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EXCHANGE RATE DYNAMICS AND UNCONVENTIONAL MONETARY POLICIES: IT'S ALL IN THE SHADOWS

by Andrea De Polis* and Mario Pietrunti**

Abstract

In this paper we estimate an open economy New-Keynesian model to investigate the impact of unconventional monetary policies on the exchange rate, focusing on those adopted since the Global Financial Crisis in the euro area and in the United States. To this end we replace effective, short-term, interest rates with shadow rates, which provide a measure of the monetary stance when the former reach their effective lower bound.

We find that since 2009, unconventional monetary policies significantly affected the dynamics of the euro-dollar exchange rate both in nominal and real terms: while the stimulus provided by the Fed prevailed between 2011 and 2014, contributing to the weakening of the dollar, in most recent years the depreciation of the euro mainly reflected the measures adopted by the ECB.

JEL Classification: C11, E52, F31, F41.
Keywords: exchange rates, shadow rates, unconventional policies.

Contents

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1 Introduction[1]

Assessing the determinants of exchange rate developments is a crucial issue in international economics and it is part of the daily job of policymakers around the world. Until the Global Financial Crisis exchange rate dynamics where evaluated through the lenses of various structural models developed within the New Open Economy Macroeconomics literature see *ex multis* Obstfeld et al. (1996) and Gali and Monacelli (2005). Since then, however, this set of structural models has faced significant challenges due to the limits imposed by the existence of an Effective Lower Bound (ELB) on policy rates and to the unprecedented adoption of a wide range of unconventional monetary measures.

Indeed, in the face of the crisis, most central banks in developed economies reacted by lowering their reference interest rates at values close to their ELB and introducing various unconventional measures, such as asset purchase programs and forward guidance, with the aim of providing further monetary policy stimulus when the short term rate is not available as a policy tool. However, the assessment of the effectiveness of such measures is hampered by the existence of the ELB, which induces a non-linearity and, consequently, non-negligible computational challenges. On the other hand, simply ignoring the ELB would lead to significant estimation biases. For example, the estimated values of Taylor rule parameters may come short of actual ones given that at the ELB the short-term interest rate would not react to inflation and output dynamics; this in turn might also bias the estimates of the effects of the unconventional measures.

To overcome the non-linearity issue, we develop an open economy New-Keynesian (NK) model and estimate it replacing effective interest rates with shadow rates, which provide a measure of the monetary stance when actual policy rates reach their effective lower bound. Our focus is on the impact of unconventional policies on the exchange rate. To the best of our knowledge, this is the first paper that estimates an open economy NK model making use of shadow interest rates.

We then perform counterfactual exercises in order to assess the impact of the unconventional monetary policies adopted both in the US and in the euro area (EA) on the value of the euro vis-à-vis the US dollar (EUR/USD exchange rate). We find that unconventional monetary policies were effective in steering the exchange rate. The last two rounds of quantitative easing by the Fed (between 2010 and 2014) led to a depreciation of the dollar vis-à-vis the euro. Afterwards, the expansionary monetary policy measures implemented by the ECB led to a significant depreciation of the euro.

This paper contributes to the literature on unconventional monetary policy in open economies. The model itself is borrowed from the literature on open-economy NK models (see ex multis Cristadoro et al., 2008; Justiniano and Preston, 2010; Rabanal and Tuesta, 2010). More precisely, the set-up is the one of Justiniano and Preston (2010) where the main difference in terms of modelling lies in a more detailed representation of the foreign country, which - instead of being summarized by a VAR - in our model is perfectly symmetrical to the home country. Our methodological contribution to this literature consists in overcoming the issue of the effective lower bound on the monetary policy rate by replacing it with a shadow rate.

The use of shadow rates in closed economy New-Keynesian DSGE models has been recently proposed by Wu and Zhang (2018) and Mouabbi and Sahuc (forthcoming), whereas in an open-economy

[1]We thank Anna Bartocci, Giuseppe Ferrero, Marco Lombardi, Luca Metelli, Stefano Neri, Alessandro Notarpietro, Roberto Pancrazi, Marcello Pericoli, Massimiliano Pisani and Alessandro Secchi for useful suggestions and discussions.

setting byWu and Zhang (2019). More precisely, Wu and Zhang (2018) develop a calibrated model of the US economy whose purpose is to show that replacing the short term interest rate with a shadow rate is an effective and convenient way to model unconventional monetary policies in reduced form. Mouabbi and Sahuc (forthcoming) build upon such findings and estimate a closed economy NK model for the euro area with a shadow rate to investigate the impact of unconventional monetary policies on the real economy. The authors find that the set of unconventional policies enacted by the ECB in recent years positively affected GDP growth (and its components) and supported inflation dynamics. Wu and Zhang (2019) instead introduce shadow rates into an open economy New-Keynesian model to show the theoretical mechanism that leads unconventional monetary policies to overcome the negative effects of a liquidity trap on output and on the terms of trade.

We apply the methodology developed above to an open economy setting in order to quantify the impact of unconventional policies enacted both in the US and in the EA on the EUR/USD exchange rate. This is a research question that has been already addressed in the recent literature, although exclusively using VAR models or event studies. The most notable contribution in the literature is Forbes et al. (2018), which introduces the shadow rate in an open economy SVAR estimated with UK data to study the exchange rate pass-through. Other papers using a VAR setting with shadow rates to investigate the exchange rate pass-through in times of unconventional monetary policies are Filardo and Nakajima (2018) and Comunale and Kunovac (2017). All of the above mentioned papers find a significant impact of unconventional monetary policy shocks, as measured by unexpected changes to the shadow rate, on the exchange rate.[2]

We contribute to the above mentioned literature by introducing shadow rates into a NK open economy setting, thus effectively taking into account monetary policy spillovers from one country to the other via the exchange rate. By introducing the shadow rates for the US and the EA within a DSGE model, we are able to perform counterfactual exercises aimed at assessing the effects of the unconventional policies enacted by the Fed and by the ECB on the EUR/USD exchange rate.

The rest of the paper is structured as follows. In Section (2) we present the model and the data used for the estimation. In Section (3) the results of the estimation exercise are reported and discussed. In Section (4) we discuss the counterfactual exercises. In Section (5) some robustness checks are shown, while Section (6) concludes.

2 The model

In this Section we provide a summary description of the model, then we discuss the introduction of shadow rates and briefly describe the data.

2.1 A bird's-eye view

To preserve comparability with the existing literature, we make use of the open-economy model described in Justiniano and Preston (2010), JP henceforth.

[2]Papers making use of event studies to assess the impact of unconventional policies on exchange rate are, *ex multis*, Georgiadis and Gräb (2016); Altavilla et al. (2015); Neely (2015). An alternative approach, which makes use of a local projection regression, is Dedola et al. (2018).

The model includes two symmetrical countries. In each country there is a representative household deriving utility from a composite consumption good and disutility from labor. Households trade one-period domestic and foreign bonds, where the foreign bond is assumed to be subject to an exogenous risk premium shock. The supply side of each economy is made of two types of agents: domestic producers and retailers. The former produce differentiated goods in a monopolistically competitive market. The latter import foreign differentiated goods for which the law of one price holds at the border. The model therefore features local currency pricing. Such assumption, along with the one on incomplete markets (given that there is just a single non-contingent asset in the economy) imply a deviation from of the law of one price. Indeed, the uncovered interest rate parity (UIRP) in its log-linear version writes:

$$\left(i_t^{ea} - \mathbb{E}_t[\pi_{t+1}^{ea}]\right) - \left(i_t^{us} - \mathbb{E}_t[\pi_{t+1}^{us}]\right) = \mathbb{E}_t\,\Delta q_{t+1} - (\chi b_t + \phi_t) \tag{1}$$

where $i_{ea,t}$ and $i_{us,t}$ are the EA and US nominal interest rates, π^{ea} and π^{us} are inflation rates in the EA and in the US. q_t is the real exchange rate, with $q_t \equiv e_t P_t^* / P_t$, where P_t^* and P_t are respectively foreign and domestic CPI and e_t is the nominal exchange rate, defined as the units of euros needed to buy one unit of US dollars. Further, b_t is the real quantity of outstanding US debt expressed in terms of euros and ϕ_t is a risk premium shock. Monetary policy enters the model in a standard fashion. The central banks in both countries set the short-term nominal interest rate according to a Taylor-type rule:

$$i_t^j = \rho_i i_{t-1}^j + (1-\rho_i^j)(\psi_\pi^j \pi_t^j + \psi_y^j \Delta y_t^j) + \varepsilon_{mp,t}^j \text{ with } j = \{ea, us\} \tag{2}$$

where ρ_i indicates the degree of inertia in setting a new interest rate level in response to domestic inflation (π_t) and real growth (Δy_t) developments and $\varepsilon_{mp,t}$ is an exogenous monetary policy shock. All the other exogenous shocks follow AR(1) processes. The complete log-linearized version of the model is reported in Appendix B.

2.2 Introducing shadow rates

Despite its widespread use in structural models, a Taylor rule like (2) faces a major drawback in periods when the ELB is binding. Indeed, at the ELB the policy rate is constrained and central banks need to resort to unconventional monetary policy tools. The failure of standard linear models to capture such constraint poses a relevant challenge to the estimation of DSGE models and to the identification of the parameters. In the literature, this issue has been tackled either by imposing the ELB in the model specification, thus effectively introducing an occasionally binding constraint (see ex multis Fernández-Villaverde et al., 2012), or, more recently, by using a shadow rate measure of the monetary policy stance (Wu and Zhang, 2018; Mouabbi and Sahuc, forthcoming). This latter approach implies deriving an interest rate that in absence of an ELB would replicate the effects of unconventional monetary policies and which is unbounded, ie. it is free to float into negative territory. The use of a shadow rate thus circumvents the structural break implied by ELB and allows monetary policy in the model to remain active even when the ELB is binding (Wu and Zhang, 2018).

