17.3	0.55	16.1
later	0.16	0.74	-0.05	0.99	1.73	71.2

While u^w does not generally affect DOL returns, the differences between the two periods are very pronounced for the other two risks. For the global risk u^g, the R^2 decreases from 17% to 1%, and the beta vanishes. For the U.S.-specific local risk u, the R^2 increases from 16% to 71%, and the beta increases threefold. These changes already indicate that many standard risk variables can be ruled out as possible candidates to represent some of the risks in the model, given the extant evidence that the correlation of such variables with exchange rates in fact sharply *increases* in the later period.

For example, Lilley et al. (2020) show that equity index returns and their implied volatility, financial intermediary returns, and credit spreads have negligible explanatory power for a dollar index before the global financial crisis, but this power increases dramatically after the crisis, with R^2's of 20 to 30% or higher. None of these variables, however, can qualify for the role of a global risk in the LRV model, because neither u^w nor u^g exhibit increased explanatory power for DOL in the later period. This model-based conclusion is puzzling, since these variables are widely recognized as global risk variables (and are referred to as "common proxies of global risk appetite" in Lilley et al. (2020)).

We note that one could derive and exploit implications of the LRV model not only for DOL, but for any other (possibly dynamic) currency trade. For simplicity, and to stay close to previous related research, we use DOL returns in the following empirical investigation.

4.2. Few risk variables qualify for risk factors in the LRV model

Table 2 shows results from univariate regressions of DOL returns on several standard risk variables, expressed as percentage changes (or differences, in the case of the uncertainty variables). The top part of the table shows the data sources for these variables. The equity market indexes have been used to explain currency returns in Daniel et al. (2017), the VIX index in Koijen et al. (we include VXO before 1990), the intermediary capital risk factor in He et al. (2017), the Global financial cycle (GFC) in Jiang et al. (2019), the currency volatility in Menkhoff et al. (2012), the variance risk premium in Londono and Zhou (2017), and the commodity index CRB in Ready et al. (2017). While a number of these variables are U.S.-related, they have also been used as proxies of global risk in prior studies.

[Table 2 about here]

Table 2 first reports on regressions that are run separately for 1985–2005 and 2006–2018. These risk variables are typically unrelated to DOL before 2005, with adjusted R^2's close to zero and often insignificant regression slope coefficients. (The slope coefficients are statistically significant only for the global equity index and the global financial cycle, but they contain foreign components that are converted into U.S. dollars and hence mechanically correlate with DOL returns.)

After 2005, however, these coefficients are much larger, and the average R^2 across all variables is 30%. This shift is not only remarkably sharp, but also: (i) is robust to excluding the financial crisis (which leaves the average R^2 almost unchanged, at 27%), (ii) has motivated the notion of "exchange rate re-connect", and

(iii) presents a major new stylized fact that needs to be modeled and rationalized. Importantly, this shift implies that the variables at hand *cannot* qualify for the role of a global factor in the LRV model, because global factors lose, *not* gain, significance in the later period.

The last five columns in Table 2 show results from tests for a structural break in the relation between DOL returns and the respective risk variables, following Bai and Perron (1998 and 2003). The test employs single regressions with a matrix of regressors that is diagonally partitioned at the break point and allow the slope coefficient to change at this point.[7] The table shows the regression coefficients, R^2's, and estimated break dates, where the significance level of the break, as measured by the p-value for the supF statistic, is denoted by one, two, or three asterisks.

These break tests show that none of the breaks (with one exception) falls close to the end of 2005. A statistically significant break is estimated in all cases, but these occur typically in 2008, coinciding with the global financial crisis. Therefore, most of these variables are not likely to represent the currency market risks in our context (either global or local).

The one prominent exception in Table 2 is the OIL variable (the WTI return), with an estimated break in 08/2005, which is significant at the 1% level. OIL is then the *only* variable in this set that can qualify for the role of a risk factor in the LRV model. Furthermore, since OIL is more strongly correlated with DOL in the later period (with an R^2 of 28.7% vs. 0.6% in the early period), it can only represent the U.S.-specific risk u. This finding underpins the unique importance of oil-related risks for the currency market changes that we examine in this paper.

Addressing the puzzling lack in Table 2 of variables that qualify for a global risk factor in the LRV model, Table 3 reports results for several additional variables. These are derived from the U.S. Treasury market and include the returns of different bond indexes, changes in yields for different maturities, and a variable that represents the slope of the Treasury yield curve. (Global bond indexes are not used here, because they, again, are mechanically correlated with DOL).

[Table 3 about here]

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[7] The slope coefficient estimates from this regression are similar to those from the separate regressions for each period when the intercepts are small and/or not too different across the two periods. We report throughout results from both types of regressions to clarify the role of the intercept and show the differences in explanatory power across these periods. The results are strictly comparable when the estimated break is close to the end of 2005.

It is now seen that *all* of these U.S. Treasury-related variables have statistically significant slope coefficients in the early period (except for the short-term Treasuries). In contrast, in the later period these coefficients are much smaller and never significant. The adjusted R^2's are between 1% and 4% in the early period, while typically they are negative in the later period.

This consistent pattern in slopes and R^2's across all variables in the table indicates that some U.S. Treasury-related risk was reflected in currency returns in that period. At the same time, none of the structural break tests shows a statistically significant break (and the estimated break dates are never in 2005). Therefore, the evidence in support of a Treasury-related global risk is mixed, at best.

Finally, we have examined an additional set of variables that includes the Gilchrist-Zakrajsek credit spread, a shipping cost index (BDI), various measures of macroeconomic and policy uncertainty, growth in real variables like industrial production or unemployment (global or for the U.S.), that have been considered previously as determinants of currency returns. For each of them we run regressions as in Table 2. We typically find low statistical significance of the slope coefficients (mostly in the early period) and no significant structural break in these coefficients. Besides, none of the estimated breaks falls around the end of 2005. Therefore, these variables are not suitable as risk factors in our context, and the results are omitted.

Overall, it is hard to find risk variables that exhibit a shift in their relation with currency returns precisely toward the end of 2005. Tables 2 and 3 reveal that OIL is uniquely suitable for a risk factor consistent with the LRV model, being the only variable that exhibits individually a statistically significant structural break in its relation to DOL returns in 2005. However, can OIL indeed can represent a *U.S.-specific* (local) risk in the later period? By definition, local risks are unrelated to all other risks that affect various currencies. Given the importance of oil for any modern economy, an exclusive link between OIL and the U.S. currency or economy needs to be further justified.

4.3. OIL as a U.S.-specific risk factor

Next we replicate the regressions of DOL returns on OIL, but now take the perspectives of other, non-dollar currencies. The goal of this exercise is to verify whether the U.S. dollar is special with respect to this relation (and in particular its time variation). If many other currencies exhibit a similar relation, then an interpretation of OIL as a U.S-specific risk factor is problematic.

Table 4 compares the regression results for DOL and OIL from Table 2 to similar results for the remaining G-10 currencies. It uses “DOL analogues” – for a currency X such an analogue is a portfolio that holds with equal weights all remaining currencies (including the U.S. dollar) against currency X. The corresponding right-hand side variables are obtained by first converting the oil price from U.S. dollars into currency X and then calculating the respective oil returns denominated in X.

[Table 5 about here]

Table 4 shows that for most of the G-10 currencies the link with OIL is much weaker than for the U.S. dollar in the later period. The corresponding R^2’s are between 1% and 6%, in both periods, whereas it is 29% for the dollar in the later period. Additionally, the slope coefficients are not statistically significant is some cases, and the breaks are not significant. (The only exception here is the JPY, for which both the slope and the R^2 are larger than for the USD in both periods, but the estimated break falls only in 07/2007.) Therefore, the relation between the U.S. dollar and OIL appears to be distinct from that for the other G-10 currencies, which justifies an interpretation of OIL as a U.S.-specific risk factor.

We note also that OIL is constructed from the spot prices for WTI, which is the U.S.-specific benchmark. Although WTI is highly correlated with Brent crude, these two major benchmarks have sometimes deviated significantly in the later period. Regressing DOL returns on Brent returns, we again find stronger relation in the later period, both for the U.S. dollar and the dollar analogues, but with much smaller slope coefficient and R^2, and an insignificant estimate of the break date. This comparison further justifies the treatment of OIL as particularly related to the U.S. dollar and/or the U.S. economy, especially in the later period.

