Revisiting the exchange rate dynamics at the US zero lower bound

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This study revisits the dynamics of dollar/euro exchange rate in response to the US monetary policy shock at the zero lower bound (ZLB) including the COVID-19 pandemic. The key findings are as follows. First, the exchange rate behavior indicates Dornbusch (1976)'s overshooting hypothesis at the states classified as beginning and ending of the ZLB. Second, the revived ZLB induced by the COVID-19 pandemic has a larger impact on the exchange rate than that induced by the global financial crisis. Third, the responses of the exchange rates demonstrate the uncovered interest rate parity and the overshooting.

Keywords: Exchange rate overshooting; Shadow federal funds rate; Zero lower bound, COVID-19 pandemic; Time-varying VAR; Uncovered interest rate parity

JEL Classification: E52; E58; F31; F41

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I. Introduction

After suffering two economic recessions including the global financial crisis and COVID-19 pandemic, the Federal Reserve System (Fed) has adopted the zero lower bound (ZLB) to overcome these recessions. The Fed decided to lower the target range for the federal funds rate (FFR) of 0% to 0.25%, which is generally called the ZLB. The ZLB was implemented to stimulate the economic conditions for the first time in the global financial crisis and revived during the COVID-19 pandemic. Such an implementation suggests that the ZLB is no longer temporary but can be a feasible monetary policy tool in the future recessions, so research on the ZLB is needed. In practice, central banks usually implement the monetary policy by setting the target of interest rates; moreover, they can influence the dynamics of exchange rates by changing the interest rates. However, unlike the conventional monetary policy, the target of interest rate is constrained near zero, so it may be possible to derive the different dynamics of exchange rate in response to the monetary policy shock.

In the field of the international finance, the traditional monetarist model of the relationship between the interest rate (monetary policy) and exchange rate is the Mundell–Fleming–Dornbusch model. The key theory is Dornbusch (1976)'s overshooting hypothesis. Dornbusch (1976) states that a monetary contraction induces an immediate appreciation in the spot exchange rate on impact, which exceeds the long-run level of appreciation, and then the exchange rate gradually depreciates toward the long-run level. Previous studies focus on finding the empirical evidence of Dornbusch's overshooting hypothesis (see Table 1). Focusing on the effects of unconventional monetary policy shocks on the exchange rates, monetary easing (tightening) leads to depreciation (appreciation) in the exchange rate. Aksit (2021) finds that the unconventional monetary policy easing (including forward guidance and large-scale asset purchases) leads to a significant depreciation in the exchange rate throughout the ZLB period. Moreover, Glick and Leduc (2018) show that the exchange rate effect of the unconventional monetary policy is much greater than that of the conventional monetary policy conducted through the FFR. Despite the many previous studies related to the exchange rate overshooting in response to conventional and unconventional monetary policies, no study explores the dynamics of exchange rates at the particular states of the ZLB – the beginning or the end of the ZLB. The present study investigates the effects of the unconventional US monetary policy shocks on the US dollar/euro exchange rates depending on the states of the ZLB, that is, when the Fed decides to begin or end the ZLB.[1]

Most previous studies have employed the vector autoregressive (VAR) model as macroeconomic policy analysis since Sims (1980). By contrast, the present study employs the time-varying VAR (TV-VAR) model with stochastic volatility described by Primiceri (2005) to model changes in the policy and represent the policy effects precisely. As TV-VAR model with stochastic volatility can capture not only structural changes between monetary policy and macroeconomic variables but also a possible time-varying structure in the economy in a flexible and robust manner, it is broadly used in analyzing macroeconomic issues.[2] Moreover, this study adopts the shadow FFR estimated by Wu and Xia (2016) as proxy of the FFR to investigate the effects of unconventional monetary policy shock.[3] In particular, for reflecting the states of the ZLB, this study considers the point estimations on December 2008 (the first beginning of the ZLB), December 2015 (the first ending of the ZLB), and March 2020 (the second beginning of the ZLB). To estimate the impulse responses in the respective periods, I make use of the TV-VAR with stochastic volatility as proposed by Primiceri (2005).

