Real Exchange Rate, Monetary Policy, and the U.S. Economy – Evidence from a FAVAR Model

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Abstract

This paper examines the effects of exchange rate depreciation to the U.S. economy in a factor-augmented VAR model using monthly data of 148 variables for the post Bretton Woods period of 1973-2017. Exchange rate shock is identified to reflect exogenous disturbances to the foreign exchange market, and movements in exchange rate that are not accounted for by changes in the U.S. monetary policy. We find that depreciation is expansionary and inflationary to the broad U.S. economy, the current account improves over time conforming to the J-curve theory, and monetary policy is leaning against the wind. *(JEL* E3, E5, F31, F32, F41*)*

Keywords: real exchange rate, monetary policy, FAVAR, U.S. economy, current account, J-curve, prices, employment

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I. INTRODUCTION

The breakdown of the Bretton Woods system in early 1970s embarked on the transition of the world monetary system from fixed exchange rates to floating. With accelerated globalization and stronger international financial linkages, exchange rate uncertainty and fluctuations are increasingly becoming a high risk to countries engaging in international trade and capital flows. Over the last 50 years global trade more than tripled, and world exports to GDP ratio reached a remarkable 30 percent (Fischer, 2015).[3] The foreign exchange market, currently the largest financial market, records an average daily transaction volume of over $5 trillion, far exceeding that of other markets including equities, bonds, and commodities; and the U.S. dollar accounts for 88% of that volume (Scutt, 2016). Fluctuations originating from the foreign exchange market can potentially distort real exchange rates, and hold far-reaching implications for an economy's production, consumption, prices, and financial conditions.

Measuring the effects of exchange rate fluctuations is becoming more important to the U.S. economy for two primary reasons. First, the U.S. economy has become much more open relative to the Bretton Woods period, which directly exposes the U.S. economy to external shocks. U.S. trade, that is, imports and exports increased from around 5% of U.S. GDP in the early 1970s to 17.3% and 13.6%, respectively, by 2011 (Figure 1). U.S. FDI, that is, assets and liabilities rose from 7.5% and 2.5% of U.S. GDP in the 1970s to 40% and 36%, respectively, by 2014 (Figure 2). U.S. residents' ownership of all types of foreign assets reached $25 trillion, or 140% of U.S. GDP, and foreign ownership of U.S. assets reached $30 trillion, or 170% of U.S. GDP, by 2015 (Fischer, 2015). With such high exposure to trade and capital flows, exchange rate fluctuations could loom very large for the U.S. economy. Second, the emergence of the Euro, the Japanese yen and the

[3] The world exports to GDP ratio is roughly 17 percent for the U.S.

strengthening of the Chinese renminbi in recent years have called for changes to the existing international monetary order, in which the dollar historically played the role of anchor since the Bretton Woods era, creating more uncertainty and volatility in the value of the U.S. dollar and potentially more risks to the U.S. economy (Eichengreen and Kawai, 2015; Fratzscher and Mehl, 2014; Galati and Wooldridge, 2009; Goldberg, 2010).

(Figure 1 - 3 about here)

We use three alternative measures of real exchange rate in this paper: REER is the real narrow effective exchange rate computed by the Bank for International Settlement; RERN is the real trade weighted U.S. dollar index against major currencies computed by the Board of Governors of the Federal Reserve System (the Fed); and RERB is the real trade weighted U.S. dollar index against a broad basket of foreign currencies computed by the Fed. Figure 3 plots the three measures of exchange rate from January 1973 to June 2017. We note that the U.S. dollar experienced three main cycles of real depreciation-appreciation during the post-Bretton Woods period: 1) January 1973 to February 1985; 2) February 1985 to April 2002; and 3) April 2002 to present. What role does the foreign exchange market play in explaining these cyclical exchange rate fluctuations? How does the exchange rate shock (idiosyncratic disturbances in the foreign exchange market) affect the broad U.S. economy? In this paper, we attempt to answer these questions using a factor-augmented VAR (FAVAR) model. In particular, we investigate the effects of exchange rate depreciation shock, which originates from the foreign exchange market as opposed to that from the U.S. money and financial sector (e.g. monetary policy), and the U.S. real sector (e.g. production, employment, consumption, prices, trade etc).