Therefore, in the model we replace nominal interest rates with shadow rates. In normal times, when the ELB is not binding, the shadow rate coincides with the short-term monetary policy rate.

When the ELB is hit, instead, the shadow rate is allowed to freely move into negative territory. This way of proceeding has a clear computational advantage, in that the linearity of the model is preserved, and allows to conveniently overcome the issue of parameter misspecification at the ELB. At the same time, we are well aware of the limits of such approach: shadow rates ignore the existence of possible structural break in terms of consumption/saving dynamics induced by the ELB by the ensuing unconventional policy response.[3]

Also, the use of shadow rates in equation (1) deserves a few words of clarification. First, since shadow rates are a theoretical artifact, the UIRP equation (1) should be interpreted as a ”pseudo UIRP”, i.e. as an equation that closes the model by providing the current and expected level of the exchange rate compatible with the monetary policy stance in each of the two countries (and with the risk premium shock). Indeed, strictly speaking, in a world with shadow rates the UIRP equation at the ELB is not a no-arbitrage condition anymore, since buying foreign currency is always a dominant strategy compared to buying the foreign asset (which yields the shadow rate). However, under a few assumptions the validity of the UIRP can be fully restored. Indeed, in Appendix A we rely on an argument brought forward by Wu and Zhang (2018) and show that shadow rates can be mapped into a QE or a lending facility programme. The logic of the argument is based on the assumption that conventional and unconventional monetary policies affect two distinct components of interest rates, with the former affecting the expectation component and the latter the risk premium. In such a setting, the validity of the UIRP is fully restored.[4]

Several measures of shadow rates have been proposed in the recent literature with the aim of evaluating the stance of monetary policy in periods in which the nominal rate is uninformative. Krippner (2013) exploits the switching-to-physical-currency option to build a continuous time Gaussian Affine Term Structure Model (GATSM) à la Black (1995). Wu and Xia (2016) propose a discrete time GATSM analogue, while Lombardi and Zhu (2018) filter out the shadow rate from a dynamic factor model.

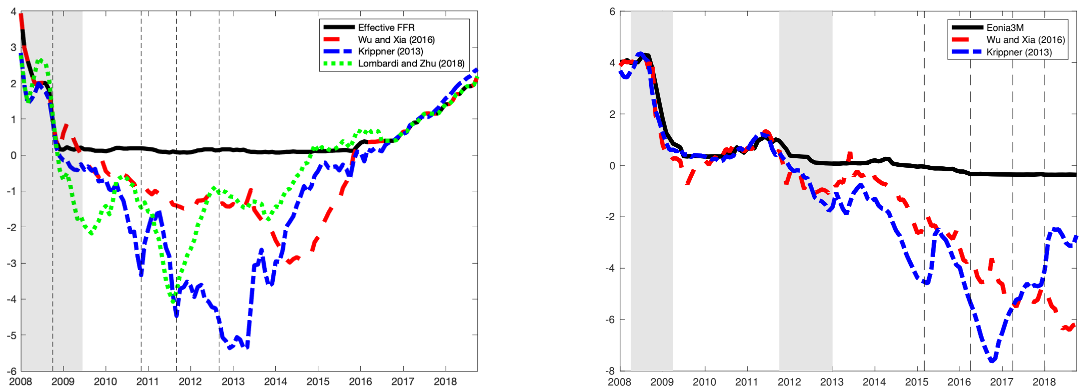
All these alternative measures suggest that taken as a whole, unconventional monetary policies can be mapped into nominal rates, significantly pushing them into negative territory (see Figure 1). Plotting together various shadow rates for the US, it can be seen that they all display similar dynamics, but of different magnitude, with the rates by Krippner (2013) and Lombardi and Zhu (2018) reaching approximately -5% in 2013, about three times the rate implied by Wu and Xia (2016) during the same time span.[5] We also plot the shadow rates by Wu and Xia (2016) and Krippner (2013) for the EA. In the right panel of Figure 1, it can be seen that the two series display a downward trend until the end of 2016. Then, from 2017 onward Krippner’s rate signals a tighter monetary policy stance, while the one by Wu and Xia suggests a prolonged accommodative stance.

[3] This issue has been tackled using an alternative approach to ours in Bodenstein et al. (2017), where the effects of foreign shocks on the domestic economy at the ELB are investigated with a piecewise-linear DSGE model. Introducing unconventional policies in the latter framework, however, remains controversial as it would require extra assumptions that would imply a departure from the standard NK setting.

[4] A recent literature has investigated the effects of unconventional monetary policy in an open-economy setting, stressing the international dimension of the portfolio balance channel (see Alpanda and Kabaca 2019 and Cova et al. 2019). These papers explicitly model unconventional monetary policies exploiting the imperfect substitutability of assets within investors’ portfolios. In such papers, when portfolios comprise both domestic and international assets, an unconventional monetary policy shock tends to spill-over on international financial markets (and thus also on the exchange rate). In our case, instead, each economy is endowed with a single asset and the degree of substitutability can be broadly interpreted as the reaction of the foreign shadow rate to domestic policy shocks.

[5] Both Lombardi and Zhu (2018) and Wu and Xia (2016) estimate the shadow rate until the lift-off in July 2016. We therefore extend the time series with the Federal Fund Rate.

Figure 1: *Shadow rates*



US shadow rates *EA shadow rates*

Both panels illustrate the shadow rate estimates of Krippner (2013), Wu and Xia (2016) and Lombardi and Zhu (2018) (only US). Vertical bands represent NBER and CEPR recession dates, respectively, while vertical dashed lines correspond to the announcement date of large asset purchase programs for both economies. For the US: QE1 (November 2008), QE2 (November 2010), Operation Twist (September 2011), QE3 (September 2012). For the EA: start of the APP (March 2015), first extension (April 2016), third extension (April 2017), last extension (January 2018). We thank Marco Lombardi for sharing the shadow rate estimates, which is not available for the euro area.

2.3 Data

We estimate the model using data on GDP, inflation, shadow interest rates for both the US and the EA and the bilateral real exchange rate. Data for the EA are retrieved from the ECB Statistical Data Warehouse, those for the US come from the FRED database (see Appendix C for further details). We feed to the model with: a) the cyclical component of the output, extracted with a one-sided Kalman filter; b) inflation rates, constructed by taking the first difference of the log CPI; c) the shadow rates of Wu and Xia (2016).[6] Lastly, we include among the observables the real exchange rate, in first differences. As in Rabanal and Tuesta (2010), we assume the euro area to be the home country, and thus we express the nominal exchange rate in terms of euros per unit of US dollars. The real exchange rate is defined as the product of the nominal exchange rate and the ratio of US CPI and Eurozone harmonized CPI.

Our sample spans from 1999Q1 to 2018Q4. In Section 5 we check the robustness of our results using different data inputs. In particular, we use the shadow rate of Krippner (2013),[7] we substitute GDP with data on hours worked from Ohanian and Raffo (2012)[8], and finally we build an higher-frequency dataset with monthly data, where GDP is obtained via temporal disaggregation with industrial production as proxy.

[6] Data available at: `https://sites.google.com/view/jingcynthiawu/shadow-rates?authuser=0`.

[7] Data available at: `https://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures`.

[8] Data available at: `http://andrearaffo.com/araffo/Research.html`.