The key findings of this study are as follows. First, the US dollar appreciates in response to a contractionary monetary policy shock regardless of the states of the ZLB. Second, the maximum appreciation

[1] Although this study covers conventional and unconventional periods, I focus on the specific points related to ZLB. Therefore, the results represent the effects of the unconventional monetary policy shocks.

[2] Studies using the TV-VAR model to analyze the effects of the monetary policy shocks on the exchange rate include Mumtaz and Sunder-Plassmann (2013), Paul (2020), and Yang and Zhang (2021). Considering the time variations can suggest the evolution in volatility of the exchange rate as well as the changes across time in response of exchange rate to structural monetary policy shocks, so the TV-VAR model can derive clear results with respect to state of ZLB.

[3] Wu and Xia (2016) find that the shadow FFR can be employed to study unconventional monetary policy's impact on the real economy. Similarly in Kim and Yim (2021), the US has adopted various unconventional monetary policies so that the estimated shadow FFR is more proper to analyze the overall monetary policy stance than FFR.

occurs within two months after the shocks in terms of nominal and real exchange rates, which is consistent with Dornbusch's overshooting hypothesis. Third, the magnitude of the exchange rate is larger during the COVID-19 pandemic than during the global financial crisis because of monetary policy uncertainty according to Dornbusch's statement.

The rest of this study is organized as follows. Section 2 briefly explains the empirical strategy, including the econometric model and the application of the US economy, with the data. Section 3 reports the empirical results. Section 4 concludes with the summary.

II. Empirical strategy

A. Econometric model

This study estimates the reduced-form TV-VAR model with stochastic volatility proposed by Primiceri (2005). In models with stochastic volatility, not only the coefficients but also the covariance matrix of residuals are allowed to change over time, that is, these models can distinguish between the structural changes in the parameters of monetary policy and changes in the magnitudes of shocks. Allowing the covariance matrix varies over time is crucial for a TV-VAR if the simultaneous interactions among variables are fundamental.

I estimate the reduced-form system of equations as follows:

$$y_t = X_t^{'} B_t + u_t, \tag{1}$$

where y_t is a vector of observed endogenous variables, B_t is a vector of time-varying coefficients, and u_t is heteroscedastic unobservable shocks with variance covariance matrix Ω_t.

Without loss of generality, I consider the triangular reduction of Ω_t defined by $A_t \Omega_t A_t' = \sum_t \sum_t'$, where A_t is the lower triangular matrix consisting of elements α_t, and $\sum_t$ is the diagonal matrix with σ_t. Consequently, $y_t = X_t' B_t + A_t' \sum_t \varepsilon_t$, where $Var(\varepsilon_t) = I_n$.

The time-varying parameters are modeled as random walks or geometric random walks as follows:

$$B_t = B_{t-1} + \nu_t \tag{2}$$

$$\alpha_t = \alpha_{t-1} + \xi_t \tag{3}$$

$$\log \sigma_t = \log \sigma_{t-1} + \eta_t, \tag{4}$$

where $\nu_t \overset{i.i.d}{\sim} N(0,Q), \xi_t \overset{i.i.d}{\sim} N(0,S), and\ \eta_t \overset{i.i.d}{\sim} N(0,W)$.

All the innovations in the model are assumed to be jointly normally distributed on the following variance-covariance matrix:

$$V = Var\left(\begin{bmatrix}\varepsilon_t \\ \nu_t \\ \xi_t \\ \eta_t\end{bmatrix}\right) = \begin{bmatrix} I_n & 0 & 0 & 0 \\ 0 & Q & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & W \end{bmatrix} \tag{5}$$

where I_n is an n-dimensional identity matrix, and Q, S, and W are positive definite matrices.

For the technical details of the Bayesian Markov chain Monte Carlo estimation with Gibbs sampling, see Primiceri (2005) and Del Negro and Primiceri (2015). Briefly, Bayesian Markov chain Monte Carlo methods are used to evaluate the posterior distributions of the parameters of interest (B^T, A^T, $\sum^T$, V) with the four steps of the Gibbs sampling. If the identification is based on recursive scheme, it easily imposes the corresponding restrictions. To estimate the TV-VAR, I identify the structural shocks using the short-run recursive restriction with Cholesky decomposition.