In sum, this section demonstrated that by requiring that risk factors (i) agree with the changes in currency returns that we observe at the end of 2005 and (ii) are consistent with the predictions of the LRV model over the early and later periods, we can strongly restrict the relevant risk factors and thus the possible interpretations of the empirical evidence. OIL is the only variable that emerges as a viable candidate for a U.S.-specific risk variable. We also find some (weak) evidence that a U.S. Treasury-related global risk was reflected in currency returns before 2005, but its relevance has diminished in the later period.

5. Probing further the link between exchange rates and oil

This last section elaborates further on the relation between (U.S. dollar-based) exchange rates and OIL and examines their links with other macro variables. We show that the relation between DOL returns and OIL exhibits a conspicuous asymmetry which matches the documented structural breaks and can be related to the remarkable change in the U.S. oil production and exports of petroleum products at the end of 2005. Similar asymmetry characterizes certain relations between DOL, OIL, inflation and interest rates.

We do not pursue here a detailed formalization of the interactions between OIL, exchange rates and other variables, which would lead us beyond the stylized LRV model that guides the analysis in this paper. Instead, we suggest some channels for these interactions. The reported results all involve structural breaks towards the end of 2005 and thus support our main theme that the recently observed changes in several classic currency puzzles reflect a major realignment among global macro variables that occurred in 2005.

5.1. Oil-related asymmetries

Studies in empirical macroeconomics (e.g., Loungani (1986), Mork (1989), Hamilton (2003, 2011)) have documented an asymmetric (nonlinear) relation between the oil price and the U.S. GDP growth. Specifically, they find different impact of oil price increases vs. decreases. Following this approach, we report in Table 5 results from regressing the U.S. GDP growth on OIL (Panel A.), or separately on the up- and down-moves in OIL (denoted by OIL^{+} and OIL^{-}, in Panel B.). The OIL variable is aggregated here to the quarterly frequency to match the GDP data. Consistent with prior literature, we use in these regressions either contemporaneous OIL variables, or the same variables lagged by one or two quarters.

Panel A. of Table 5 indicates a statistically stronger relation between U.S. GDP growth and the contemporaneous oil price in the later period, but the break is not significant and falls far from 2005. For lagged OIL the two periods differ less, and again no break is observed near 2005. In contrast, Panel B. shows that when splitting OIL (following prior studies), the regression results change dramatically: (i) the slope coefficients on OIL^{+} and OIL^{-} increase in magnitude and gain statistical significance, especially for the later period, (ii) the adjusted R^2 also increase, and most conspicuously in the later period (when it is about 20% for zero- and one-quarter lags in the oil variables), and (iii) the structural break is estimated at the last quarter of 2005 or first quarter of 2006, which is essential in our context. While the break estimate is not statistically significant at conventional levels, we have verified that the sums of squared residuals calculated for each possible break in the sample (which the test uses to determine the break date) have a clear global maximum in each of the three cases.

Furthermore, the slope coefficients are negative for OIL^{+} and positive for OIL^{-} (with two exceptions for statistically insignificant estimates), which implies that large moves in the oil price, *either* up or down, affect negatively the U.S. GDP growth. This non-linearity differs from those in prior studies, which find, in their sample periods, that oil price increases are much more important than oil price decreases (e.g., Hamilton (2003), but see also Kilian and Vigfusson (2011)). In Table 5, the slope coefficient estimates on OIL^{-} are all statistically significant in the later period (i.e., post-2005), and are of similar magnitude as those for OIL^{+}. The recent strong negative impact of oil price *de*creases on U.S. GDP growth is consistent with a growing importance after 2005 of the oil sector in the U.S., for which such decreases present an obvious risk (a similar argument from an earlier age is in Hamilton (1988)). However, it contrasts Blanchard and Riggi (2013), who show diminishing response of growth (and inflation) to the oil price over time.

To bring these findings closer to our exchange rate context, we also run similar regressions but for the GDP growth averaged across the other developed economies. In these regressions we use either OIL itself, or OIL adjusted for DOL returns, reflecting the fact that OIL is priced in U.S. dollars and the other economies convert its price to their own currencies. In both cases we find that the slope coefficient estimates are about twice smaller in magnitude than those in Table 5, and, importantly, the estimated breaks fall only in 2008. Therefore, if exchange rates and their changes in 2005 can be linked to a fundamental as the GDP growth, it is only growth in the U.S. that could account for such a link.

Motivated by these results, next we test for a structural break in the relation between DOL returns and the up- and down-moves in OIL and obtain the following:

	α	β_1^{+}	β_1^{-}	β_2^{+}	β_2^{-}	R^2	break
I	-0.47	0.06	-0.03	0.13	0.13	15.1	08/2005***
	[0.77]	[0.00]	[0.17]	[0.00]	[0.00]		
II	-0.62	0.05	0.03	0.12		9.2	01/2001
	[0.75]	[0.02]	[0.27]	[0.00]			
III	0.19	0.07	-0.03		0.13	13.5	06/2005***
	[0.92]	[0.00]	[0.24]		[0.00]		

As previously, α is the intercept and β_1^+ and β_1^- (β_2^+ and β_2^-) are the slope coefficient estimates for OIL^+ and OIL^- in the pre-break (post-break) period. The three test specifications differ in the regressors that are allowed to change their slope coefficient at the break point. When the slope coefficient on one of the oil variables is not allowed to change, the estimated coefficient for this variable applies for the full period and is only reported under β_1^+ or β_1^-. The intercept is not allowed to change.

The main insight from these tests is that the break in the relation between DOL returns and OIL is driven specifically by the *down*-moves in OIL (i.e., OIL^-). When the slope coefficient on OIL^- is allowed to change (specifications I and III), it is statistically insignificant in the early period, and positive and large in the later period. The estimated break point is in the second half of 2005 and significant at the 1% confidence level. In contrast, when only the slope coefficient on OIL^+ is allowed to change (specification II), then the R^2 is smaller, and the estimated break is in 01/2001 and not statistically significant.

In sum, the results discussed in this section strengthen the interpretation of OIL as a U.S.-specific risk factor which gains importance as the U.S. oil sector grows after 2005. They reveal that the change in 2005 in the relation between OIL and the dollar-based exchange rates is driven specifically by the *down*-moves in the oil price, which have turned into a major exchange rate determinant in the later period.

5.2. Further structural breaks: inflation and interest rates

With this clarification in mind, next we examine the relation between OIL or DOL returns on one hand, and the inflation differential between the U.S. and the remaining economies with the G-10 currencies on the other. Our focus on inflation differentials is natural, given the key role of purchasing power parity (PPP) in classic theories of exchange rate determination (e.g., the sticky-price monetary model of Dornbusch (1976), and the flexible-price monetary model (Frenkel (1976), Mussa (1976)) assumed either a long-run or continuous PPP). We measure inflation with CPI data from the OECD (stats.oecd.org).

We use here OIL^+ and OIL^- as separate regressors. In a similar spirit, we use DOL returns conditioned on the up- and down-moves in OIL, i.e., the regressors in this case are $DOL^+ \equiv DOL * (OIL > 0)$ and $DOL^- \equiv DOL * (OIL < 0)$. Table 6 reports regression results for (i) the oil variables alone, (ii) the interacted DOL variables alone, and (iii) the oil and DOL variables combined.

Panel A. in Table 6 shows that in the early period the explanatory power of the regressions is low

(R^2 of 1 to 3%). Besides, the slope coefficients and statistical significance remain almost the same when combining the oil and DOL variables – therefore, they impact inflation in unrelated ways. In the later period, however, the explanatory power of the oil variables alone markedly increases (R^2 of 17%). The increase is due mostly to OIL^-, as its slope coefficient estimate increases four-fold, while this estimate for OIL^+ remains insignificant. The slope coefficient on DOL^- also increases (from -0.016 to 0.04) and becomes significant, while that on DOL^+ loses significance. But most notably, the increase in explanatory power of DOL^- in the later period is fully subsumed by that of OIL^-: when combining the two types of regressors, the slope coefficient on DOL^- vanishes. This implies that the relation between U.S. dollar-based exchange rates and inflation differentials in the later period is entirely driven by the oil price.

Panel B. in Table 6 shows the structural test results for the same combinations of regressors as above. The key insight here is that in all cases the estimated break is in 10/2005 (although not statistically significant). That the conditioned DOL variables exhibit the same break as the OIL ones confirms our conclusion about the role of oil in the relation between exchange rates and inflation.