According to Buiter (2000), “under a high degree of international financial integration, market-determined exchange rates are primarily a source of shocks and instability”. Despite its importance, not much attention has been paid in the literature to the effects of this important "source of shocks" (Buiter, 2000; and Artis and Ehrmann, 2006). Most existing studies on the effects of exchange rate (for various countries) focus only on one or two aspects of the economy; further, most of them do not distinguish movements in exchange rate explained as an endogenous reaction to monetary policy shocks from fluctuations in exchange rate caused by exogenous exchange rate shocks originating from the foreign exchange market (Edwards, 1986; Clarida, 1997; Kamin and Rogers, 2000; Shi, 2006; Bahmani-Oskooee and Ratha, 2008; Chiu et al., 2010; and so on). Our study attempts to fill the gap and makes the following important contributions to the literature. First, we are able to successfully disentangle movements in the exchange rate explained by exchange rate shocks from those explained by U.S monetary policy shocks, it is the former whose effects to the economy is the main focus of this study. Second, unlike many studies which only focus on one or two aspects of the U.S. economy due to limited information set and degrees of freedom issue in their traditional VAR approach, we examine the broad spectrum of the U.S. economy using the more recent and less restrictive factor-augmented vector autoregression (FAVAR) framework. To the best of our knowledge, our paper is the first study of the comprehensive and stand-alone effects of the U.S. dollar exchange rate depreciation shock to the U.S. economy in an integrated FAVAR framework.

Our empirical framework is an extension of the novel model developed by Bernanke et al. (2005) in the context of the effects of U.S. monetary policy shock to the U.S. economy. Using the one-step Bayesian likelihood approach and the Gibbs sampling technique, we estimate a four-dimensional FAVAR model, with three latent factors representing abstract economic concepts for "economic activity", "price level", and "monetary policy", respectively, and the real exchange rate as the observable variable. We identify the exchange rate shock as innovations to the real exchange rate using the conventional Cholesky decomposition. We then evaluate the effects of the exchange rate depreciation shock to a wide selection of U.S. macroeconomic variables. Our dataset contains monthly time series data of 148 variables for the post-Bretton Woods period ranging from January 1973 to March 2017.

According to Bernanke et al. (2005), FAVAR model has several distinctive advantages over traditional VAR models. First, abstract economic concepts like "economic activity" and "price level" cannot be accurately measured by a single variable, like industrial production or consumer price index, instead, latent factors can be estimated from a large number of relevant variables to more closely measure such broad concepts. Moreover, combining information from multiple data series in this fashion generates superior estimates to using a single data series for each concept. Second, FAVAR model allows us to conduct our analysis using a large number of macroeconomic variables, which better reflect the true information set used by policymakers and economic agents in making economic decisions.

An important issue in our study is to correctly identify the exchange rate shock. Seminal works by Lastrapes (1992) and Clarida and Gali (1994) have spawned numerous research in understanding sources of real exchange rate fluctuations. Using different identification schemes and VAR models, Clarida and Gali (1994), Farrant and Peersman (2006), and Artis and Erhmann (2006) find that nominal shocks explain a substantial amount of variation in the U.S. dollar real exchange rate. Further, Artis and Erhmann (2006) decompose nominal shocks into monetary policy and pure exchange rate shocks (shocks purely originating from the foreign exchange market) and find that the latter plays a more important role in real exchange rate fluctuations. Following Artis and Ehrmann (2006), and Bernanke et al. (2005), we identify four structural shocks: supply shock, demand shock, monetary policy shock, and exchange rate shock, using a recursive identification structure of the factors/observable variable and Cholesky decomposition. Our monetary policy shock is similar to that of Clarida and Gali (1994); our monetary policy factor is estimated from a large number of monetary variables reflecting both money supply and money demand. However it is different from Bernanke et al. (2005), where only the observable federal funds rate is used as a measure of monetary policy.[4] Our exchange rate shock resembles that of Artis and Erhmann (2006); it reflects the residual shocks to real exchange rate when supply shock, demand shock, and monetary shock are all controlled for.