B. Application of the US economy

The econometric model and techniques described above are applied to estimate a monthly model of the US economy. Six variables are included in the model: industrial production for US and euro area, consumer price index for US, shadow FFR estimated by Wu and Xia (2016), shot-term interest rate for euro area, and nominal exchange rate in terms of US dollar relative to euro.[4] For the policy rate, I choose the shadow FFR instead of FFR. During the ZLB period, the FFR no longer conveys any information about monetary policy, so the shadow FFR displays the summary for the monetary policy.[5]

[4] The VAR model is ordered as US industrial production, US consumer price index, euro area industrial production, euro area short-term interest rate, Wu and Xia shadow federal funds rate, and US dollar/euro exchange rate, referring to Eichenbaum and Evans (1995).

[5] Studies that use the Wu and Xia shadow FFR instead of FFR include Chen,

The sample runs from January 2000 to December 2021. Six-month lags are used for the estimation. The simulations are based on 10,000 iterations for the Gibbs sampler, discarding the first 2,000 for convergence. The first five years (60 observations, from January 2000 to December 2004) are used to calibrate the prior distributions.

The estimated points are selected by the states of the ZLB, including three points based on the FOMC statements — the first beginning on December 2008, the first ending on December 2015, and the second beginning on March 2020.

III. Empirical results

A. Main results

I focus on the exchange rate dynamics in response to monetary policy shock depending on the states of the ZLB. The key theory is Dornbusch (1976)'s overshooting hypothesis, which predicts that an exchange rate appreciates on impact and then gradually depreciates toward its long-run value in response to a contractionary monetary policy shock. I estimate the impulse responses of the exchange rate for three points based on the states of the ZLB.[6]

Figure 1 plots the impulse responses of the nominal exchange rate for US to a US contractionary monetary policy shock with 68% probability bands.[7] First, I obtain the following empirical evidence from the median impulse responses of the exchange rate. The contractionary monetary policy shock leads to appreciation for all points. In addition, the maximal appreciation of US dollar occurs within two months followed by gradual depreciation (overshooting). These findings are consistent with those of the previous empirical studies — Rosa (2012), Neely (2015), Glick and Leduc (2018), Rogers, Scotti and Wright (2018), Inoue and Rossi (2018), and Akisit (2021).

Lombardi, Ross, and Zhu (2017); Eksi and Tas (2017); Francis, Jackson, and Owyang (2020); and Debortoli, Galí, and Gambetti (2020).

[6] I focus on the dynamics of the exchange rate and provide the impulse responses of other variables in the Appendix. Even though I use the recursive identification scheme, the price falls in response to contractionary monetary policy shock, which indicates no puzzle in price.

[7] I take the innovations in Wu and Xia (2016)'s shadow FFR to identify the unconventional monetary policy shocks.

Second, I compare the median responses between the states of the ZLB. During the first round of the ZLB, the response at the beginning of the ZLB is much larger than that at the ending of the ZLB. Moreover, the second beginning of the ZLB has much larger response than the first beginning of the ZLB.

These results indicate that the dynamics of the exchange rate verifies the exchange rate overshooting and that the exchange rate reacts more volatile during the second round of the ZLB than during the first round. Dornbusch (1976) states that the monetary policy uncertainty can be the key driver of the exchange rate dynamics, implying that the ZLB due to the COVID-19 pandemic leads to larger monetary policy uncertainty than that due to the global financial crisis. Hence, the larger monetary policy uncertainty makes the larger response of exchange rate dynamics.[8]

Furthermore, the uncovered interest rate parity (UIP) is the one of the key assumptions in Dornbusch's overshooting hypothesis. Figure 2 plots the impulse responses of interest rate differentials (*i.e.*, differences in impulse responses between Wu and Xia (2016)'s shadow FFR and euro area short-term interest rate) and the exchange rate to test the UIP conditions. If the UIP holds, the US dollar appreciates in response to a contractionary US monetary shock that leads to higher US interest rate relative to foreign interest rate (i.e., positive interest rate differentials). The interest rate differentials are positive, and the exchange rates appreciate in response to a US contractionary monetary policy shock.[9] This evidence demonstrates that the UIP holds, supporting the exchange rate overshooting.