Table 1: *Parameters estimation*

	Parameters	Prior			Posterior		HPDI[a]			Parameters	Prior			Posterior		HPDI[a]	
		Dist.[b]	Mean	S.D.	Mode	Mean	5%	95%			Dist.[b]	Mean	S.D.	Mode	Mean	5%	95%
Euro Area																	
η	Inv. elasticity of subs.	$\mathcal{G}$	1.5	0.25	1.02	1.13	0.815	1.423	ρ_i	Taylor rule persistence	$\mathcal{B}$	0.5	0.1	0.38	0.38	0.252	0.514
φ	Inverse Frisch elasticity	$\mathcal{G}$	1.5	0.25	1.3	1.37	0.948	1.785	ρ_a	TFP persistence	$\mathcal{B}$	0.5	0.1	0.93	0.91	0.86	0.958
δ	Indexation domestic	$\mathcal{B}$	0.5	0.15	0.35	0.38	0.155	0.607	ρ_g	Preferences persistence	$\mathcal{B}$	0.5	0.1	0.98	0.97	0.954	0.991
θ	Calvo domestic prices	$\mathcal{B}$	0.7	0.1	0.1	0.12	0.065	0.18	ρ_{cp}	Cost push persistence	$\mathcal{B}$0.5	0.1	0.63	0.63	0.458	0.806	
δ^*	Indexation import	$\mathcal{B}$	0.5	0.15	0.51	0.51	0.263	0.76	σ_a	TFP std. dev.	$\mathcal{IG}$	0.5	2	0.05	0.06	0.047	0.063
θ^*	Calvo import prices	$\mathcal{B}$	0.5	0.15	0.3	0.3	0.22	0.386	σ_g	Preferences std. dev.	$\mathcal{IG}$	0.5	2	0.1	0.1	0.07	0.126
ψ_π	Taylor rule, inflation	$\mathcal{G}$	2	0.3	3.31	3.34	2.775	3.899	σ_{cp}	Cost push std. dev.	$\mathcal{IG}$	00.5	2	0.1	0.1	0.075	0.128
ψ_y	Taylor rule, ΔGDP	$\mathcal{G}$	0.5	0.1	0.52	0.55	0.365	0.734	σ_{mp}	Mon. pol. std. dev.	$\mathcal{IG}$	00.5	2	0.07	0.07	0.057	0.084
h	Habit	$\mathcal{B}$	0.5	0.1	0.1	0.12	0.06	0.177									
United States																	
η	Inv. elasticity of subs.	$\mathcal{G}$	1.5	0.25	0.87	0.91	0.66	1.149	ρ_i	Taylor rule persistence	$\mathcal{B}$	0.5	0.1	0.3	0.3	0.19	0.413
φ	Inverse Frisch elasticity	$\mathcal{G}$	1.5	0.25	1.01	1.07	0.686	1.444	ρ_a	TFP persistence	$\mathcal{B}$	0.5	0.1	0.97	0.97	0.957	0.983
δ	Indexation domestic	$\mathcal{B}$	0.5	0.15	0.5	0.5	0.255	0.749	ρ_g	Preferences persistence	$\mathcal{B}$	0.5	0.1	0.99	0.99	0.979	0.992
θ	Calvo domestic prices	$\mathcal{B}$	0.5	0.15	0.5	0.5	0.253	0.748	ρ_{cp}	Cost push persistence	$\mathcal{B}$	0.5	0.1	0.71	0.7	0.558	0.846
δ^*	Indexation import	$\mathcal{B}$	0.5	0.15	0.3	0.35	0.124	0.561	σ_a	TFP std. dev.	$\mathcal{IG}$	0.5	2	0.06	0.06	0.051	0.068
θ^*	Calvo import prices	$\mathcal{B}$	0.7	0.1	0.03	0.04	0.019	0.058	σ_g	Preferences std. dev.	$\mathcal{IG}$	0.5	2	0.11	0.12	0.08	0.151
ψ_π	Taylor rule, inflation	$\mathcal{G}$	2	0.3	3.49	3.59	3.026	4.142	σ_{cp}	Cost push std. dev.	$\mathcal{IG}$	0.5	2	0.14	0.15	0.094	0.203
ψ_y	Taylor rule, ΔGDP	$\mathcal{G}$	0.5	0.1	0.49	0.52	0.351	0.69	σ_{mp}	Mon. pol. std. dev.	$\mathcal{IG}$	0.5	2	0.08	0.08	0.062	0.091
h	Habit	$\mathcal{B}$	0.5	0.1	0.04	0.04	0.024	0.065									
Risk premium shock																	
ρ_u	persistence	$\mathcal{B}$	0.5	0.1	0.24	0.24	0.144	0.334	σ_u	std. dev.	$\mathcal{IG}$	0.5	2	0.05	0.05	0.046	0.061

The table reports the prior density and the posterior estimates for the model's parameters, along with the 5% and 95% credible intervals.
[a] *The highest posterior density intervals (HPDI) are computed with respect to the mode of the posterior distribution.*
[b]*The distributions we consider are: Gamma, $\mathcal{G}$, Beta, $\mathcal{B}$ and Inverse Gamma, $\mathcal{IG}$.*

3 Estimation results

We use standard Bayesian techniques to recover parameters' estimates. Specifically, parameters' posterior distributions are sampled by means of the Metropolis-Hastings algorithm.[9] Prior distributions are in line with the literature[10] and posterior distributions are characterized by their mode, standard deviation and 95% credible intervals. Table 5 reports the results.

Overall, the euro area economy displays somewhat stronger nominal and real rigidities. Indeed, the habit coefficient is higher for the EA (0.11) than for the US (0.04), thus signaling a smoother reaction of consumption to shocks. Similarly, labor supply is less elastic, as the inverse of the Frisch elasticity is higher (1.02) in the EA than in the US (0.87). Coefficients related to nominal rigidities are found to be higher in the EA, both with respect to the domestic goods' Phillips curve and to the one related to import goods. Overall, nominal rigidities parameters are found to be lower than in similar, pre-crisis papers in the literature (see eg. Rabanal and Tuesta (2010)). As highlighted in Burlon et al. (2018), a low degree of nominal rigidities (especially in import prices) leads to a low sensitivity of the nominal exchange rate, since most of the adjustment in terms of the real exchange rate happens via price inflation. The Taylor rule coefficients are instead roughly similar in both countries. In terms of shocks persistence, our estimation suggests that in the US preference and technology shocks are more persistent (0.99 and 0.97 respectively in the US vs. 0.93 and 0.98 in the EA), while the persistence of monetary policy and cost push shocks displays a similar magnitude (0.30 and 0.71 in the US vs. 0.38 and 0.63 in the EA).

Figure (2) plots the IRFs for the main variables of the model to a restrictive monetary policy shock hitting the shadow rates in the euro area and in the US. The effect of a domestic monetary policy shock

[9]We set 1,000,000 draws for 5 Markov chains. The convergence of the former is checked using Brooks and Gelman (1998) diagnostics.

[10]Parameters whose support is non-negative have Gamma priors, those with support bounded between 0 and 1 follow Beta distributions, variances have Inverse Gamma distributed prior distributions.

on domestic inflation and GDP is as expected. However, we find that monetary policy in the EA has a stronger impact on domestic GDP than domestic monetary policy on domestic GDP in the US, while the opposite happens for inflation. As for the impact of monetary policy on foreign variables, the effect on foreign inflation is negligible for both countries. Also, a restrictive monetary policy shock in the euro area leads to a slight fall in US GDP, while a restrictive monetary policy shock in the US determines a modest rise in EA GDP. Such dynamics are related to the dynamics of the exchange rate and to a different slope of the Phillips curve for importers in the two countries, which in turn implies a different reaction of the inflation on imported goods to a change in the terms of trade. The impact on the exchange rate of the two types of monetary policy shocks is also qualitatively similar in that a restrictive shock in the US leads to a depreciation of the euro, whereas a restrictive shock in the EA leads to an appreciation of the currency. However, the EA shock appears to have a more relevant impact on the real exchange rate.

We then look at the contribution of each exogenous shock to the variance of some relevant variables (Table 2). The variance decomposition exercise suggests that domestic output in both economies is mainly driven by the domestic technology shock and to a lesser amount by the domestic cost push shock. Domestic inflation, instead, as expected, is mostly driven by domestic monetary policy. The key variable of the paper, the exchange rate (in nominal and in real terms), is mostly determined by shocks to the UIP, which account for 25-30% of the variability. This is a well known fact in the literature, usually labelled the "exchange rate disconnect".[11] EA and US shocks contribute almost equally to the rest of the variability (almost 37% and 33% respectively).

Table 2: *Variance decomposition*

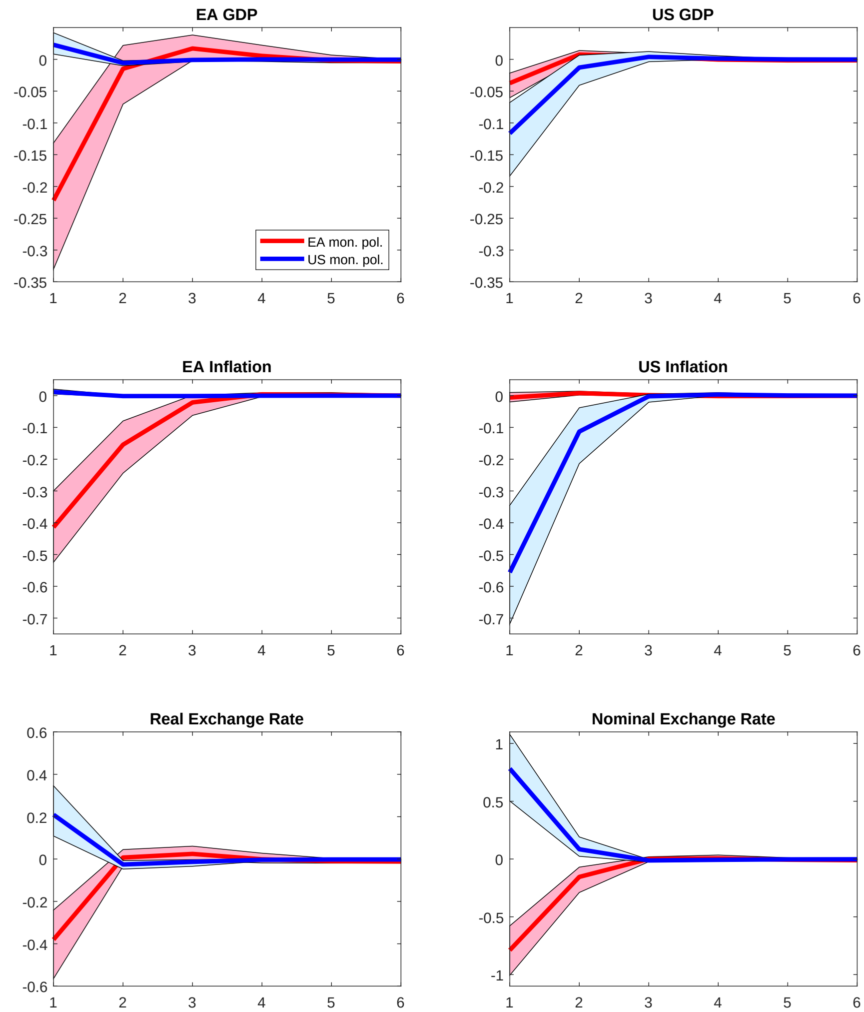
	Euro area					United States			
	TFP	Pref.	Cost push	Monetary policy	Risk premium	TFP	Pref.	Cost push	Monetary policy
Output EA	73.08	1.15	17.96	1.92	3.02	0.55	2.25	0.05	0.02
Inflation EA	25.12	11.6	13.48	45.00	3.6	0.28	0.82	0.07	0.03
Output US	0.78	0.41	0.31	0.05	0.7	93.3	0.7	3.29	0.46
Inflation US	0.43	0.3	0.19	0.02	0.87	14.81	11.3	5.25	66.83
RER	11.12	13.49	16.11	0.98	24.51	14.72	17.52	1.22	0.33
NER	8.01	10.57	14.17	4.75	28.35	12.89	15.81	0.79	4.66

Values are expressed as percentage points.