To correctly identify movements in exchange rate caused by exogenous exchange rate shocks (originating from the foreign exchange market), it is necessary to purge out movements in exchange rate explained as an endogenous reaction to U.S. monetary policy shocks, given the latter's guiding role in the world financial markets. The literature provides rich evidence for the significant effects of U.S. monetary policy, especially to the exchange rate, for both developed and emerging economies (Eichenbaum and Evans, 1995; Bouakez and Normandin, 2010; Bluedorn and Bowdler, 2011; Bonser-Neal et al., 1998, and so on). Eichenbaum and Evans (1995) find that a contractionary shock to U.S. monetary policy leads to persistent, significant appreciations in U.S.

[4] An important issue is whether to use a monetary policy factor extracted from a group of related interest rate and monetary quantity variables, or use the observable federal funds rate (FFR) alone as an indicator of monetary policy in our model. With the latter case, FFR would enter the estimation as an observable variable rather than a factor. Given our studied period, the former – the monetary policy factor – is a better idea because of the following reason: monetary policy in practice could be conventional or unconventional, depending on what the economic situation warrants. Monetary policy is not exclusively represented/measured by the FFR, but rather by a whole package of actions by the Fed which can affect both the long-term interest rate and the short-term interest rate; this is most reflective during the recent Great Recession of 2007-2009, when the Fed intentionally lowered the long-term interest rate by the "twist operation". Further, during the Great Recession, FFR hit the zero lower bound and became an ineffective policy tool, in response to which, the Fed resorted to unconventional monetary policies, and other more quantitative measures of monetary policy tools to exert further influence on the economy. Based on the above discussion, our understanding is that during periods of unconventional monetary policy, just using one short term interest rate, i.e., the FFR as an indicator of monetary policy, could potentially lead to bias in the estimation results (this is also consistent with arguments of Francis et al., 2014; Laurent, 1988). In lieu of the above, we have a strong preference for using the "monetary policy factor" over simply the observable FFR as an indicator of monetary policy in our empirical model. To further check if using the FFR alone as an indicator of monetary policy really causes any bias in the results, we ran the estimation using the FFR as an observable variable (rather than as a factor) in robustness check. We find that most results are consistent with the baseline model but the CPI showed a puzzling response – a decrease rather than an increase in response to an exchange rate depreciation shock. The results are shown in Appendix E, Figure AE10.

nominal and real exchange rates. Bonser-Neal et al. (1998) find that U.S. exchange rate responds immediately to U.S. monetary policy actions like changes in the federal funds rate target. Bouakez and Normandin (2010) document that exchange rate depreciates in response to U.S. monetary expansion and that monetary policy shocks account for a non-trivial proportion of exchange rate fluctuations. Bluedorn and Bowdler (2011) find that U.S. dollar appreciates relative to the G6 currencies in response to a contractionary U.S. monetary policy. On the general macroeconomic front, Goldberg and Tille (2009) find that the dollar's role as the international currency has magnified the exposure of periphery countries to the U.S. monetary policy even though their trade with the U.S. is limited. Mackowiak (2007) also finds that U.S. monetary policy shocks affect interest rates and the exchange rate in a typical emerging market quickly and strongly and that the price level and real output in a typical emerging market respond to U.S. monetary policy shocks by more than the price level and real output in the U.S. itself.

All the studies document U.S. monetary policy shocks to be a major source of real exchange rate fluctuations. Therefore, for the purpose of our study, it is imperative to disentangle exchange rate movements as a result of U.S. monetary policy shocks from those caused by pure exchange rate shocks. In our FAVAR framework, supply, demand, and monetary policy shocks are all accounted and controlled for, thus the remaining real exchange rate fluctuation can be plausibly attributed to idiosyncratic disturbances in the foreign exchange market. The main objective of our study is to examine the effects of this "last" shock to the U.S. economy.