Figure 3 plots the impulse responses of real exchange rate instead of nominal exchange rate. The nominal and real exchange rates behave very similarly. The exchange rate overshoots at all points, and the largest response occurs at the second beginning of the ZLB. The

[8] Based on Baker–Bloom–Davis monetary policy uncertainty index, the monetary policy uncertainty is larger and more volatile at the ZLB during the COVID-19 pandemic (from March 2020 to March 2022) than during the global financial crisis (from December 2008 to December 2015).

[9] In detail, if UIP holds, a positive innovation in Wu and Xia shadow FFR relative to euro interest rate should lead to a persistent depreciation of the US dollar over time after the impact appreciation. Figure 2 shows the positive interest rate differential leads to impact appreciation followed by gradual depreciation.

robustness of the results to use nominal exchange rates is consistent with previous studies.

Therefore, the dynamics of the exchange rate is consistent with Dornbusch (1976)'s overshooting hypothesis. To compare between the states of the ZLB, the exchange rate responses largely at the beginning of the ZLB than at the ending of the ZLB, which suggests that the response at the second ending of the ZLB on March 2020 is smaller than that at the second beginning of the ZLB. However, due to the large monetary policy uncertainty, it can be larger than that at the first ending of the ZLB. Therefore, policymakers need to prepare the stabilization policy, which can absorb the feasible negative shocks on exchange rate in response to Fed's big step.

B. Model extensions

This study extends the benchmark model in two directions: (1) by replacing Wu and Xia (2016)'s shadow FFR with the FFR in the benchmark model to check whether Wu and Xia (2016)'s shadow rate is effective monetary policy indicator at the ZLB or not and (2) by excluding a stochastic volatility in the benchmark VAR model to check whether the stochastic volatility captures the changes in the states of the ZLB or not.

First, regarding the FFR, as a tool of the conventional monetary policy, Figure 4 plots the impulse responses of the exchange rate in response to a contractionary monetary policy shock at the ZLB. The US dollar depreciates on impact, which indicates the exchange rate puzzle at the first round of the ZLB. However, at the second beginning of the ZLB, the exchange rate appreciates and overshoots. These results confirm that Wu and Xia (2016)'s shadow FFR can act as the proper proxy indicator of the FFR at the ZLB.

Second, regarding the stochastic volatility, which is crucial for analyzing the dynamics of the contemporaneous relations among the variables of the system, Figure 5 plots the impulse responses in response of the exchange rate without a stochastic volatility in benchmark VAR model. The US dollar depreciates regardless of the state of the ZLB, which is the exchange rate puzzle. Moreover, the responses are very similar, suggesting that the states of the ZLB cannot be distinguished. These results verify that the stochastic volatility is empirically important to distinguish the specific states of the ZLB.

Overall, employing the estimated indicator of the unconventional monetary policy and stochastic volatility is necessary to clearly analyze the effects of the unconventional monetary policy at the ZLB.

IV. Conclusion

This study investigates the effects of the monetary policy shock on the exchange rate at the ZLB. This study draws the impulse responses of the exchange rate by employing the time-varying structural VAR model with stochastic volatility and applying Wu and Xia (2016)'s shadow FFR as a proxy indicator of the FFR. In addition, this study classifies the states of the ZLB based on the FOMC statements, which are the beginning and ending of the ZLB.

The key findings of this study are as follows. First, after a contractionary US monetary policy shock defined as an increase in Wu and Xia (2016)'s shadow FFR, the US dollar always appreciates on impact, achieving a peak appreciation within two months, and then depreciates gradually. The increase in the US interest rate leads to increase in the interest rate differential, and the US dollar appreciates on impact, indicating that uncovered interest parity holds. These findings are consistent with Dornbusch (1976)'s overshooting hypothesis. Second, the ZLB has the most sizable impact on the US dollar on March 2020, which implies that the COVID-19 pandemic has larger uncertainty. Moreover, the ZLB induced by the COVID-19 pandemic has a larger influence on the US dollar than that induced by the global financial crisis. Therefore, the exchange rate behavior is in line with the theoretical predictions by Dornbusch (1976) even at the ZLB.