These results are robust in many dimensions, as discussed in the following sections. In particular, if we replace the shadow rate measures of Wu and Xia with the ones provided by Krippner, the

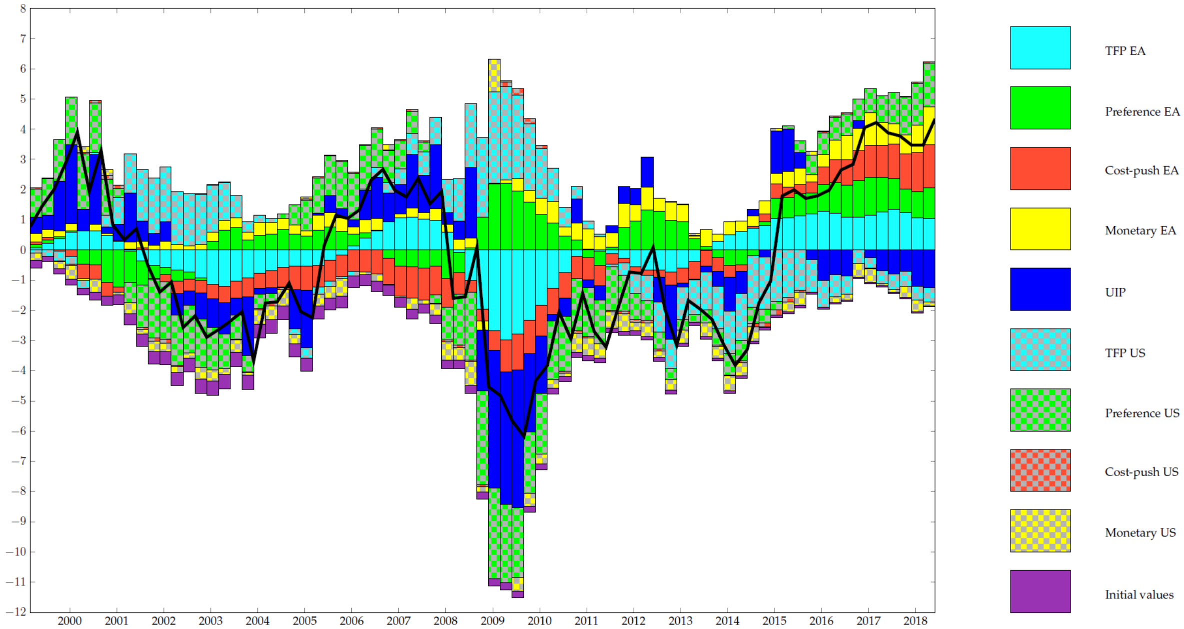
[11] In other papers, such as Cristadoro et al. (2008) and Rabanal and Tuesta (2010), even higher values for the contribution of such shock are found (60% and above). This is due to the use, as observable, of the exchange rate in levels, instead of growth rates, as we do here. We also performed estimations (available upon request) using the real exchange rate in levels and we recover results in line with the literature.

Figure 2: *IRFs to monetary policy shocks*

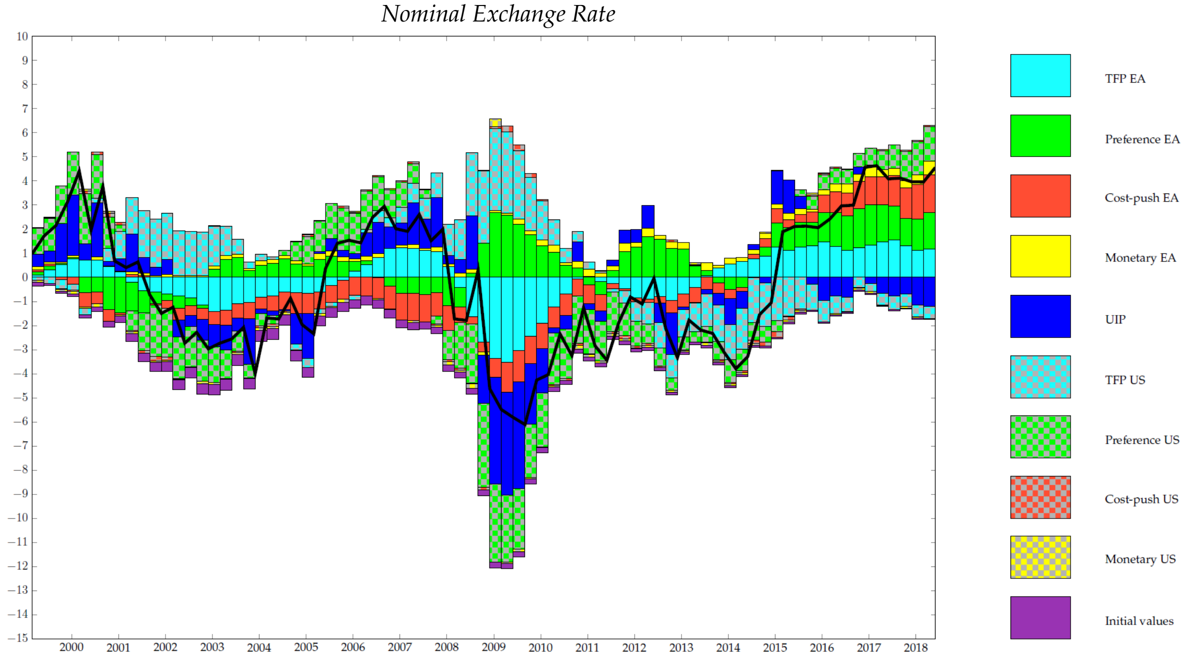


Note: the Figure depicts the Bayesian IRFs of selected variables to a 100bp positive monetary policy shock in the EA and in the US. The IRFs are plotted at the posterior mean, with 90% confidence intervals. Values on the y-axis are percentage deviations from the steady state.

Figure 3: *Historical decomposition of the Exchange Rate*



Nominal Exchange Rate



Real Exchange Rate

contribution of each shock to the variance of the above mentioned variables is confirmed. Moreover, focusing on the subsample after 2008, the message arising from the variance decomposition exercise remains fairly unaffected.

We further focus on the dynamics of the nominal and real exchange rates, by reporting their historical shock decomposition in Figure 3.

From a monetary policy perspective, in the most recent years the contribution of EA monetary shocks to the depreciation of the euro has been relevant. Due to the fact that the EONIA rate has not significantly moved since 2016, these shocks can be interpreted as unconventional monetary policy shocks. Besides, US monetary policy seems to have contributed more to the dynamics of the bilateral EUR/USD real exchange rate between 2010 and 2014.

A few more remarks concerning the dynamics of the shocks are in order. First, it can be clearly seen that from the Global Financial Crisis onward negative preference shocks adversely impacted on aggregate demand in both countries, thus pushing for a depreciation of the domestic currency. Also, since 2014 the EA cost push shock significantly contributed to the appreciation of the dollar. This is a finding that can be put in relationship with the drastic fall in oil prices recorded in 2014-15 (Klitgaard et al., 9th January 2019).

4 Counterfactual results on the exchange rate

In order to better appreciate the impact of unconventional monetary policies on the exchange rate, in this section we present some counterfactual exercises. We aim at exploiting the difference between actual and shadow rates to gauge the impact of unconventional monetary policy shocks in the EA and in the US. In other words, the goal of this section is to compare the actual dynamics of the exchange rate with the one that would have observed if no unconventional policy was in place, with the short term rate constrained at the ELB. This is an exercise that has been performed for the EA in a closed economy model by Mouabbi and Sahuc (forthcoming).

Therefore, we extract the filtered shocks from the estimated model, we feed the model with all the filtered shocks (excluding monetary policy shocks) and replace the shadow rates with data on effective interest rates (3-month EONIA and FFR). Hence, the observables in the counterfactual model comprises the filtered TFP, preferences, cost-push and risk premium shocks along with effective interest rates. We filter the model with such inputs to track the exchange rate path that would have prevail if unconventional monetary policy was not accounted for (via the shadow rates).

We perform such exercise three times. First, replacing the two shadow rates with the actual rates in both EA and US; then introducing the actual rate only in the EA or in the US. In this way we are able to analyze the impact of the Fed's and ECB's unconventional policies both jointly and in isolation. For robustness, in Appendix D we do the same exercise using the shadow rates by Krippner.