Our results lend support to the view that exchange rate depreciation shock is expansionary and inflationary to the U.S. economy. Among the evidence for expansionary effects of depreciation are falling unemployment rate, increasing industrial production, manufacturing, employment, nonagricultural payroll, capacity utilization, housing start, stock market prices, trade, import and export. Among the evidence for its inflationary effects, are rise in all prices – import price, export price, consumer price, producer price, and ISM manufacturing price index – in response to the depreciation shock. Consistent with most studies, we find that exchange rate depreciation shock helps improve the U.S. current account over time. Further, our results support the J-curve hypothesis, that is, exchange rate depreciation tends to first worsen the current account balance and then improve it later. We also find that monetary policy in the U.S. is leaning against the wind. The Fed tightens the money supply and increases the federal funds rate in response to depreciation shock. However, the effect on consumption appears insignificant. Not only consumer confidence falls but personal consumption at best rises transitorily in response to exchange rate depreciation. For most macroeconomic variables, exchange rate shock accounts for a nontrivial share of the forecast error variance decompositions, at 7-20+%. These results suggest that monetary policy alone may not be enough to mitigate the potential effects of exchange rate fluctuations on the U.S. economy. Other measures are called for if mitigating the exchange rate shock arising from the foreign exchange market seems important. Our results hold for multiple schemes of robustness check analysis, including the alternative two-step principal component analysis of FAVAR estimation (following Stock and Watson, 2011; Bahadir and Lastrapes, 2015; and others).

The rest of the paper is organized as follows. Section II describes the empirical methodology. Section III discusses the data and presents the empirical results. Section IV checks for robustness. And Section V concludes.

II. EMPIRICAL MODEL

Assume that Y_t is a $M \times 1$vector of observable variables, which has widespread effects on the economy. In this paper, Y_t contains one variable, the U.S. dollar real exchange rate. The economy that Y_t affects can be described by X_t, which is an $N \times 1$ vector of macroeconomic variables, where

N is large. Assume that a $K \times 1$ vector of unobservable factors, F_t, can be extracted from X_t and reflects the co-movements of variables in X in period t. F_t represents abstract economic concepts, such as, for this paper in particular, "economic activity", "price level", and "monetary policy", respectively, that cannot be simply represented by one or two time series. We assume that X_t are related to the unobservable factors F_t and the observable real exchange rate Y_t in the following observation equation:

$$X_t = \Lambda^f F_t + \Lambda^y Y_t + u_t\,,\ u_t \sim N(0, R) \qquad (2.1)$$

where Λ^f and Λ^y are $N \times K$ and $N \times M$ matrices of factor loadings, respectively, and u_t is the vector of $N \times 1$ error terms with mean 0 and covariance matrix R (assumed to be diagonal).

Assume that the joint dynamics of (F_t, Y_t) are described by the following VAR process:

$$\begin{bmatrix} F_t \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_{t-1} \\ Y_{t-1} \end{bmatrix} + v_t\,,\ v_t \sim N(0, Q) \qquad (2.2)$$

where $\Phi(L)$ is the conformable lag polynomial of order p, which may contain *a priori* restrictions. The error term v_t has mean 0 and covariance matrix Q.