Finally, we examine in a similar manner the relation of OIL and DOL with real interest rates, which are relevant in our context, because they are a main focus of monetary policy. Namely, counteracting inflation with an increase in the real interest rate is the central implication of the Taylor rule and is incorporated in standard economic models (e.g., Nikolsko-Rzhevskyy et al. (2019)), and also, the Taylor rule is related directly to currency puzzles, as in Backus et al. (2013) among others. (For the relation between the oil price, inflation and monetary policy see also Bernanke et al. (1997) and Kilian and Lewis (2011).) Furthermore, the U.S. monetary policy has exhibited a distinct regime change in the early 2000's (e.g., Taylor (2012)), shifting away from CPI inflation in its forecasts since the mid-2000's (Mehra and Sawhney (2010), Bernanke (2015)). This shift could dovetail with the various breaks that we find in this paper, and especially with the stronger impact of the oil price on the CPI differential in the later period, as per Table 6.

Table 7 shows results similar to those in Table 6, but for the differences between the short- and long-term real interest rates in the U.S. and the economies with the remaining G-10 currencies. As with inflation, the relation between real rates and the OIL or DOL variables pre-2005 is weak, with R^2's below 0.5% and no significant slope coefficient estimates. After 2005 this relation strengthens significantly, which again is due to the explanatory power of OIL^-, which subsumes that of DOL^- when they are used together (both in separate regressions and in structural break tests). Furthermore, the break date estimate is now statistically significant for the OIL variables. We note that the results for the real interest rates mirror closely those for inflation, both in terms of coefficient estimate magnitudes and R^2's, implying that these results are largely driven by the inflation components of the real interest rates.

Among other possible interpretations, such results are consistent with the real interest rates in the U.S. in the later period being more responsive to oil price moves, compared to the rates in the remaining advanced economies. This can be tested directly by regressing the changes in an average real rate of those economies on the corresponding U.S. real rate. For the three-month rates we obtain:

pre-2005			**post-2005**			**structural break test**				
α	β	R^2	α	β	R^2	α	β_1	β_2	R^2	break
0.016	0.269	14.9	-0.042	0.191	6.9	-0.009	0.296	0.170	11.9	11/2005
[0.91]	[0.00]		[0.86]	[0.00]		[0.94]	[0.00]	[0.00]		

It is seen that the relation between the two real interest rates weakens in the later period, with the slope coefficient decreasing by a third and the R^2 decreasing from 14.9 to 6.9%. Additionally, a similar reduction in slope coefficients and R^2's is obtained if using one-, five-, or 10-year Treasury real yields instead of the three-month rates, with a statistically significant break at the end of 2005 in some cases.

These shifts are apparently driven by the inflation differentials and point to the following economic mechanism: (i) a revival in the U.S. oil sector raises the importance of the oil price (and in particular its down-moves) as a U.S.-specific risk factor in the later period, (ii) the oil price (and again its down-moves) impacts inflation in the U.S. significantly more than in the remaining economies, and (iii) this oil-driven inflation differential increases the deviation between real interest rates in the U.S. and the remaining economies. Although this is only a sketch for an economic mechanism, it is appealing because each of its elements is supported with evidence for a statistically significant break in the relation between the respective variables precisely at the end of 2005, and each element can be related to the currency market changes in 2005 that we aim to explain. We reiterate that breaks that fall within a particular short period raise significantly the bar to the empirical verification of any model or economic interpretation – for example, recall Tables 2 and 3, which showed that no standard risk variable, with the single exception of OIL, can deliver a break in 2005.

6. Conclusion

This paper argues that reversals in several long-standing currency puzzles that have been documented in recent years share common roots and can be traced to changes that occurred around 2005 in the U.S. economy, and especially the U.S. oil sector. Our conclusions are based on formal tests for structural breaks and in particular on the concurrent breaks that we find in different markets.

We rationalize the empirical evidence from the currency market using the LRV model, which we modify to reflect essential differences between the pre-2005 and post-2005 periods. The modifications include lower exposure of all economies to some global risk and higher exposure to local risks in the later period. Furthermore, we search explicitly for the global and local risks that drive the observed changes in the currency market, guided by model-based insights and the structural breaks in the data. We find that many standard risk variables cannot serve as currency risk factors, except for oil returns, and, possibly, some U.S. Treasury-related variables.

Our results pose new challenges to currency research and highlight the limitations of the traditional unconditional approach to studying currency returns and risks (including a number of studies that have adapted the original LRV model in different settings). Our findings can also have implications for the more general debate on the global role of the U.S. dollar and can motivate rigorous modeling efforts that go significantly beyond the analytical framework used in this paper.

In particular, the last Section 5 has offered further insights into the economic underpinnings of the observed currency market changes. Accommodating these insights may require various departures from the parsimony of the LRV model. For example, some links between OIL, interest rates, and inflation (and possibly one of the global factors) can be formalized following Backus et al. (2013), who explain the forward premium puzzle relying on a Taylor rule for the nominal interest rates, where inflation arises endogenously in equilibrium. Such a link to U.S. monetary policy and its global spillovers can be key in addressing the challenging interplay between local and global risks that are examined in this paper.

Appendix

A. The LRV model

Following the notation in Lustig et al. (2014), the model is given by:

$$\begin{aligned}
-m^i_{t+1} &= \alpha+\chi z^i_t+\sqrt{\gamma z^i_t}u^i_{t+1}+\tau z^w_t+\sqrt{\delta^i z^w_t}u^w_{t+1}+\sqrt{\kappa z^i_t}u^g_{t+1}, \qquad \text{(economy } i\text{)} && \text{(A-1)}\\
-m_{t+1} &= \alpha+\chi z_t+\sqrt{\gamma z_t}u_{t+1}+\tau z^w_t+\sqrt{\delta z^w_t}u^w_{t+1}+\sqrt{\kappa z_t}u^g_{t+1}, \qquad \text{(the U.S.)}\\
z^i_{t+1} &= (1-\phi)\theta^n+\phi z^i_t-\sigma\sqrt{z^i_t}u^i_{t+1} \qquad \text{and} \qquad z_{t+1}=(1-\phi)\theta+\phi z_t-\sigma\sqrt{z_t}u_{t+1},\\
z^w_{t+1} &= (1-\phi^w)\theta^w+\phi^w z^w_t-\sigma^w\sqrt{z^w_t}u^w_{t+1},
\end{aligned}$$

where m^i and m are the log pricing kernels of economy i and the U.S., and z^i, z and z^w are state variables. Superscript i denotes variables for different economies, except for the respective U.S. variables, which have no superscript. The shocks (or risks) u^i, u^w, and u^g are all independent standard normal variables. We allow the U.S. parameter θ to differ from θ^n which is common for all the remaining economies. All parameters are positive and the parameter δ for the U.S. takes the average value of the δ^i's.[8]

The (continuously compounded) interest rates r^i_t and r_t in this model are:

$$\begin{aligned}
r^i_t &= -E_t[m^i_{t+1}]-\frac{1}{2}Var_t[m^i_{t+1}]=\alpha+\left(\tau-\frac{1}{2}\delta^i\right)z^w_t-\left(\frac{1}{2}(\gamma+\kappa)-\chi\right)z^i_t && \text{(A-2)}\\
r_t &= \alpha+\left(\tau-\frac{1}{2}\delta\right)z^w_t-\left(\frac{1}{2}(\gamma+\kappa)-\chi\right)z_t. && \text{(A-3)}
\end{aligned}$$

Then, the interest rate differentials rd^i_t, spot exchange rate changes sx^i_{t+1}, and currency excess returns rx^i_{t+1} (of currency i against the U.S. dollar and in log form) are as given in equations (1) - (3) in the text, and reproduced below:

$$\begin{aligned}
rd^i_t &= r^i_t-r_t=-\frac{1}{2}\left(\delta^i-\delta\right)z^w_t-\left(\frac{1}{2}(\gamma+\kappa)-\chi\right)(z^i_t-z_t) && \text{(A-4)}\\
sx^i_{t+1} &= -m_{t+1}+m^i_{t+1}=-\chi(z^i_t-z_t)\\
&\quad -\sqrt{\gamma}\left(\sqrt{z^i_t}u^i_{t+1}-\sqrt{z_t}u_{t+1}\right)-\left(\sqrt{\delta^i}-\sqrt{\delta}\right)\sqrt{z^w_t}u^w_{t+1}-\sqrt{\kappa}\left(\sqrt{z^i_t}-\sqrt{z_t}\right)u^g_{t+1} && \text{(A-5)}\\
rx^i_{t+1} &= rd^i_t+sx^i_{t+1}=-\frac{1}{2}(\delta^i-\delta)z^w_t-\frac{1}{2}(\gamma+\kappa)(z^i_t-z_t)\\
&\quad -\sqrt{\gamma}\left(\sqrt{z^i_t}u^i_{t+1}-\sqrt{z_t}u_{t+1}\right)-\left(\sqrt{\delta^i}-\sqrt{\delta}\right)\sqrt{z^w_t}u^w_{t+1}-\sqrt{\kappa}\left(\sqrt{z^i_t}-\sqrt{z_t}\right)u^g_{t+1}. && \text{(A-6)}
\end{aligned}$$

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[8] Similar to Mueller, Stathopoulos, and Vedolin (2017, Section 5.1), we treat the m^i's and m in (A-1) as nominal pricing kernels, because inflation risk is not priced, and all economies share the same expected inflation rates.