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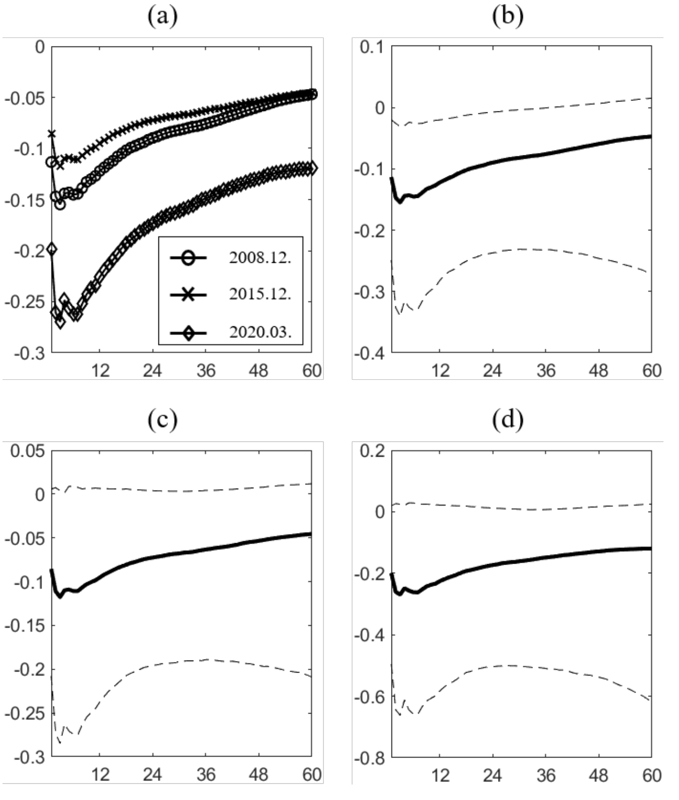
Table and Figures

TABLE 1

SELECTED EMPIRICAL STUDIES ON THE RESPONSE OF EXCHANGE RATES

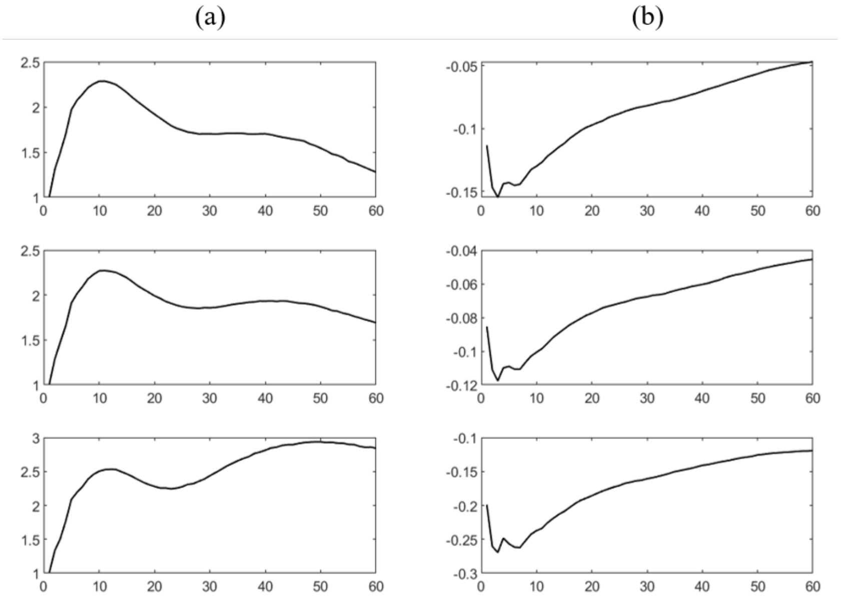
Response of exchange rates	References
Overshooting	• Kalyvitis and Michaelides (2001); Forni and Gambetti (2010); Binder, Chen, and Zhang (2010); Inoue and Rossi (2019); Rüth (2020)
Delayed overshooting	• Eichenbaum and Evans (1995), Scholl and Uhlig (2008), Bouakez and Normandin (2010), Ahn and Kim (2021)
Either overshooting or delayed overshooting	• Faust and Rogers (2003); Bluedorn and Bowdler (2011); Kim, Moon, and Velasco (2017); Rogers, Scotti, and Wright (2018)