The system in (2.1) and (2.2) follows Bernanke et al. (2005). Our extensions are the following: 1) we incorporate monetary policy as a factor rather than an observable variable as in Bernanke et al. (2005), and extract the factor from a large number of variables representing both money supply and money demand in the spirit of Clarida and Gali (1994); and 2) we include the real exchange rate as the observable variable (assumed to have pervasive effects on the U.S. economy), and order it last in a recursive structure.[5] Following Artis and Erhman (2006), we treat the exchange rate

[5] In the spirit of the FAVAR model proposed by Bernanke et al. (2005), the variable from which the central economic shock of study is identified is treated as the observable variable. For example, in the paper by Bernanke et al. (2005), monetary policy shock is the focus of the study and thus the federal funds rate is used as the observable variable; in a study of how oil price shock affects the U.S. economy, An et al. (2014) use the crude oil price as the observable variable in their nonlinear FAVAR model; and in a study of how U.S. dollar appreciation shock affects the U.S. and other Asian economies, Liu et al. (2017) use the trade-weighted U.S. dollar index as the observable variable in their

shock as idiosyncratic disturbances/innovations to the real exchange rate originating from the foreign exchange market, as opposed to that as a reaction to U.S. monetary policy changes.

A. Estimation

Equation (2.2) cannot be estimated directly because the factors, F_t, are unobservable. According to Bernanke et al. (2005), there are two approaches to estimate the system. One is a two-step principal component approach proposed by Stock and Watson (2011), and the other is a single-step Bayesian likelihood method. The principal component approach is recognized for its computational simplicity but it does not take into account the VAR structure at the step of extracting the factors; on the other hand, the Bayesian approach may be more computationally cumbersome but takes into account the VAR structure while estimating the factors. Further, Gibbs sampling is complimented for "its ability to circumvent the high-dimensionality of the model and trace the shape of the joint posterior even if the posterior is irregular and complicated" (Bernanke, et al., 2005). Thus it is unclear which method is theoretically superior. In this paper, we use the one-step Bayesian approach of FAVAR estimation as our baseline model, where we conduct the joint estimation of factors, and the VAR system using the likelihood-based Gibbs sampling technique, developed by Geman and Geman (1984), Gelman and Rubin (1992), and Carter and Kohn (1994).[6] However, we use the two-step principal component analysis of FAVAR estimation

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FAVAR model. In our study, exchange rate shock is the center of study, thus we use alternative measures of the real exchange rate as the observable variable. Among others, Artis and Ehrmann (2006), and Farrant and Peersman (2006) also use real exchange rate to identify the exchange rate shock. To check for robustness, we also estimate the model using the nominal broad trade-weighted U.S. dollar index as the observable variable, and find qualitatively similar results. See Robustness check results in Appendix E, Figure AE9 for details.

[6] Appendix B. provides a detailed summary of the estimation process using Gibbs sampling. Please refer to Bernanke et al. (2004) for more technical details. The Bayesian approach with Gibbs sampling is also used by An et al. (2014), Kose et al. (2003), Bianchi et al. (2009), and Liu et al. (2017), among others.

as an alternative to check for the robustness of our baseline results (section IV) and find highly consistent results.[7]

B. Identification

Two identification concerns arise in our estimation, when using Gibbs sampling. One concerns uniquely identifying the factors against any rotations. The other concerns identifying the exchange rate shock in the VAR.

For the first concern, we assume that a general rotation of F_t has the following form:

$$F_t^* = AF_t - BY_t, \tag{2.3}$$

where A is $K \times K$ and nonsingular, and B is $K \times M$. We substitute F_t from the rotation form *(2.3)* into the observation equation (2.1), we get:

$$X_t = \Lambda^f A^{-1} F_t^* + (\Lambda^y + \Lambda^f A^{-1} B) Y_t + u_t \tag{2.4}$$

In order to uniquely identify the factors against their rotations, it is necessary that their loadings meet the following criteria: $\Lambda^f A^{-1} = \Lambda^f$ and $\Lambda^y + \Lambda^f A^{-1} B = \Lambda^y$. It is sufficient to set the upper $K \times (K + M)$ block of the loadings matrix Λ to be $[I_K, 0_{KxM}]$, that is, to set the upper $K \times K$ block of Λ^f to an identity matrix and the upper $K \times M$ block of Λ^y to zero. This only requires that the first K variables be the "slow-moving" variables; slow moving variables indicate variables which do not contemporaneously respond to innovations in the real exchange rate.[8] To identify the exchange rate shock from the VAR system (2.2), we assume a simple recursive ordering, and place the real exchange rate last. We identify the structural shocks using Cholesky decomposition.[9]