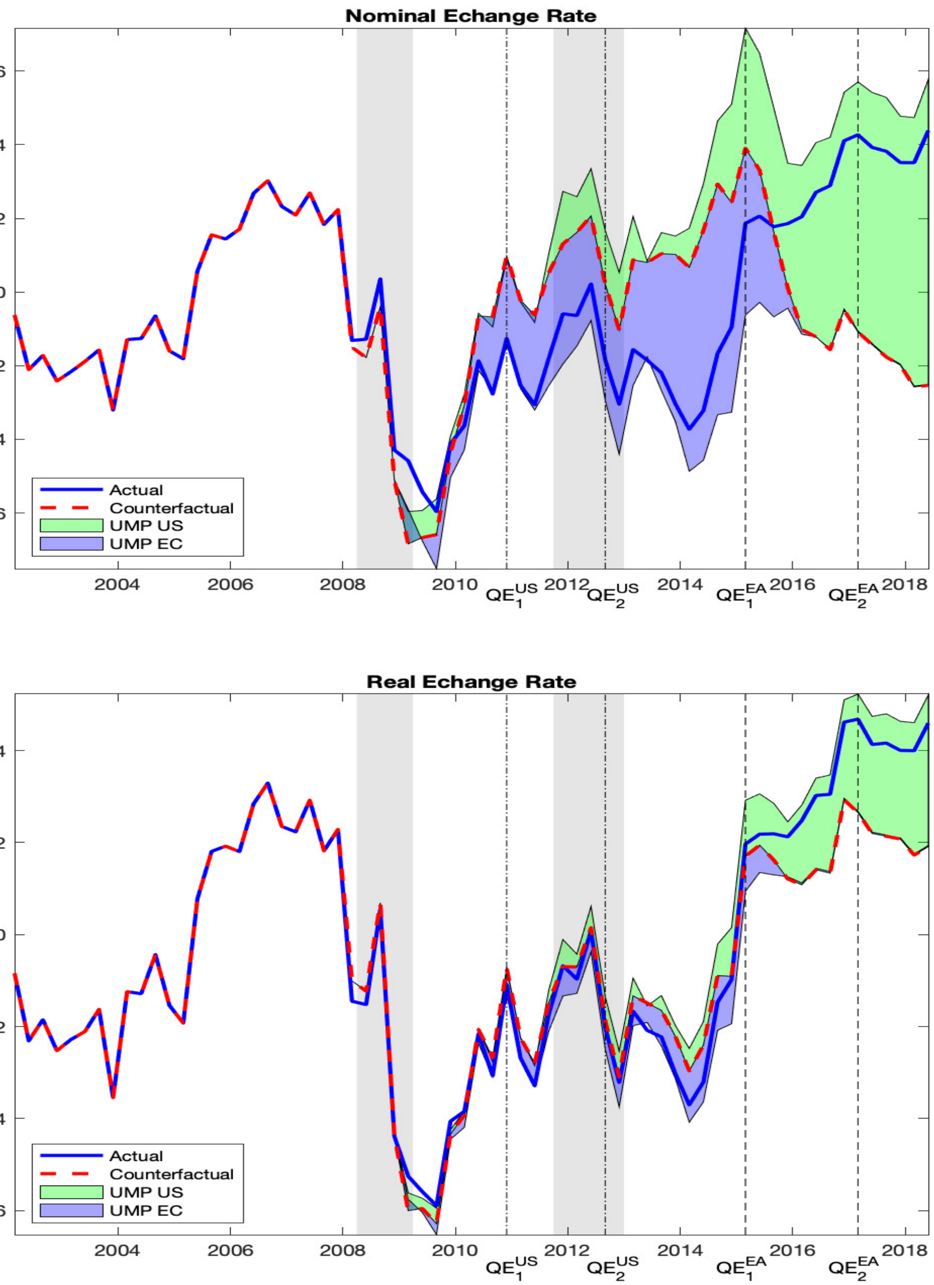
The results of the counterfactual exercises are reported in Figure 4.[12] They show that, from 2008 onwards the dynamics of the actual exchange rate would have been significantly different in absence of unconventional monetary policies across the Atlantic. As of December 2008 the counterfactual nominal exchange rate (red dashed) soars above the actual one (blue solid). From the second half of 2015 this trend reverts as the counterfactual rate drops below the actual one. More precisely, between 2010 and 2014, the difference between the actual exchange rate and the counterfactual one can be mainly attributed to the unconventional monetary policies enacted by the Fed. These policies contributed to a depreciation of the dollar against the euro up to 6.3% in nominal terms and of 1.2% in real terms. On the other hand, in most recent years ECB's unconventional policies contributed for

[12]The slight difference before 2010 between actual and counterfactual values of the exchange rates in the two figures is due to a filtering approximation from the first difference of the exchange rate (with which we feed the model) and the reconstructed series in levels.

the most part to the divergence between the actual exchange rate and its counterfactual value. In the last part of the sample (from 2014 to mid 2018), the ECB's measures contributed to a depreciation of the nominal exchange rate of 8.3% and of while he depreciation of the real exchange rate would have instead been of 2-3%.

Such findings are in line with other papers displaying a significant impact of unconventional policies on the exchange rate (see e.g. Cecioni, 2018; Beck et al., 2019).

Figure 4: *Counterfactual exchange rate developments*



Note: the blue solid line in both panels is the actual exchange rate (respectively in nominal and in real terms), the dashed red line is the counterfactual exchange rate in absence of unconventional monetary policies in both the EA and US, the green area represents the contribution of unconventional monetary policies in the EA, while the violet area represents the contribution of unconventional policies in the US.

5 Robustness

This Section is devoted to the presentation of the results of some robustness exercises we performed to validate our results. The broad message of the paper is confirmed across different specifications of the model. Tables and figures are reported in Appendix D.[13]

Changing the shadow rate measures The first robustness check concerns performing the estimation using different shadow rates. More precisely, we substitute the Wu and Xia shadow rates used in the baseline exercises with the shadow rates provided in Krippner (2013). In Table 4 we report the variance decomposition obtained from replacing these new shadow rates in the model. It can be clearly seen that our findings hold in this case as well, as confirmed by the counterfactual exercise in Figure 6 in Appendix D. Indeed, the main divergence between the two measures is related to the most recent years in the EA.

Changing the observables and the frequency of the data Two further robustness checks involve changing the observable variables and their frequency. In a first exercise (Table 6 in Appendix D), we substitute data on GDP with data on hours worked, retrieved from Ohanian and Raffo (2012). We do this since the fluctuations in GDP may be affected by variables that are not taken into account in our framework, such as government spending or investment in physical capital. Hours worked instead provide a narrower measure of economic activity, which is more in line with the production function of the domestic good, which in the linearized version of the model (see Justiniano and Preston, 2010) writes $y_t^h = a_t^h + n_t^h$, ie. the sum of the TFP shock and domestic labor demand. Interestingly, also in this case the estimation results are broadly confirmed. A further exercise consists instead of using data at a higher (monthly) frequency. This can easily be done, as all the data we employ are also available at the monthly frequency, except data on GDP, which we temporally disaggregate with the Dagum and Cholette (2006) method, using industrial production as higher frequency proxy. Results of this further estimation exercise are reported in Table 7 in Appendix D. Differently from the previous robustness checks, in this case several differences arise with respect to the baseline case. Indeed, the model estimated at a monthly frequency implies a less relevant role of the risk premium shock and of EA monetary policy in explaining the variance of the exchange rate. On the other hand, other EA shocks such as TFP, preferences and cost push contribute more significantly in explaining the variance of the exchange rate, both in nominal and in real terms. The contribution of the shocks originating from the US is overall untouched.

Before and after the Global Financial Crisis A final robustness check involves estimating the model in two different subsamples, before and after the outbreak of the Global Financial Crisis in 2008. We then estimate the baseline model in the subperiod from 1999 to 2007 and from 2008 onwards. The exercise is aimed at investigating whether some structural changes in the underlying economy have taken place that may affect the results. Also, we aim at testing whether unconventional monetary policies, which were adopted since 2008 onwards and are thus reflected in the divergence between actual and shadow interest rates may contribute differently in explaining the variance of the

[13] More detailed results for each robustness exercise are available upon request.

relevant variables. The Tables 8 and 9 in Appendix D reporting the variance decomposition of output, inflation and exchange rate in the two subperiods display indeed some differences. Focusing on the variance of the exchange rate (in nominal and real terms) it can be noted that monetary policy in both countries after the GFC played a slightly less relevant role than before. On the other hand, the role of the risk premium shock increased somewhat, as well as domestic EA shocks different from the monetary policy one. Using only the pre-crisis subsample (1999-2007), what emerges from Table 9 is that a reduction in the persistence of preference and TFP shocks for both economies, lead to a significant increase in the contribution of monetary policy and risk sharing shocks in determining the exchange rate variability. Substituting the real exchange rate growth rate with its level more than doubles the contribution of the risk premium shock to the exchange rate variance, to the detriment of all other shocks but the domestic monetary one.

6 Conclusions

In this work we propose to study the effect of unconventional monetary policies adopted across the Atlantic on the dynamics of the exchange rate. To this end, we augment a standard open economy New-Keynesian model with shadow rates, which allow us to assess the contribution of monetary instruments like quantitative easing and forward guidance to recent developments of the euro-dollar exchange rate. Indeed, the introduction of shadow rates helps overcoming the issue entailed by the effective lower bound on short-term interest rates and allows to provide counterfactual evidence on the level of effective interest rates.

Our estimated model, which proves to be robust across multiple specifications and sub-samples, points to a relevant impact of monetary policy shocks on the dynamics of the exchange rate, both in real and nominal terms, even when the effective lower bound is binding.

Furthermore, we identify the contribution of the unconventional monetary policies put in place by the Fed and the ECB, respectively. We show that between 2010 and 2014 the expansionary stance of the Fed contributed to a depreciation of the dollar against the euro, whereas the bilateral exchange rate was significantly affected by ECB's unconventional policies afterwards. These results suggest that unconventional measures were successful in stimulating the economy and put upward pressure on domestic inflation also though the exchange rate channel, thus contributing to the achievement of the central bank mandate.