Note: (a) Median impulse responses of exchange rate on December 2008, December 2015, and March 2020; (b), (c), (d) Impulse responses of exchange rate with 68% probability bands, respectively.

Figure 1

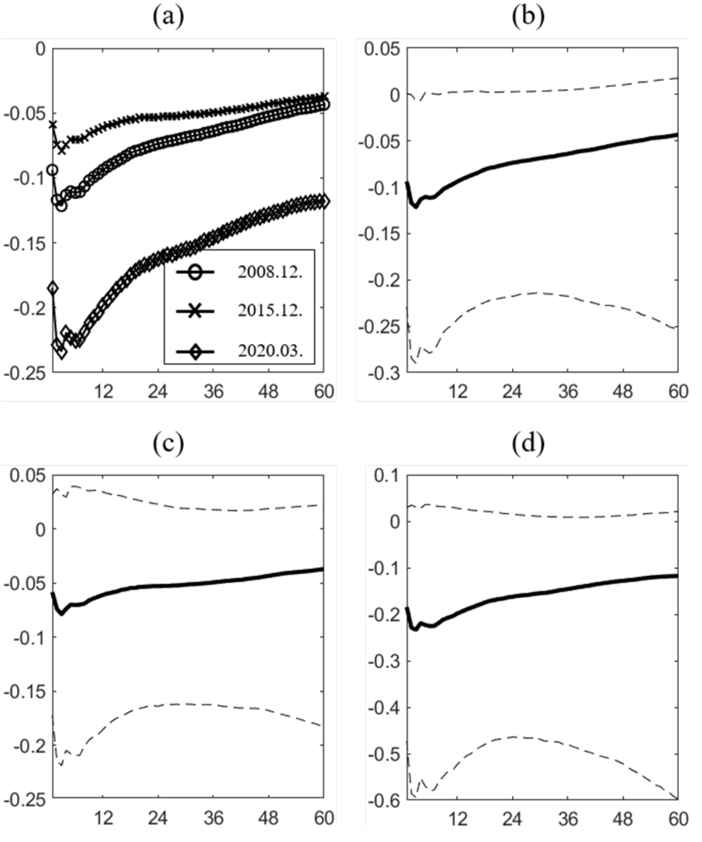
Impulse responses of the exchange rate



Note: (a) Interest rate differentials, (b) Impulse responses of exchange rate; each row represents on December 2008, December 2015, and March 2020.

Figure 2

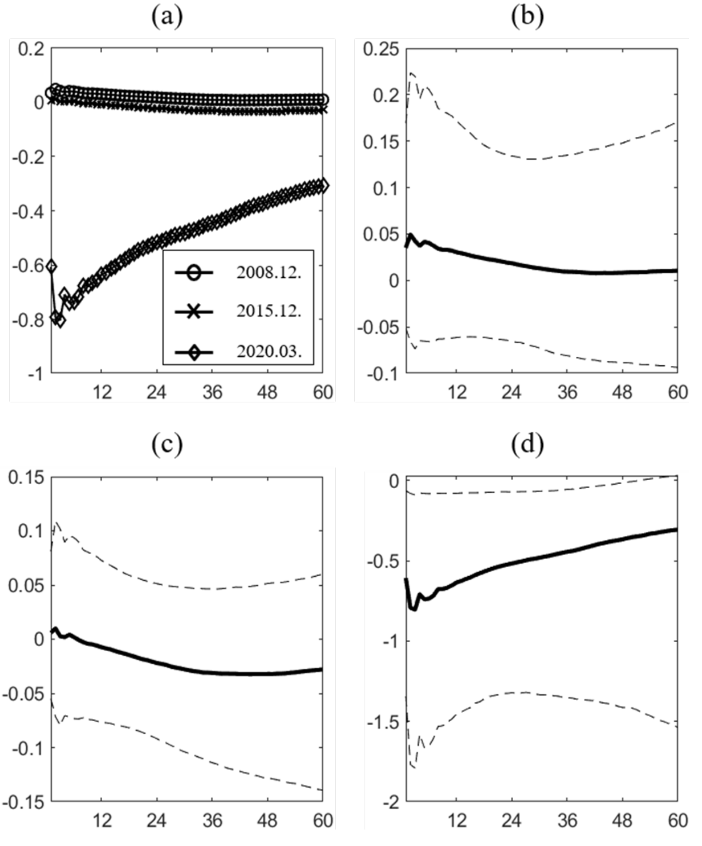
Median impulse responses of the interest rate differentials and exchange rate