If an over-bar denotes an average across all currencies except for the U.S. dollar, the cross-sectional average interest rate differential of the U.S. dollar (which in the model equals the AFD) is:

$$\overline{r_t^i} - r_t = AFD_t = -\frac{1}{2}\underbrace{(\overline{\delta^i} - \delta)}_{=0} z_t^w - \left(\frac{1}{2}(\gamma + \kappa) - \chi\right)(\overline{z_t^i} - z_t). \tag{A-7}$$

From equations (A-5) and (A-6), the average cross-sectional change in the exchange rates against the U.S. dollar (denoted FX) and the return of the DOL trade (which is just the sum of AFD and FX) are:

$$\begin{aligned} FX_{t+1} &= -\chi(\overline{z_t^i} - z_t) - \sqrt{\gamma}\left(\overline{\sqrt{z_t^i}u_{t+1}^i} - \sqrt{z_t}u_{t+1}\right) - \left(\overline{\sqrt{\delta_t^i}} - \sqrt{\delta}\right)\sqrt{z_t^w}u_{t+1}^w - \sqrt{\kappa}\left(\overline{\sqrt{z_t^i}} - \sqrt{z_t}\right)u_{t+1}^g \quad \text{(A-8)} \\ DOL_{t+1} &= -\frac{\gamma + \kappa}{2}(\overline{z_t^i} - z_t) - \sqrt{\gamma}\left(\overline{\sqrt{z_t^i}u_{t+1}^i} - \sqrt{z_t}u_{t+1}\right) - \left(\overline{\sqrt{\delta_t^i}} - \sqrt{\delta}\right)\sqrt{z_t^w}u_{t+1}^w - \sqrt{\kappa}\left(\overline{\sqrt{z_t^i}} - \sqrt{z_t}\right)u_{t+1}^g. \end{aligned}$$

Finally, from equations (A-7) and (A-8) the (unconditional) expectations of AFD and FX are:

$$\mathbb{E}[AFD_t] = -\left(\frac{1}{2}(\gamma + \kappa) - \chi\right)(\theta^n - \theta) \qquad \text{and} \qquad \mathbb{E}[FX_{t+1}] = -\chi(\theta^n - \theta). \tag{A-9}$$

B. Model calibration

Note first that the average values of AFD and FX are available in closed form as in equation (A-9), while the UIP slope coefficient is given in equation (4) in the text. Next we note from equation (A-8) that two terms have little impact on the variance of DOL: the contribution to var_{DOL} of the first term in this equation is approximately equal to the variance of z_t and that of the third term reflects the convexity correction for the square root of the deltas. We have verified that both of these contributions are much smaller than the contributions of the remaining two terms in our context, and this is also consistent with the calibration in Lustig et al. (2014). On the other hand, the variance of the second term in DOL is approximately equal to $\gamma\theta$, assuming that the number of currencies is sufficiently large. Finally, the variance of the last term is approximately equal to $\kappa(A^2 + \theta - 2AB)$, where $A = \sqrt{\theta^n} - \sigma^2/(16(1-\phi)\sqrt{\theta^n})$ and $B = \sqrt{\theta} - \sigma^2/(16(1-\phi)\sqrt{\theta})$, using the approximation to the expectation of a square root of a random variable as in Brockhaus and Long (2000).

It is important to note that in the expression for var_{DOL}, γ and κ are multiplied by *different* constants, which allows us to calibrate these parameters separately (in contrast, the expressions for the expected AFD and the UIP slope coefficient in equations (A-9) and (4) include the term $(\gamma + \kappa)$, and hence do not allow for such a separation). For this reason, we force the calibration to reproduce precisely var_{DOL}, by assigning a large weight to it (10 times bigger than the other weights). Furthermore, $\sqrt{\theta^n}$ and $\sqrt{\theta^n}$ in A and B above are two orders of magnitude larger than the remaining terms, both in Lustig et al. (2014) and as per our calibration; hence, $(A^2 + \theta - 2AB) \ll \theta$. Since the expression for var_{DOL} contains $\gamma\theta$ and $\kappa(A^2 + \theta - 2AB)$, both of these terms will be important only if γ is much smaller than κ. This is consistent with the calibrated values of γ and κ and our intuition that it is the interplay between κ and χ in equation (4) that determines the sign of the UIP slope coefficient.

The average returns of the static and dynamic components of the U.S. dollar-based carry trade are not available analytically but can be obtained numerically in an efficient way. For this purpose we note that the (stationary) distributions of z_t^w, z_t^i and z_t are gamma, but with large shape parameters (above 40) and small scale parameters, both in the original calibration of the LRV model and in our version. Therefore, these distributions are approximately normal. Assuming a joint normal distribution for these state variables, we find numerically the range of their values, which jointly yield positive or negative interest rate differentials, as per equation (A-4), and thus determine the long and short positions for each currency. Finally, we apply these positions to the returns from equation (A-6) to calculate numerically the expected returns of the dollar-based carry trade and its components.

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Table 1

Model calibrations for two periods

This table shows results from calibrating the LRV model to target moments from the early and later periods (i.e., 1985-2005 and 2006-2018). As in Section 2.1, the target moments are: the average returns of the static and dynamic components of the dollar-based carry trade (denoted by STA and DYN), the average of the interest differential of all G-10 currencies against the U.S. dollar (denoted by AFD), the average change in the exchange rates of these currencies against the dollar (denoted by FX), the return variance of the DOL portfolio which holds all currencies long against the dollar, and the slope coefficient from regressing FX on AFD (denoted by UIP slope). The first four moments are shown annualized and in percent. The table shows also the return of the standard carry trade (denoted by SC, and shown annualized and in percent), as well as its annualized Sharpe ratio, which, however, are not used as target moments.

We keep as in Lustig et al. (2014, Table 5) the following parameters:

α	τ	ϕ^w	θ^w	σ^w (%)	ϕ	σ (%)
0.018	0.06	0.99	0.02	0.28	0.91	0.68

The δ^i's range between 0.2 and 0.7, and the economy with the middle value of the δ^i's represents the U.S. The parameters that we estimate separately for each period are κ, χ, and γ. We estimate one θ^n for both periods and a separate θ for the early period, while for the later period we assume that $\theta = \theta^n$. Together with each target moment, we show the corresponding quantity obtained from simulating the model using the estimated parameters. We show averages from 1,000 simulations. Each simulation represents 11 economies, for which we generate time series of interest rate differentials, exchange rate changes and currency excess returns as per equations (1), (2), and (3). Each series is of length 500, similar to our monthly data series.