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A Mapping QE with shadow rates in an open-economy setting

In this section we show how a model with shadow rates and a model with QE lead to the same UIRP condition. To do so, we simply bring the argument by Wu and Zhang (2018) to our open-economy setting. More precisely, two variations on our baseline model are needed. First, we replace risk free bonds assuming instead that the assets available in our model are one period bonds with a risk premium:[14]

$$i_t^B = i_t + \xi_t. \tag{3}$$

Here i_t^B, the return on the bond, is the sum of the policy rate i_t and of the risk premium ξ_t. Second, we add one more dimension of monetary policy: besides setting the interest rate, the central bank in each country buys domestic assets by creating reserves. We denote b_t^{CB} the amount of the domestic bond purchased by the central bank and we model the risk premium as made of an exogenous (fixed) component and of an endogenous component, which depends on central bank purchases:[15]

$$\xi_t = \xi - \gamma(b_t^{CB} - b^{CB}). \tag{4}$$

In such setting the UIP writes:

$$\left(i_{ea,t}^B - \mathbb{E}_t[\pi_{t+1}^{ea}]\right) - \left(i_{us,t}^B - \mathbb{E}_t[\pi_{t+1}^{us}]\right) = \mathbb{E}_t\,\Delta q_{t+1} - (\chi b_t + \phi_t). \tag{5}$$

Notice that under the above assumptions, when the risk-free rate is at the zero lower bound, monetary policy is still effective, as it can reduce the risk premium via QE. Indeed, it suffices to rewrite the UIRP as:

$$\left(i_{ea,t} - \mathbb{E}_t[\pi_{t+1}^{ea}]\right) - \left(i_{us,t} - \mathbb{E}_t[\pi_{t+1}^{us}]\right) = \mathbb{E}_t\,\Delta q_{t+1} - (\chi b_t + \phi_t + \xi_{ea,t} - \xi_{us,t}) \tag{6}$$

We will now show that such condition can be mapped in a model with shadow rates: let us then define:

$$b_t^{CB} = b^{CB} - \frac{s_t}{\gamma} \tag{7}$$

where γ is a mapping parameter. Then, the condition for mapping the two models is the following:

$$\begin{cases} i_t = s_t \text{ and } b_t^{CB} = b^{CB} & \text{for } s_t \geq 0 \\ i_t = 0 \text{ and } b_t^{CB} = b^{CB} - \frac{s_t}{\gamma} & \text{for } s_t < 0 \end{cases} \tag{8}$$

In both cases, it can be easily seen that the UIRP will look like

$$\left(s_{ea,t} - \mathbb{E}_t[\pi_{t+1}^{ea}]\right) - \left(s_{us,t} - \mathbb{E}_t[\pi_{t+1}^{us}]\right) = \mathbb{E}_t\,\Delta q_{t+1} - (\chi b_t + \phi_t). \tag{9}$$

[14] The source of this risk premium (liquidity or default risk) for the case at hand is immaterial. Similarly, instead of having a one period bond, we could introduce a long-term bond and interpret the spread with the risk free asset as a term premium due to duration risk.

[15] Such assumption is indeed justified by a vast literature on the portfolio balance effect of quantitative easing policies (see eg.Gagnon et al. 2011).

B Log-linearized equations of the model

Euro area economy

$$c_{ea,t} - h_{ea}\bar{c}_{ea,t-1} = \mathbb{E}_t[c_{ea,t+1} - h_{ea}\bar{c}_{ea,t}] - \tfrac{1-h_{ea}}{\sigma}(i_{ea,t} - \mathbb{E}_t\,\pi_{ea,t+1}) + \tfrac{1-h_{ea}}{\sigma}(g_,t^{ea} - \mathbb{E}_t\,g^{ea}_{t+1}) \quad \text{(B.1)}$$

$$y_{ea,t} = (1-\alpha_{ea})c_{ea,t} + \eta_{ea}\alpha_{ea}(2-\alpha_{ea})s_t + \eta_{ea}\alpha_{ea}\psi_{us,t} + \alpha_{ea}y_{us,t} \quad \text{(B.2)}$$

$$\pi^{ea}_t = \pi^*_{ea,t} + \alpha_{ea}\Delta s_t \quad \text{(B.3)}$$

$$mc_{ea,t} = \frac{\sigma}{1-h_{ea}}(c_{ea,t} - h_{ea}\bar{c}_{ea,t-1}) - \varphi_{ea}y_{ea,t} + \alpha_{ea}s_t - (1+\varphi_{ea})a^{ea}_t \quad \text{(B.4)}$$

$$\pi_{ea,t} - \delta_{ea}\pi_{ea,t-1} = \frac{(1-\theta_{ea})(1-\theta_{ea}\beta)}{\theta_{ea}}mc_{ea,t} + \beta\,\mathbb{E}_t[\pi_{ea,t+1} - \delta_{ea}\pi_{ea,t}] + cp^{ea}_t \quad \text{(B.5)}$$

$$\pi^*_{ea,t} - \delta^*_{ea}\pi^*_{ea,t-1} = \frac{(1-\theta^*_{ea})(1-\theta^*_{ea}\beta)}{\theta^*_{ea}}\psi_{ea,t} + \beta\,\mathbb{E}_t[\pi^*_{ea,t+1} - \delta^*_{ea}\pi^*_{ea,t}] + cp^{ea}_t \quad \text{(B.6)}$$

US economy

$$c_{us,t} - h_{us}\bar{c}_{us,t-1} = \mathbb{E}_t[c_{us,t+1} - h_{us}\bar{c}_{us,t}] - \tfrac{1-h_{us}}{\sigma}(i_{us,t} - \mathbb{E}_t\,\pi_{us,t+1}) + \tfrac{1-h_{us}}{\sigma}(g^{us}_t - \mathbb{E}_t\,g^{us}_{t+1}) \quad \text{(B.7)}$$

$$y_{us,t} = (1-\alpha_{us})c_{us,t} + \eta_{us}\alpha_{us}(2-\alpha_{us})s_t + \eta_{us}\alpha_{us}\psi_{us,t} + \alpha_{us}y_{ea,t} \quad \text{(B.8)}$$

$$\pi^{us}_t = \pi^*_{us,t} + \alpha_{us}\Delta s_t \quad \text{(B.9)}$$

$$mc_{us,t} = \frac{\sigma}{1-h_{us}}(c_{us,t} - h_{us}\bar{c}_{us,t-1}) - \varphi_{us}y_{us,t} + \alpha_{us}s_t - (1+\varphi_{us})a^{us}_t \quad \text{(B.10)}$$

$$\pi_{us,t} - \delta_{us}\pi_{us,t-1} = \frac{(1-\theta_{us})(1-\theta_{us}\beta)}{\theta_{us}}mc_{us,t} + \beta\,\mathbb{E}_t[\pi_{us,t+1} - \delta_{us}\pi_{us,t}] + cp^{us}_t \quad \text{(B.11)}$$

$$\pi^*_{us,t} - \delta^*_{us}\pi^*_{us,t-1} = \frac{(1-\theta^*_{us})(1-\theta^*_{us}\beta)}{\theta^*_{us}}\psi_{us,t} + \beta\,\mathbb{E}_t[\pi^*_{us,t+1} - \delta^*_{us}\pi^*_{us,t}] + cp^{us}_t \quad \text{(B.12)}$$

International risk sharing

$$i_{ea,t} - \mathbb{E}_t\,\pi^{ea}_{t+1} = i_{us,t} - \mathbb{E}_t\,\pi^{us}_{t+1} + \mathbb{E}_t\,\Delta q_{t+1} - (\chi b_t + \phi_t) \quad \text{(B.13)}$$

$$b_t = \beta^{-1}b_{t-1} - \alpha_{ea}(q_t - \alpha_{ea}s_t) + y_{ea,t} - c_{ea,t} \quad \text{(B.14)}$$

$$\psi_{us,t} = e_t + p^*_t - p_{us,t} = q_t - (1-\alpha)s_t \quad \text{(B.15)}$$

$$\Delta s_t = \pi_{us,t} - \pi_{ea,t} \quad \text{(B.16)}$$

Monetary policy

$$i_{ea,t} = \rho^{ea}_i i_{ea,t-1} + (1-\rho^{ea}_i)(\psi_{\pi,h}\pi_{ea,t} + \psi_{y,h}y_{ea,t}) + \sigma^{ea}_{mp}\varepsilon^{ea}_{mp,t} \quad \text{(B.17)}$$

$$i_{us,t} = \rho^{us}_i i_{us,t-1} + (1-\rho^{us}_i)(\psi_{\pi,f}\pi_{us,t} + \psi_{y,f}y_{us,t}) + \sigma^{us}_{mp}\varepsilon^{us}_{mp,t} \quad \text{(B.18)}$$

Exogenous shocks ($j = ea, us$)

$$g^j_t = \rho^j_g g^j_{t-1} + \sigma^j_g\varepsilon^j_{g,t} \quad \text{(B.19)}$$

$$a^j_t = \rho^j_a a^j_{t-1} + \sigma^j_a\varepsilon^j_{a,t} \quad \text{(B.20)}$$

$$\phi_t = \rho_\phi\phi_{t-1} + \sigma_\phi\varepsilon_{\phi,t} \quad \text{(B.21)}$$

$$cp^j_t = \rho^j_{cp}cp^j_{t-1} + \sigma^j_{cp}\varepsilon^j_{cp,t} \quad \text{(B.22)}$$

C Description of the data

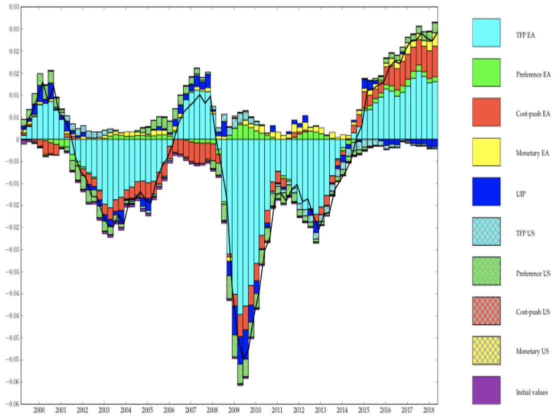
We download data for the euro area from the ECB Statistical Data Warehouse and data for the United Stated from the FRED database. For the EA we employ quarterly seasonally adjusted GDP and in the robustness section we disaggregate it using the industrial production index the the monthly frequency and data on population. We use CPI and GDP deflators as consumer price index and producer price index respectively. The official monetary policy rate is proxied the EONIA rate for the EA and by the FedFunds Rate for the US. All data for the EA is based on the 19 countries aggregation. We collect the same variables for the US from the FRED database. The exchange rate comes from the ECB dataset, and it is originally defined as dollars per unit of euros.