Note: (a) Median impulse responses of real exchange rate on December 2008, December 2015, and March 2020; (b), (c), (d) Impulse responses of exchange rate with 68% probability bands, respectively.

Figure 3

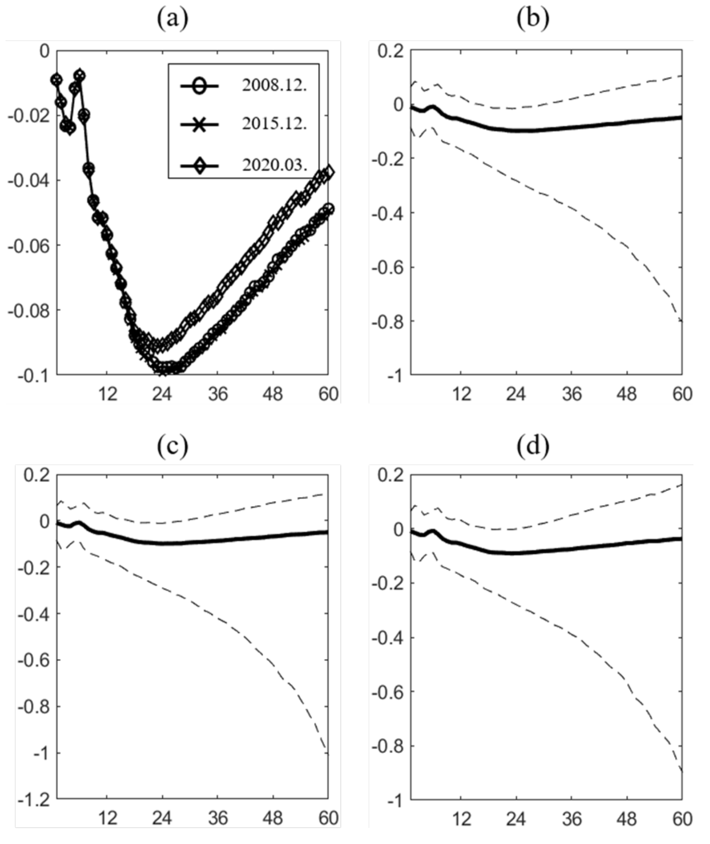
Impulse responses of the real exchange rate



Note: (a) Median impulse responses of exchange rate on December 2008, December 2015, and March 2020; (b), (c), (d) Impulse responses of exchange rate with 68% probability bands, respectively.

Figure 4

Impulse responses of the exchange rate with FFR



Note: (a) Median impulse responses of exchange rate on December 2008, December 2015, and March 2020; (b), (c), (d) Impulse responses of exchange rate with 68% probability bands, respectively.