[7] Appendix D provides a detailed summary of the estimation process using the two-step principal component analysis. Appendix E, Figures AE11-AE12 presents the results. Please refer to Stock and Watson (2011), and Bahadir and Lastrapes (2015) for more technical details.
[8] Appendix A. provides detailed description of the slow and fast moving variables.
[9] We are aware that other identification schemes can be used as well, such as the Blanchard and Quah (1989) long run zero restrictions, the mixture of long run and short run zero restrictions as in Artis and Ehrmann (2006), or sign restrictions as in Farrant and Peersman (2006), among others. But as Bernanke et al. (2004) discusses, use of more complicated identification schemes like the above mentioned will introduce an excessive amount of computational

We base our inferences from 15,000 Gibbs sampling draws with the first 3,000 discarded as burn-in. To check for convergence, we apply various priors on parameters, and the VAR equations. Convergence appears to occur as the use of alternative priors or 30,000 or 60,000 draws generate qualitatively similar results.[10] We estimate our baseline model with 7 lags, and 3 factors: for economic activity, price level and monetary policy, respectively.[11] We calculate the impulse responses, and report the median as well as the 16% and 84% quantiles from the posterior distributions of the factors and parameters.[12] We also compute the variance decompositions for the first 60 months.

III. EMPIRICAL RESULTS

X_t consists of a balanced panel of 147 monthly U.S. macroeconomic variables ranging from 1973:02 to 2017:03. The dataset is obtained from the Federal Reserve Economic Database (FRED) of the St. Louis Fed, and the *International Financial Statistics (IFS)* of the International Monetary Fund (IMF). The variables are log first differenced or first differenced to impose stationarity (as in Kose, Otrok, and Whiteman, 2003).[13]

A. Estimated Factors

(Figure 4 about here)

burden to the already computation-heavy Gibbs sampling process. However, it is in the authors' intention to pursue other identification schemes for further research along the line.

[10] The results are not presented here to save space but will be made available upon request.

[11] It is an important concern to select the appropriate number of factors. As discussed in Bernanke et al. (2004), the criterion by Bai and Ng (2002) cannot be directly applied to the Bayesian likelihood estimation used in this paper. In the robustness check section, we estimate with 4 factors, 5 factors, or 13 lags and find qualitatively similar results.

[12] The Gibbs sampling method assumes that all the model parameters $\Omega = (\Lambda^f, \Lambda^y, R, vec(\Phi), Q)$ and the factors $\{F_t\}_{t=1}^{T}$ are random variables. The multi-move Gibbs sampling algorithm is then applied to approximate the marginal posterior distributions of Ω and Ft, and the joint posterior distribution by alternately sampling the parameters Ω and the unobserved factors Ft. Thus, the factor loadings matrix – Λ – is not solely defined, but there is a whole distribution of them. However, the mean or the median of the distribution of the factor loadings can be obtained, upon request. The same is true for the estimated factors. Please refer to Appendix B for a description of the estimation process and Bernanke et al. (2004) for more technical details of the method.

[13] A detailed description of the data and their transformation is provided in Appendix A.

RERN is used as the observable real exchange rate in our baseline model estimation.[14] Factor 1, factor 2, and factor 3 are extracted from the large dataset of X_t , representing, respectively, economic activity, price level, and monetary policy. As can be seen in Figure 4, they resemble closely the variables of industrial production, consumer price index, and the federal funds rate, respectively. Correlation coefficients (shown in Appendix C) show that factor 1 is highly correlated with the "real economic activity" variables in the categories of production and employment. Factor 2 is highly correlated with the "price level" variables. And factor 3 is highly correlated with the "monetary policy" variables such as the federal funds rate, 3-month T-bill rate, and etc. These results provide evidence that the factors are plausibly estimated.[15]

(Table 1 about here)

Further we test for the Granger causality relationship between the estimated factors and the real exchange rate and report the results in Table 1. Real exchange rate seems to Granger cause economic activity factor and price factor but not vice versa.[16] No causality is found between the real exchange rate and the monetary policy factor, but when the real exchange rate is replaced with its nominal counterpart, causality runs in both directions.[17] In both cases, causality from the

[14] REER and RERB are used for robustness analysis and the results are presented in Appendix E.