Table 3: *Data series tickers*

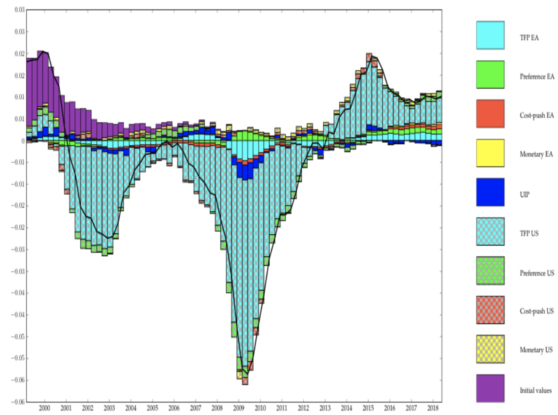
Series	ECB Data warehouse	FRED database
GDP	MNA.Q.Y.I8.W2.S1.S1.B.B1GQ._Z._Z._Z.EUR.LR.N	GDPC1
CPI	ICP.M.U2.Y.000000.3.INX	CPIAUCS
i	FM.M.U2.EUR.4F.MM.EONIA.HSTA	FEDFUNDS
NER	EXR.D.USD.EUR.SP00.A	
IP	STS.M.I8.Y.PROD.NS0040.4.000	INDPRO
POP	DD.A.I8.POPE.LEV.4D	POPTHM

D Additional graphs and tables

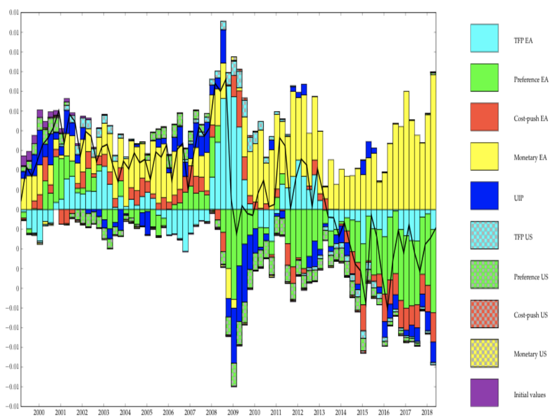
Figure 5: *Historical decomposition of output and inflation for the EA and the US*



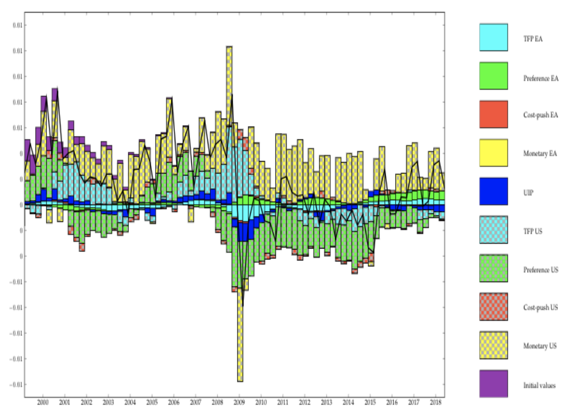
Output EA



Output US



Inflation EA



Inflation US

Figure 6: *Counterfactual exchange rate developments with Krippner's (2013) shadow rate*

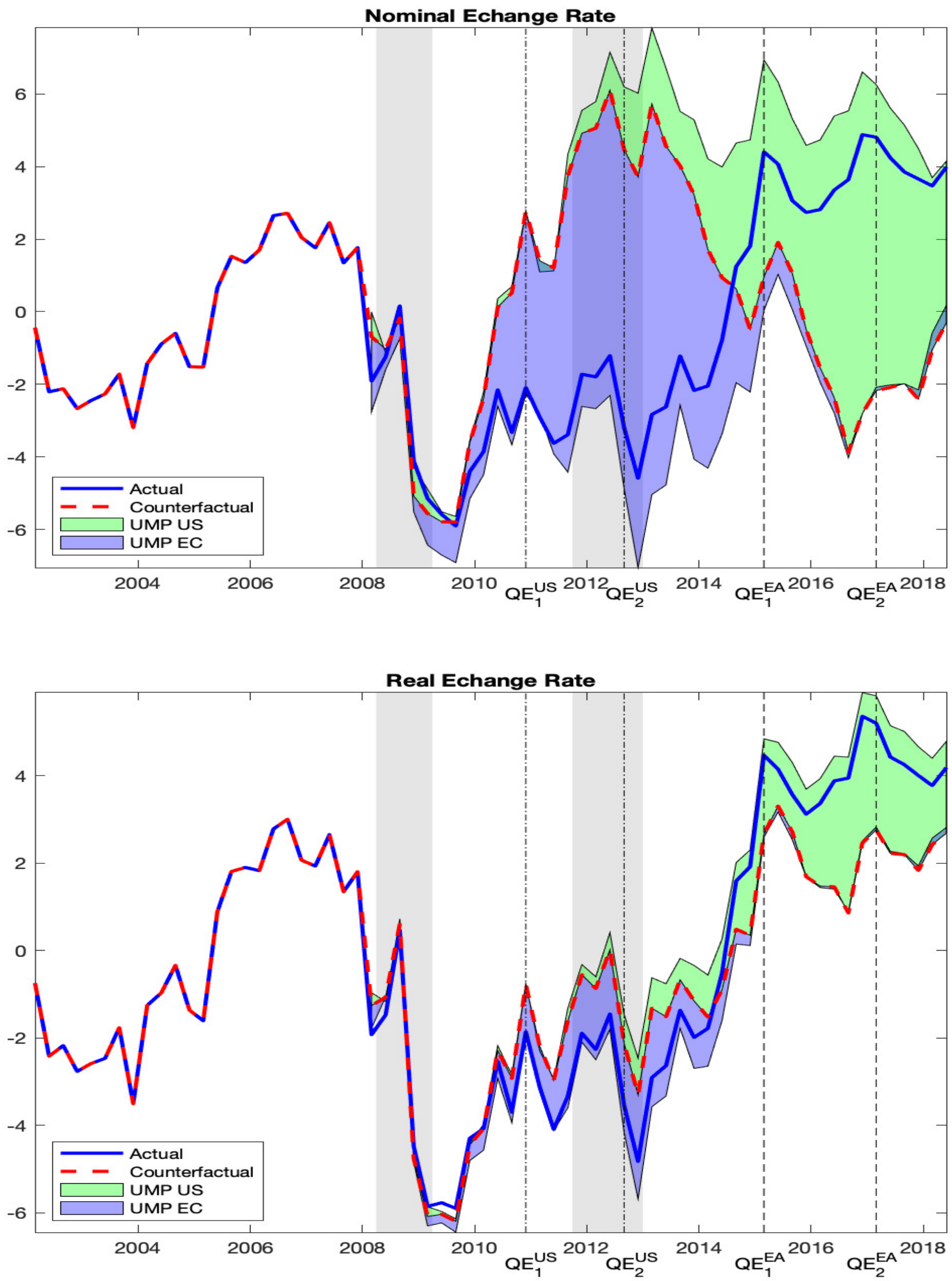
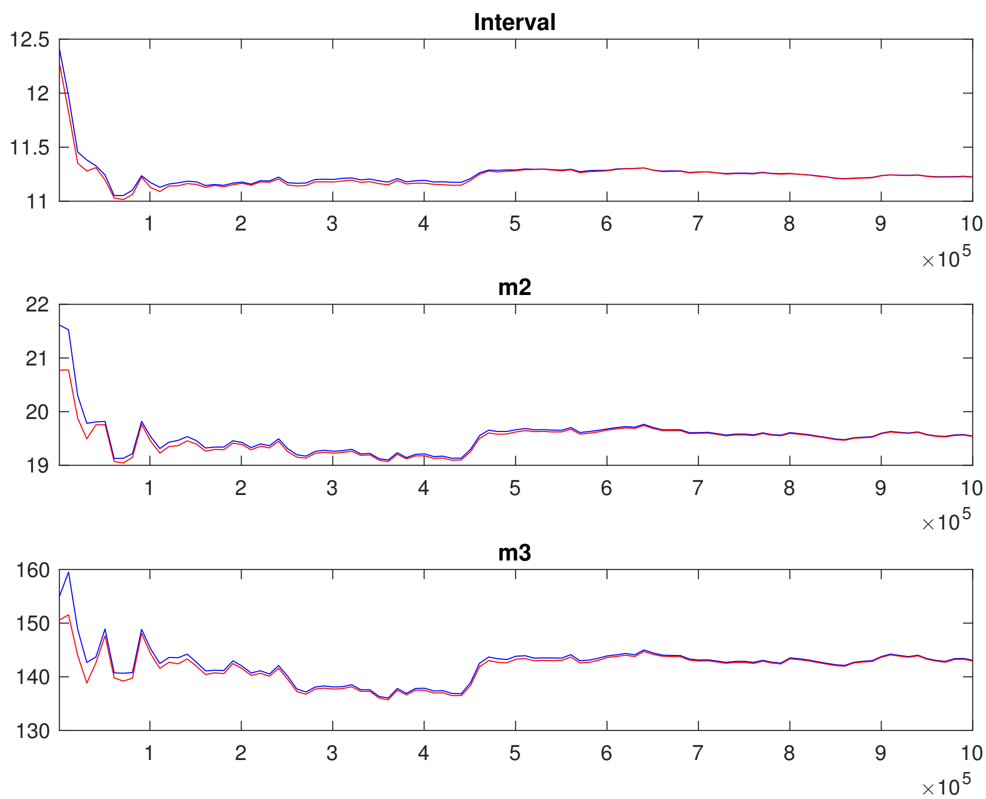


Figure 7: *Multivariate convergence a lá (Brooks and Gelman, 1998)*



Note that interval tells the length of the HPDI with an 80% coverage of the posterior distribution, M2 represenst the variance and M3 the skewness; the red and blue lines represent the within-sequence and the between-sequence of the sum of the chains.