A. Estimated parameters

	κ	χ	γ (in %)	θ^n (in %)	θ (in %)
early	3.69	1.19	0.41	1.53	1.66
later	1.39	1.30	2.38	1.53	1.53

B. Target moments and simulations with the estimated parameters

		STA	DYN	AFD	FX	var_{DOL}	UIP slope	SC	Sharpe
early	target	1.8	2.9	1.1	1.6	0.45	1.8	3.0	0.67
	sim.	1.9	3.0	0.8	1.5	0.44	1.9	5.1	0.69
later	target	0.5	-0.5	0.0	0.0	0.55	-2.2	0.5	0.15
	sim.	0.5	-0.6	0.0	0.0	0.51	-2.4	0.8	0.11

Table 2

DOL vs. various risk variables

DOL represents a portfolio of equally weighted long positions in the G-10 currencies against the U.S. dollar (see Section 2). We regress monthly DOL returns on each of the following variables:

	abbrev.	availability	data source
MSCI-US Equity return index	US Eqty	01/1985 to 12/2018	Datastream
MSCI-WORLD Equity return index	Glob Eqty	— ” —	— ” —
VIX	VIX	01/1986 to 12/2018	CBOE
Intermediary capital risk factor	ICR	01/1985 to 12/2018	He et al. (2017)
Global financial cycle	GFC	— ” —	M.-Agrippino and Rey (2020)
Global currency volatility	FXV	— ” —	Menkhoff et al. (2012)
Variance risk premium	VRP	01/1990 to 12/2017	Bollerslev et al. (2009)
Financial uncertainty measure (1 month)	FINU	01/1985 to 12/2018	Jurado et al. (2015)
CRB commodity price index	CRB	— ” —	Datastream
WTI spot price	OIL	— ” —	— ” —

The intercepts (α) are annualized and in percent, β denotes the slope coefficients, p-values are in square brackets. The first six columns show results from separate regressions for 1985–2005 and 2006–2018. The last five columns show results from tests for a single structural break in the slope coefficient, as in Bai and Perron (1998 and 2003), where β_1 and β_2 are the slope coefficients before and after the estimated break. The month of the estimated break is shown in the last column. One, two or three asterisks indicate a supF test statistic that is significant at the 10% or 5% or 1% confidence level.

	pre-2005			**post-2005**			**structural break test**				
	α	β	R^2	α	β	R^2	α	β_1	β_2	R^2	break
US Eqty	3.29	0	-0.4	-2.26	0.31	32.3	1.11	0.01	0.33	14.9	08/2008***
	[0.04]	[0.90]		[0.21]	[0.00]		[0.35]	[0.82]	[0.00]		
Glob. eqty	1.62	0.13	7.4	-2	0.35	46.2	0.27	0.14	0.37	25.4	06/2008***
	[0.28]	[0.00]		[0.21]	[0.00]		[0.81]	[0.00]	[0.00]		
VIX	2.65	0.01	-0.4	0.61	-0.23	23.0	1.79	0.01	-0.25	12.6	08/2008***
	[0.08]	[0.75]		[0.75]	[0.00]		[0.12]	[0.63]	[0.00]		
ICR	3.49	-0.03	0.6	0.43	0.14	16.3	2.01	-0.03	0.16	9.9	09/2008***
	[0.02]	[0.11]		[0.83]	[0.00]		[0.09]	[0.14]	[0.00]		
GFC	2.82	0.04	5.7	1.62	0.08	48.4	2.12	0.05	0.1	25.7	04/2009***
	[0.06]	[0.00]		[0.29]	[0.00]		[0.05]	[0.00]	[0.00]		
FXV	3.23	-0.03	-0.2	2.24	-0.26	39.9	2.50	0.05	-0.26	20.8	03/2000***
	[0.03]	[0.46]		[0.20]	[0.00]		[0.03]	[0.24]	[0.00]		
VRP	1.64	-0.01	-0.5	7.59	-0.38	16.9	6.85	-0.21	-0.81	10.5	08/2011***
	[0.47]	[0.88]		[0.00]	[0.00]		[0.00]	[0.00]	[0.00]		
FINU	3.24	0	-0.4	1	-0.21	9.5	2.08	0.01	-0.27	6.1	06/2008***
	[0.03]	[0.99]		[0.62]	[0.00]		[0.09]	[0.84]	[0.00]		
CRB	3.13	0.11	1.0	-0.93	0.44	41.5	1.19	0.03	0.44	20.4	04/2002***
	[0.04]	[0.07]		[0.57]	[0.00]		[0.28]	[0.65]	[0.00]		
OIL	3.04	0.02	0.6	0	0.13	28.7	1.88	0.02	0.13	13.4	08/2005***
	[0.04]	[0.11]		[1.00]	[0.00]		[0.11]	[0.13]	[0.00]		

Table 3

DOL vs. U.S. Treasury market variables

In the format of Table 2, this table shows results from regressing DOL returns on U.S. Treasury market variables before and after 2005, and the corresponding tests for a single structural break in the slope coefficient over 1985-2018. The variables are the monthly returns of Barclay's U.S. Treasury Bond index (denoted by US Tsry) and US Tsry short-term, intermediate and long-term U.S. Treasury bonds, with data from Bloomberg, as well as the changes in the 3-month, 1-year, 5-year and 10-year constant maturity Treasury yields, and the differences between the 10-year and 3-month yields (Fed data). The α and β estimates are as in Table 2. The break test is as in Bai and Perron (1998 and 2003), and the month of the estimated break is shown in the last column of the table. One, two, or three asterisks indicate a supF test statistic that is significant at the 10%, 5% or 1% confidence levels, respectively.

	pre-2005			**post-2005**			**structural break test**				
	α	β	R^2	α	β	R^2	α	β_1	β_2	R^2	break
US Tsry	1.36	0.23	2.5	0.43	-0.02	-0.6	1.00	0.25	-0.32	2.9	12/2009
	[0.41]	[0.01]		[0.85]	[0.92]		[0.45]	[0.00]	[0.15]		
Short Tsry	3.05	-0.35	-0.3	-0.9	0.96	-0.2	2.14	-0.07	-4.75	1.06	03/2008
	[0.37]	[0.58]		[0.73]	[0.41]		[0.37]	[0.89]	[0.19]		
Int. Tsry	0.42	0.39	3.4	0.09	0.09	-0.5	0.34	0.55	0.16	2.9	11/1992
	[0.81]	[0.00]		[0.97]	[0.67]		[0.80]	[0.00]	[0.26]		
Long Tsry	2.24	0.10	1.3	0.78	-0.06	0.2	1.54	0.12	-0.17	3.8	03/2009
	[0.15]	[0.04]		[0.72]	[0.25]		[0.23]	[0.02]	[0.02]		
3m yld	3.05	-0.99	1.2	0.44	0.53	-0.4	2.69	-0.38	-9.25	2.4	12/2008
	[0.04]	[0.04]		[0.84]	[0.56]		[0.03]	[0.42]	[0.00]		
1yr yld	3.01	-1.02	1.8	0.28	-0.7	-0.3	2.34	-0.71	-7.24	3.76	11/2008
	[0.05]	[0.02]		[0.90]	[0.49]		[0.06]	[0.09]	[0.00]		
5yr yld	2.87	-1.15	3.5	0.35	-0.16	-0.6	1.87	-1.18	0.24	2.5	04/2008
	[0.05]	[0.00]		[0.87]	[0.83]		[0.13]	[0.00]	[0.82]		
10yr yld	2.88	-1.03	2.3	0.43	0.40	-0.5	1.85	-1.13	1.73	2.9	03/2009
	[0.05]	[0.01]		[0.84]	[0.59]		[0.13]	[0.01]	[0.11]		
10y–3m yld	-3.19	0.31	2.7	2.19	-0.08	-0.5	-1.79	0.5	0.12	2.6	01/1991
	[0.24]	[0.00]		[0.61]	[0.62]		[0.41]	[0.00]	[0.21]		

Table 4

DOL analogues vs. OIL – other currency perspectives

The first two lines in this table reproduce the results from regressing DOL returns on OIL in the early and later periods from Table 2, and in the same format. The rest of the table shows similar results, but for the analogues of DOL, constructed from the perspective of each G-10 currency (as shown in the first column), and regressed on oil returns as seen from the perspective of the same currency. The "DOL analogue" constructed from the perspective of currency X is a portfolio that holds with equal weights all remaining currencies (including the U.S. dollar) against currency X. Furthermore, the oil price in U.S. dollars is converted into currency X, and the respective returns, denominated in X, are used as the regressor.