Figure 5

Impulse responses of the exchange rate without stochastic volatility

Appendix

TABLE A1
DATA DESCRIPTION AND SOURCES

Variable	Description	Source
y	Industrial Production for the US	FRED, Federal Reserve Bank of St. Louis
p	Consumer Price Index for the US	OECD Statistics
y^*	Total industry Excluding Construction for the Euro Area	FRED, Federal Reserve Bank of St. Louis
i^*	Call Money/Interbank Rate for the Euro Area	FRED, Federal Reserve Bank of St. Louis
wx	Wu and Xia (2016)'s Shadow FFR	https://sites.google.com/view/jingcynthiawu/shadow-rates
ff	Federal Funds Effective Rate	FRED, Federal Reserve Bank of St. Louis
e	US Dollars to Euro Spot Exchange Rate (in terms of US dollar)	FRED, Federal Reserve Bank of St. Louis
q	$q = ep^* / p$	Author's calculation
p^*	Consumer Price Index for the Euro Area	OECD Statistics

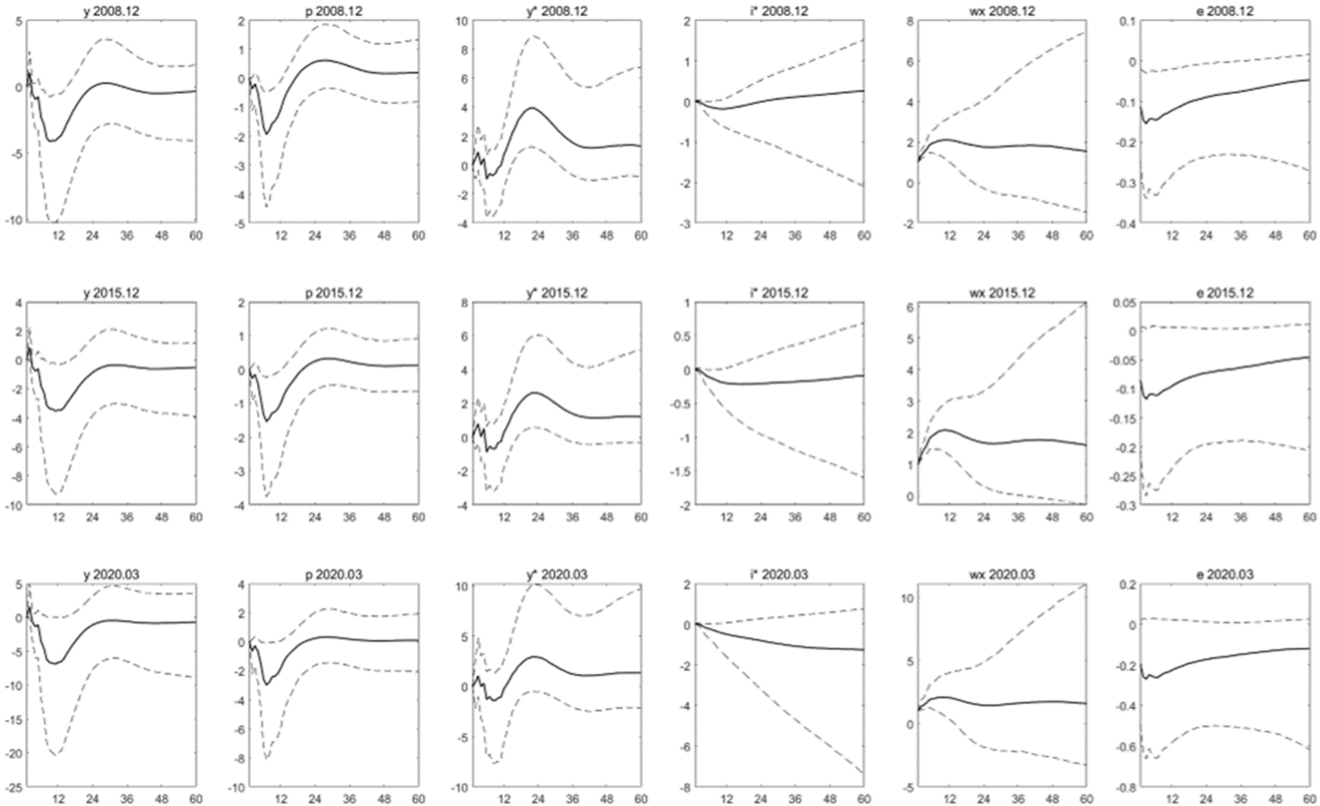


Figure A1

Impulse responses of the relevant variables in benchmark model

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