Table 4: *Variance decomposition with Krippner's (2013) shadow rate*

	Euro area					United States			
	TFP	Pref.	Cost push	Monetary policy	Risk premium	TFP	Pref.	Cost push	Monetary policy
Output EA	74.69	1.26	15.98	1.69	3.28	0.61	2.38	0.08	0.03
Inflation EA	24.56	11.33	14.24	44.24	4.1	0.33	1.03	0.12	0.05
Output US	1.06	0.59	0.36	0.05	1.05	90.56	1.06	4.66	0.61
Inflation US	0.44	0.31	0.17	0.02	1.07	15.99	13.81	7.4	60.79
RER	11.27	13.64	14.34	0.87	25.67	14.13	18	1.63	0.45
NER	8.29	10.9	12.56	4.38	29.81	12.16	15.87	1.04	4.99

Values are expressed as percentage points.

Table 5: *Parameters estimation with Krippner (2013) shadow rate*

		Prior			Posterior		HPDI[a]				Prior			Posterior		HPDI[a]	
	Parameters	Dist.[b]	Mean	S.D.	Mode	Mean	5%	95%		Parameters	Dist.[b]	Mean	S.D.	Mode	Mean	5%	95%
									Euro Area								
η	Inv. elasticity of subs.	$\mathcal{G}$	1.5	0.25	1.68	1.24	0.663	1.884	ρ_i	Taylor rule persistence	$\mathcal{B}$	0.5	0.1	0.73	0.62	0.49	0.753
φ	Inverse Frisch elasticity	$\mathcal{G}$	1.5	0.25	1.49	1.49	1.086	1.892	ρ_a	TFP persistence	$\mathcal{B}$	0.5	0.1	0.48	0.42	0.257	0.571
δ	Indexation domestic	$\mathcal{B}$	0.5	0.15	0.34	0.4	0.164	0.609	ρ_g	Preferences persistence	$\mathcal{B}$	0.5	0.1	0.64	0.9	0.644	0.996
θ	Calvo domestic prices	$\mathcal{B}$	0.5	0.05	0.46	0.49	0.411	0.581	ρ_{cp}	Cost push persistence	$\mathcal{B}$	0.5	0.1	0.45	0.41	0.242	0.564
δ^*	Indexation import	$\mathcal{B}$	0.5	0.15	0.57	0.55	0.343	0.779	σ_a	TFP std. dev.	$\mathcal{IG}$	0.25	2	0.04	0.04	0.033	0.05
θ^*	Calvo import prices	$\mathcal{B}$	0.5	0.05	0.46	0.47	0.392	0.539	σ_g	Preferences std. dev.	$\mathcal{IG}$	0.25	2	0.04	0.05	0.034	0.061
ψ_π	Taylor rule, inflation	$\mathcal{G}$	2	0.3	1.99	1.62	1.227	2.207	σ_{cp}	Cost push std. dev.	$\mathcal{IG}$	0.25	2	0.04	0.04	0.035	0.054
ψ_y	Taylor rule, ΔGDP	$\mathcal{G}$	0.5	0.1	0.75	1.37	0.67	1.83	σ_{mp}	Mon. pol. std. dev.	$\mathcal{IG}$	0.25	2	0.03	0.03	0.025	0.036
h	Habit	$\mathcal{B}$	0.5	0.1	0.28	0.14	0.043	0.306									
									United States								
η	Inv. elasticity of subs.	$\mathcal{G}$	1.5	0.25	1.01	1.07	0.816	1.343	ρ_i	Taylor rule persistence	$\mathcal{B}$	0.5	0.1	0.38	0.38	0.244	0.504
φ	Inverse Frisch elasticity	$\mathcal{G}$	1.5	0.25	1.52	1.56	1.122	1.991	ρ_a	TFP persistence	$\mathcal{B}$	0.5	0.1	0.93	0.92	0.888	0.952
δ	Indexation domestic	$\mathcal{B}$	0.5	0.15	0.5	0.5	0.248	0.741	ρ_g	Preferences persistence	$\mathcal{B}$	0.5	0.1	0.96	0.96	0.936	0.975
θ	Calvo domestic prices	$\mathcal{B}$	0.5	0.05	0.5	0.5	0.423	0.582	ρ_{cp}	Cost push persistence	$\mathcal{B}$	0.5	0.1	0.81	0.79	0.691	0.901
δ^*	Indexation import	$\mathcal{B}$	0.5	0.15	0.14	0.18	0.057	0.303	σ_a	TFP std. dev.	$\mathcal{IG}$	0.25	2	0.03	0.03	0.029	0.04
θ^*	Calvo import prices	$\mathcal{B}$	0.5	0.05	0.22	0.22	0.167	0.273	σ_g	Preferences std. dev.	$\mathcal{IG}$	0.25	2	0.05	0.05	0.039	0.069
ψ_π	Taylor rule, inflation	$\mathcal{G}$	2	0.3	3.14	3.13	2.609	3.674	σ_{cp}	Cost push std. dev.	$\mathcal{IG}$	0.25	2	0.06	0.06	0.043	0.087
ψ_y	Taylor rule, ΔGDP	$\mathcal{G}$	0.5	0.1	0.64	0.67	0.443	0.879	σ_{mp}	Mon. pol. std. dev.	$\mathcal{IG}$	0.25	2	0.04	0.04	0.03	0.043
h	Habit	$\mathcal{B}$	0.5	0.1	0.07	0.08	0.043	0.112									
									Risk premium shock								
ρ_u	persistence	$\mathcal{B}$	0.5	0.1	0.23	0.22	0.134	0.299	σ_u	std. dev.	$\mathcal{IG}$	0.25	2	0.03	0.03	0.025	0.035

The table reports the prior density and the posterior estimates for the model's parameters, along with the 5% and 95% credible intervals.

[a] *The highest posterior density intervals (HPDI) are computed with respect to the mode of the posterior distribution.*
[b]*The distributions we consider are: Gamma, $\mathcal{G}$, Beta, $\mathcal{B}$ and Inverse Gamma, $\mathcal{IG}$.*

Table 6: Variance decomposition with hours worked

	Euro area					United States			
	TFP	Pref.	Cost push	Monetary policy	Risk premium	TFP	Pref.	Cost push	Monetary policy
Output EA	59.63	0.82	29.75	3.96	2.76	1.04	1.88	0.12	0.04
Inflation EA	26.86	9.65	19.11	40.33	2.61	0.55	0.71	0.14	0.04
Output US	0.37	0.15	0.26	0.05	0.31	92.38	0.34	5.56	0.58
Inflation US	0.51	0.2	0.05	0.03	0.62	24.58	9.41	8.19	56.41
RER	10.11	10.21	17.13	1.65	19.43	24.35	13.92	2.66	0.54
NER	6.6	7.52	14.24	6.89	23.28	21.18	12.42	1.84	6.03

Values are expressed as percentage points.

Table 7: Variance decomposition at the monthly frequency

	Euro area					United States			
	TFP	Pref.	Cost push	Monetary policy	Risk premium	TFP	Pref.	Cost push	Monetary policy
Output EA	95.34	0.74	2.5	0.16	0.43	0.13	0.67	0.02	0.01
Inflation EA	17.87	12.23	10.84	54.8	2.82	0.35	0.88	0.14	0.09
Output US	3.32	1.76	0.78	0.01	0.9	88.66	1.86	2.43	0.3
Inflation US	0.1	0.12	1.01	0.03	0.42	17.24	14.35	7.49	59.24
RER	14.98	20.15	20.31	0.18	10.1	15	17.72	1.13	0.43
NER	13.79	19.38	20.16	1.79	10.67	13.09	15.77	0.84	4.51

Values are expressed as percentage points.

Table 8: Variance decomposition before the GFC

	Euro area					United States			
	TFP	Pref.	Cost push	Monetary policy	Risk premium	TFP	Pref.	Cost push	Monetary policy
Output EA	55.18	0.38	28.31	5.76	5.43	1.18	2.42	0.82	0.52
Inflation EA	24.62	8.31	20.4	39.73	3.33	1.07	1.47	0.75	0.32
Output US	2.25	0.72	0.98	0.4	2.96	48.99	7.79	31.24	4.67
Inflation US	0.76	0.29	0.02	0.01	0.73	29.58	18.17	21.67	28.77
RER	10.68	7.78	13.17	2.81	26.81	13.64	12.26	9.17	3.68
NER	5.59	4.55	9.19	11.61	32.54	7.94	7.28	5.19	16.11

Values are expressed as percentage points.

Table 9: *Variance decomposition after the GFC*

	Euro area					United States			
	TFP	Pref.	Cost push	Monetary policy	Risk premium	TFP	Pref.	Cost push	Monetary policy
Output EA	62.11	0.62	24.53	3.53	5.43	0.96	1.86	0.54	0.41
Inflation EA	24.7	11.06	20.28	36.53	4.34	0.93	1.21	0.6	0.34
Output US	2.86	1.22	1.1	0.35	3.54	56.43	5.56	24.54	4.41
Inflation US	0.82	0.44	0.03	0.01	0.97	26.22	15.6	18.55	37.36
RER	12.81	10.88	14.19	2.19	28.56	11.98	10.14	6.24	3.01
NER	7.63	6.94	10.36	8.16	33.57	8.02	6.66	3.91	14.74

Values are expressed as percentage points.

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