	pre-2005			**post-2005**			**structural break test**				
	α	β	R^2	α	β	R^2	α	β_1	β_2	R^2	break
USD	3.04	0.02	0.6	0	0.13	28.7	1.88	0.02	0.13	13.4	08/2005***
	[0.04]	[0.11]		[1.00]	[0.00]		[0.11]	[0.13]	[0.00]		
NZD	-3.78	0.06	4.7	-1.96	0.08	6.1	-3.01	0.05	0.11	6.2	05/2012*
	[0.04]	[0.00]		[0.41]	[0.00]		[0.04]	[0.00]	[0.00]		
AUD	0.25	0.04	1.4	-1.57	0	-0.6	-0.27	0.05	0	1.9	12/1998
	[0.91]	[0.03]		[0.45]	[1.00]		[0.86]	[0.05]	[0.90]		
NOK	-1.16	0.03	2.9	1.71	-0.06	4.9	-0.06	0.03	-0.06	4.2	02/2006
	[0.34]	[0.00]		[0.31]	[0.00]		[0.95]	[0.02]	[0.01]		
GBP	-1.65	0.05	5.7	2.54	0.02	-0.1	-0.08	0.05	0.01	4.0	02/2008
	[0.24]	[0.00]		[0.19]	[0.36]		[0.94]	[0.00]	[0.69]		
SEK	0.05	0.04	3.9	1.25	0	-0.6	0.63	0.05	0.01	3.1	12/1995
	[0.97]	[0.00]		[0.44]	[0.77]		[0.54]	[0.01]	[0.25]		
CAD	1.39	0.02	0.3	1.44	0	-0.6	1.33	0.02	-0.02	1.1	09/2008
	[0.37]	[0.20]		[0.42]	[0.90]		[0.26]	[0.07]	[0.25]		
EUR	0.27	0.05	7.9	0.91	0.03	1.7	0.57	0.05	0.02	6.7	09/2001
	[0.82]	[0.00]		[0.49]	[0.06]		[0.53]	[0.00]	[0.05]		
CHF	1.33	0.06	9.9	-0.8	0.08	13.6	0.41	0.05	0.08	12.1	02/1991
	[0.35]	[0.00]		[0.64]	[0.00]		[0.71]	[0.03]	[0.00]		
JPY	2.2	0.07	7.5	0.64	0.21	42.7	1.71	0.07	0.21	24.5	07/2007***
	[0.24]	[0.00]		[0.77]	[0.00]		[0.24]	[0.00]	[0.00]		

Table 5

U.S. GDP growth vs. OIL

In the format of Table 2, Panel A. shows results from regressing U.S. GDP growth on OIL (aggregated quarterly), where the oil variable is contemporaneous, or lagged by one or two quarters. Panel B. shows results from similar regressions, but now the regressors are $OIL^+ = \max(OIL, 0)$ and $OIL^- = \min(OIL, 0)$ (again aggregated quarterly). As before, β_1 and β_2 denote coefficients for the pre- and post-break period.

A. U.S. GDP vs. OIL

	pre-2005			**post-2005**			**structural break test**				
	α	β^{OIL}	R^2	α	β^{OIL}	R^2	α	β_1^{OIL}	β_2^{OIL}	R^2	break
no lag	3.16	0.002	-0.4	1.67	0.011	11.4	2.53	0.000	0.012	8.4	12/1998
	[0.00]	[0.43]		[0.00]	[0.01]		[0.00]	[0.99]	[0.06]		
1 lag	3.23	-0.003	0.3	1.58	0.007	3.0	2.65	-0.004	0.012	6.3	06/2008
	[0.00]	[0.27]		[0.00]	[0.12]		[0.00]	[0.31]	[0.13]		
2 lags	3.19	-0.002	-0.7	1.65	-0.001	-2.0	2.64	-0.004	0.006	2.8	06/2008
	[0.00]	[0.50]		[0.00]	[0.89]		[0.00]	[0.23]	[0.19]		

B. U.S. GDP vs. OIL$^+$ and OIL$^-$

	pre-2005				**post-2005**				**structural break test**						
	α	β^{OIL^+}	β^{OIL^-}	R^2	α	β^{OIL^+}	β^{OIL^-}	R^2	α	$\beta_1^{OIL^+}$	$\beta_1^{OIL^-}$	$\beta_2^{OIL^+}$	$\beta_2^{OIL^-}$	R^2	break
no lag	3.32	0.000	0.006	-0.8	2.56	-0.009	0.022	19.3	3.09	0.002	0.004	-0.017	0.025	19.6	03/2006
	[0.00]	[0.91]	[0.26]		[0.00]	[0.34]	[0.00]		[0.00]	[0.77]	[0.58]	[0.01]	[0.00]		
1 lag	3.75	-0.012	0.009	8.0	2.78	-0.02	0.023	19.6	3.45	-0.009	0.006	-0.029	0.027	23.4	12/2005
	[0.00]	[0.01]	[0.10]		[0.00]	[0.03]	[0.00]		[0.00]	[0.10]	[0.14]	[0.00]	[0.00]		
2 lags	3.30	-0.004	0.001	-1.5	2.54	-0.02	0.011	5.5	3.08	-0.002	-0.002	-0.027	0.015	13.8	12/2005
	[0.00]	[0.39]	[0.92]		[0.00]	[0.05]	[0.12]		[0.00]	[0.77]	[0.63]	[0.07]	[0.02]		

Table 6

Inflation differentials vs. OIL and DOL variables

Panel A. shows results from regressing the difference between the U.S. CPI and the average CPI in the remaining G-10 economies on various combinations of the following variables: (i) $OIL^{+} = \max(OIL, 0)$ and $OIL^{-} = \min(OIL, 0)$, as in Table 5, and (ii) $DOL^{+} \equiv DOL * (OIL > 0)$ and $DOL^{-} \equiv DOL * (OIL < 0)$. The corresponding regression coefficients are denoted $\beta^{OIL^{+}}$, $\beta^{OIL^{-}}$, $\beta^{DOL^{+}}$ and $\beta^{DOL^{-}}$. The regressions are run separately for the pre- and post-2005 periods. Panel B. shows results from structural break tests for the same variables and variable combinations as in Panel A. The test results are reported in the format of Table 2, and subscripts 1 and 2 denote again regression coefficients (betas) for the pre- and post-break period. The CPI data is from stats.oecd.org.

A. Regressions for two periods

pre-2005						**post-2005**					
α	$\beta^{OIL^{+}}$	$\beta^{OIL^{-}}$	$\beta^{DOL^{+}}$	$\beta^{DOL^{-}}$	R^2	α	$\beta^{OIL^{+}}$	$\beta^{OIL^{-}}$	$\beta^{DOL^{+}}$	$\beta^{DOL^{-}}$	R^2
0.54	-0.001	0.007			1.6	1.75	-0.006	0.027			17.0
[0.03]	[0.76]	[0.02]				[0.00]	[0.24]	[0.00]			
0.30			-0.017	-0.016	1.8	0.53			0.006	0.040	3.3
[0.09]			[0.05]	[0.08]		[0.11]			[0.70]	[0.01]	
0.53	0.000	0.006	-0.019	-0.013	3.4	1.75	-0.007	0.027	0.003	-0.001	15.9
[0.03]	[0.84]	[0.03]	[0.03]	[0.16]		[0.00]	[0.27]	[0.00]	[0.85]	[0.96]	

B. Structural break tests

α	$\beta_1^{OIL^{+}}$	$\beta_1^{OIL^{-}}$	$\beta_1^{DOL^{+}}$	$\beta_1^{DOL^{-}}$	$\beta_2^{OIL^{+}}$	$\beta_2^{OIL^{-}}$	$\beta_2^{DOL^{+}}$	$\beta_2^{DOL^{-}}$	R^2	break
0.95	-0.003	0.009			-0.001	0.022			10.1	10/2005
[0.00]	[0.28]	[0.00]			[0.86]	[0.00]				
0.39			-0.018	-0.019			0.008	0.04	4.1	10/2005
[0.01]			[0.05]	[0.02]			[0.46]	[0.07]		
0.95	-0.002	0.009	-0.021	-0.015	-0.001	0.021	0.003	0.003	11.4	10/2005
[0.00]	[0.51]	[0.00]	[0.02]	[0.05]	[0.81]	[0.00]	[0.83]	[0.86]		

Table 7

Interest rate differentials vs. OIL and DOL variables

In the format of Table 6, this table shows results for (i) the difference between the short-term real interest rate in the U.S. and the average short-term real interest rate in the remaining G-10 economies (measured by the three-month Treasury yields or equivalent), and (ii) the same difference for long-term real interest rates (10-year Treasury yields or equivalent). The interest rate data is from Jonathan Wright's website and Bloomberg.

A. Regressions for two periods

pre-2005						post-2005					
α	β^{OIL^+}	β^{OIL^-}	β^{DOL^+}	β^{DOL^-}	R^2	α	β^{OIL^+}	β^{OIL^-}	β^{DOL^+}	β^{DOL^-}	R^2
Real short-term interest rates											
-1.94	0	-0.004			0.1	-1.95	0.004	-0.024			12.9
[0.00]	[0.93]	[0.18]				[0.00]	[0.43]	[0.00]			
-1.79			0.004	-0.011	-0.3	-0.85			-0.013	-0.029	1.6
[0.00]			[0.65]	[0.28]		[0.01]			[0.42]	[0.06]	
-1.97	0	-0.005	0.006	-0.013	0.1	-2.00	0.006	-0.026	-0.01	0.009	12.1
[0.00]	[0.87]	[0.13]	[0.51]	[0.20]		[0.00]	[0.32]	[0.00]	[0.56]	[0.59]	
Real long-term interest rates											
-0.50	-0.001	-0.003			0.1	-1.32	0.006	-0.028			17.6
[0.05]	[0.73]	[0.23]				[0.01]	[0.27]	[0.00]			
-0.45			0.013	-0.001	0.1	-0.06			-0.012	-0.04	3.5
[0.01]			[0.14]	[0.93]		[0.86]			[0.47]	[0.01]	
-0.52	-0.002	-0.004	0.016	-0.003	0.5	-1.35	0.007	-0.028	-0.009	0.002	16.7
[0.04]	[0.49]	[0.21]	[0.08]	[0.78]		[0.01]	[0.22]	[0.00]	[0.58]	[0.88]	

B. Structural break tests

α	$\beta_1^{OIL^+}$	$\beta_1^{OIL^-}$	$\beta_1^{DOL^+}$	$\beta_1^{DOL^-}$	$\beta_2^{OIL^+}$	$\beta_2^{OIL^-}$	$\beta_2^{DOL^+}$	$\beta_2^{DOL^-}$	R^2	break
Real short-term interest rates										
-1.96	0	-0.004			0.005	-0.024			10.5	09/2005**
[0.00]	[0.90]	[0.21]			[0.15]	[0.00]				
-1.47			0.002	-0.009			-0.005	-0.039	2.4	09/2005
[0.00]			[0.84]	[0.41]			[0.62]	[0.05]		
-1.99	-0.001	-0.004	0.007	-0.011	0.007	-0.026	-0.012	0.007	10.9	09/2005
[0.00]	[0.83]	[0.15]	[0.44]	[0.30]	[0.09]	[0.00]	[0.34]	[0.71]		
Real long-term interest rates										
-0.79	0.001	-0.005			0.002	-0.024			11.2	10/2005*
[0.00]	[0.85]	[0.08]			[0.47]	[0.00]				
-0.32			0.012	0.001			-0.008	-0.045	3.6	09/2005
[0.05]			[0.17]	[0.89]			[0.41]	[0.05]		
-0.81	0	-0.005	0.017	-0.001	0.004	-0.024	-0.01	-0.001	11.9	10/2005
[0.00]	[0.89]	[0.07]	[0.07]	[0.90]	[0.30]	[0.00]	[0.41]	[0.95]		

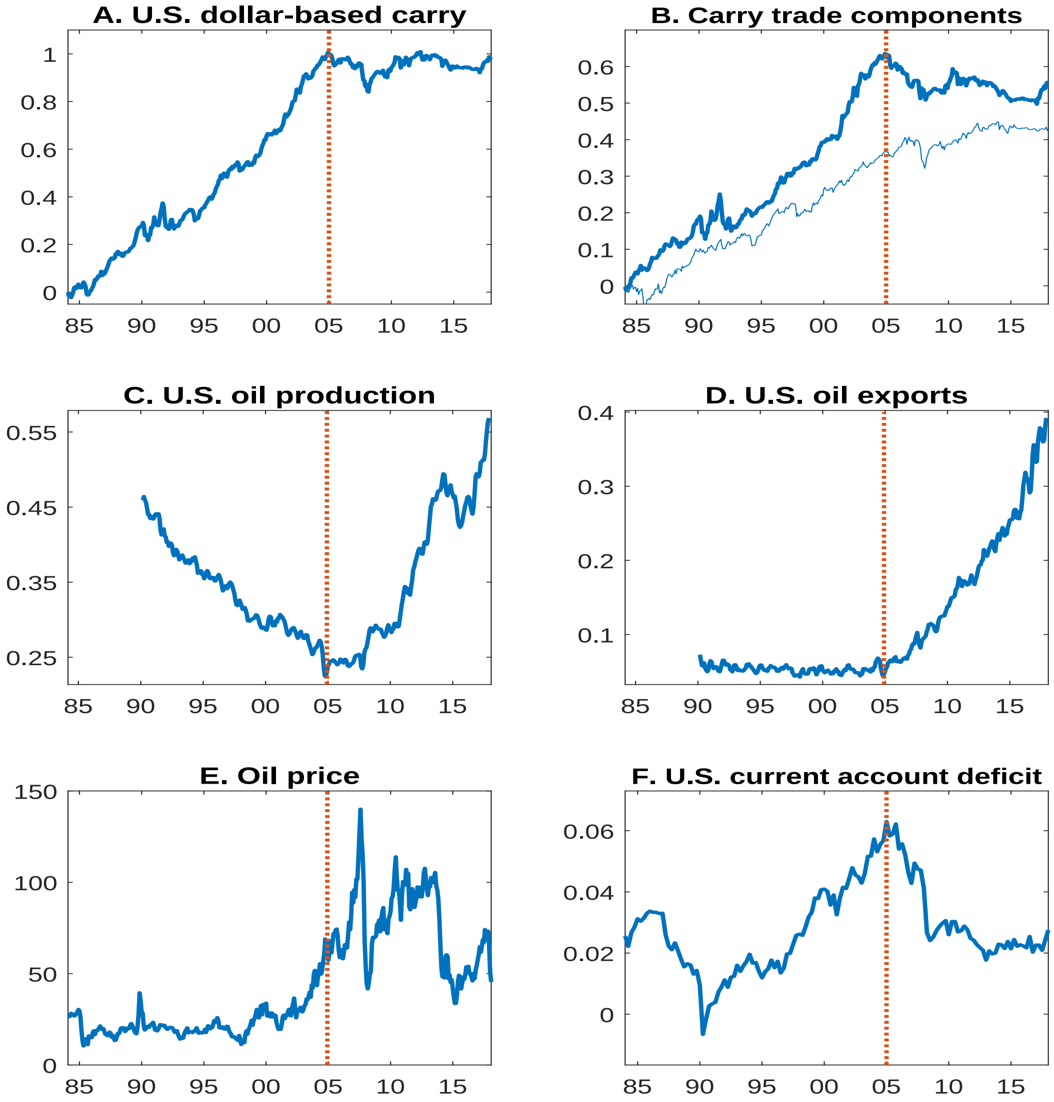

Figure 1. **Currency trade returns and U.S. oil production and exports**
Panel A shows the cumulative monthly returns of the U.S. dollar-based carry trade which goes long (short) against the USD, with equal weights, the G-10 currencies that have a positive (negative) forward differential against the USD. Panel B shows with a thin line the cumulative returns of this trade that are due to the four currencies with the highest and lowest (on average) forward differentials (tickers NZD, AUD, CHF, and JPY). The thick line shows the return component due to the remaining G-10 currencies (NOK, GBP, SEK, CAD, and EUR). The two components add up to the total return of the trade in Panel A. The data is from Barclays Bank, via Datastream, and Bloomberg. Panel C plots the U.S. field production of crude oil, scaled by the U.S. consumption of petroleum products (measured as the four-week average supply of petroleum products, which is available since 12/1990). Panel D shows the U.S. exports of crude oil and petroleum products, in thousand barrels per day and again scaled by the U.S. oil consumption. In Panels C and D, the respective variable is shown as a three-month moving average of the raw data, to account for the strong seasonal patterns in these variables, and the data source is the Energy Administration Agency (www.eia.gov/petroleum/data.php). Panel E plots the monthly time series of the WTI spot price (from which the OIL variable is derived), and Panel F shows the U.S. current account deficit as a percentage of the U.S. GDP (quarterly data from www.stats.oecd.org), where larger positive numbers denote larger deficit. In all plots the sample period is 01/1985–12/2018. On the horizontal axis are marked the ends of the respective years, and a vertical dashed line in each plot marks the end of 2005.

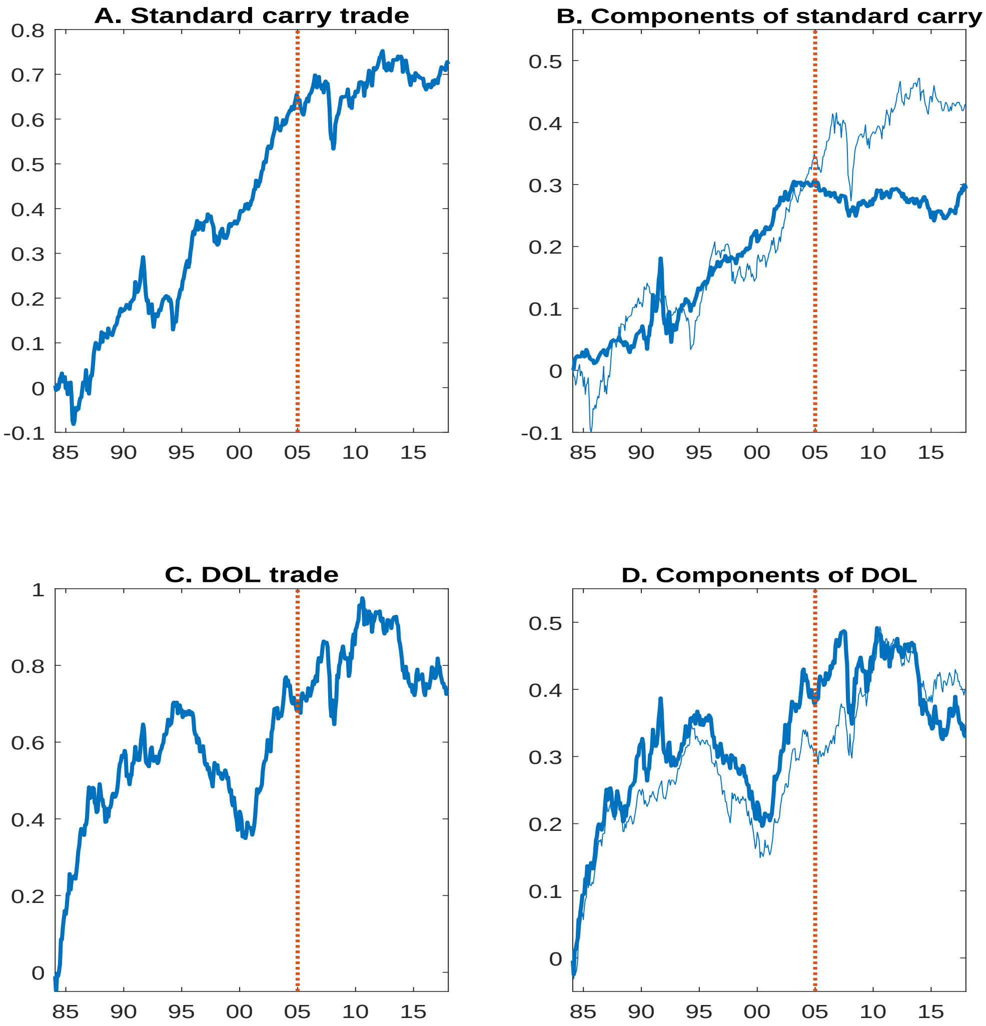

Figure 2. **Two more currency trades**

Panels A and B in this figure refer to a *standard* carry trade, implemented with the G-10 currencies, which goes long (short) with equal weights the three currencies with the highest (lowest) interest rates, and is re-balanced monthly. Panels C and D refer to a simple trade that goes long against the USD, with equal weights, all G-10 currencies (denoted by DOL). Transaction costs are ignored for both trades. Panels A and C show the cumulative monthly returns of the two trades. Panels B and D show with a thin (thick) line the cumulative returns due to the "static" ("dynamic") components of each trade, similar to Figure 1. The static component is the contribution of the four currencies with extreme (highest and lowest) forward differentials, which, in our sample, are the New Zealand dollar, Australian dollar, Swiss franc and Japanese yen. The dynamic component comes from the remaining G-10 currencies. The two components add up to the total return of each trade. The data is from Barclays Bank, via Datastream, and Bloomberg, and the sample period is 01/1985–12/2018. On the horizontal axis are marked the ends of the respective years. A vertical dashed line in each plot marks the end of 2005.

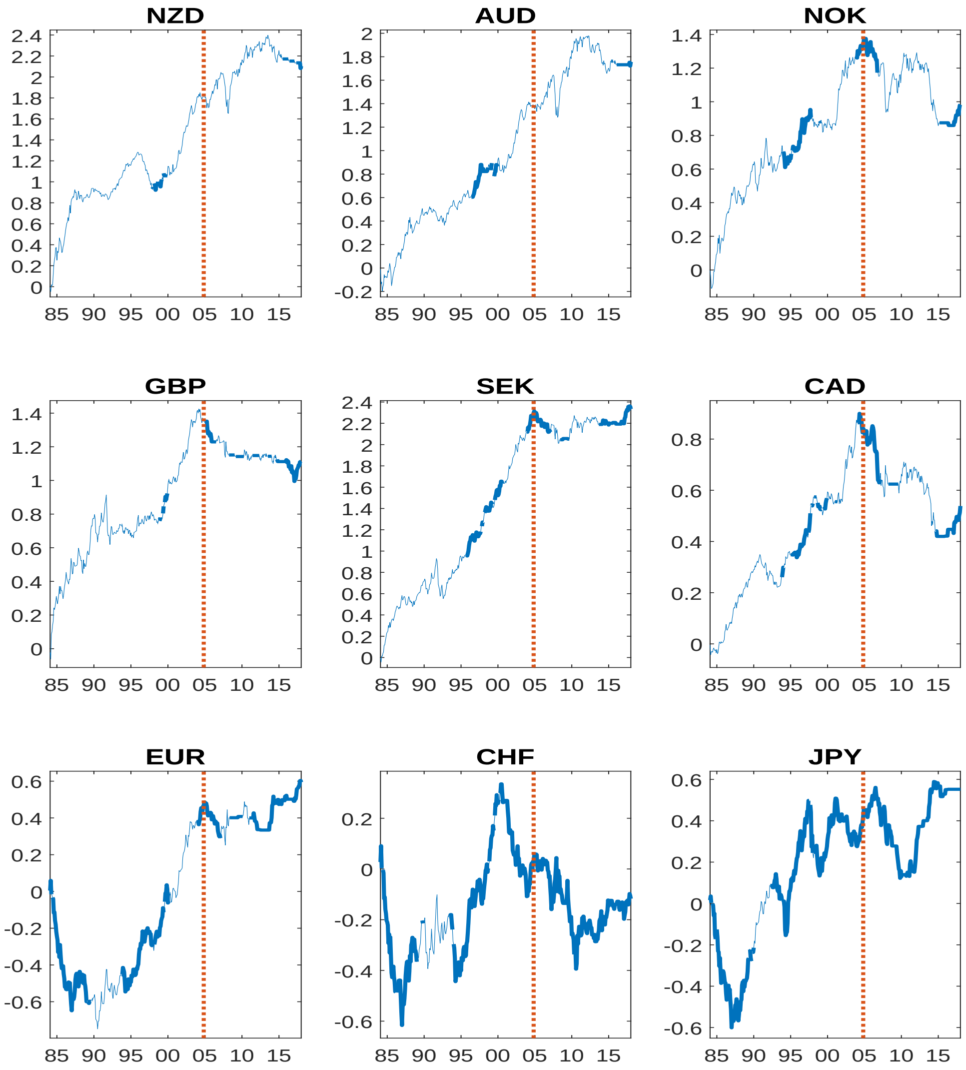

Figure 3. **Individual carry trades against the U.S. dollar**

Each plot shows the cumulative monthly returns from trading each currency (as shown at the top of the plot) against the U.S. dollar, as done in the U.S. dollar-based carry trade from Figure 1. The return of the dollar-based trade is the average of these individual returns. The thin portions on each line correspond to periods when the interest rate of the respective currency was higher than that of the U.S. dollar, and, accordingly, the currency was held long in the dollar-based carry trade. The thick portions correspond to periods when the currency was held short in the trade. The data is from Barclays Bank, via Datastream, and Bloomberg, and the sample period is 01/1985–12/2018. On the horizontal axis are marked the ends of the respective years. A vertical dashed line in each plot marks the end of 2005.