[15] Currently in the literature, the assignment of factors on economic concepts - economic activity, price level, monetary policy, etc - are done in two ways. One way is to see how closely the estimated factor traces the indicator it is supposed to represent, i.e., price level factor vs. consumer price index; economic activity factor vs. industrial production or real GDP, and etc. This method is used by He et al. (2013, pp 94, Figure 4). The second way is by checking the correlations between the estimated factors and the individual variables, as in An et al. (2014, pp 220, Table 1). In our paper, both methods are used. Figure 4 presents the graphs of the estimated factors with the indicators that they proxy, following He et al. (2013). Following An et al. (2014), we present the correlations table between the estimated factors and individual variables in Appendix C. Both methods indicate that our assignment of the factors to the economic concepts is consistent with the literature.

[16] Since the price variables are embedded in both factor 2 – the price level factor and the real exchange rate, causality could be biased if we use the real exchange rate; instead, we need to first remove the price effect from the real exchange rate, that is, to use its nominal counterpart - the nominal trade weighted U.S. dollar index against major currencies published by the Fed – to test for causality between exchange rate and the price level factor. We find that causality runs from the exchange rate to the price factor, but not vice versa. The results from the use of the nominal exchange rate are reported in Table 2.

[17] When we use the real exchange rate, we do not find any causality. But when we replace the real exchange rate with the nominal exchange rate, as done in Footnote 14, we find that causality runs both directions, from the exchange rate to monetary policy and from monetary policy to the exchange rate as well. These results make sense on a careful

exchange rate to the monetary policy factor is larger than that from the monetary policy factor to the exchange rate. These results support that: 1) our model identification scheme to further decompose the exchange rate fluctuations into that accounted for by U.S. monetary policy and that for exogenous foreign exchange market shocks is well justified (Artis and Ehrmann, 2006); and 2) it makes sense to order the real exchange rate last, after the monetary policy factor in the recursive structure.

B. Impulse Responses

Figure 5 through 8 present the impulse responses of 38 selected macroeconomic variables to a one standard deviation depreciation shock in RERN with 16th and 84th percentile confidence bands. The selected macroeconomic variables represent a wide spectrum of the U.S. economy including trade, production and employment, prices and consumption, and money and financial sectors.

(Figure 5 about here)

Trade. Consistent with the J-curve theory, current account balance deteriorates on impact, following the exchange rate depreciation shock but gradually improves over time. In about 15 months after the shock, the increase in the current account balance stabilizes and remains statistically significant.[18] This finding is consistent with the literature (Bahmani-Oskooee and Fariditavana, 2016; Bahmani-Oskooee and Harvey, 2015; Chiu et al., 2010; Thorbecke, 2006; and so on). For example, Chiu et al. (2010) finds that the devaluation of the US dollar deteriorates U.S.

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second thought. The results of no causality when using the real exchange rate support the notion of price stickiness in the short run and the inability of monetary policy to influence prices within a month, where prices are reflected in the real exchange rate. The results of two-way causality with nominal exchange rate suggest the true relationship between monetary policy and the exchange rate, that they are constantly influencing each other. This latter finding further supports the need to remove monetary policy shock as a source of exchange rate fluctuation.

[18] The statistical significance of the impulse responses of the current account appears to be sensitive to the number of Gibbs sampling draws. When using 10,000 draws with the first 2,000 discarded, the impulse response of current account appears to be only marginally significant; but when using 15,000 draws and above, the results are highly significant across all models. As the posterior distributions converge better at higher number of draws, the statistical significance increases.

bilateral trade balance with 13 trading partners, but improves it with 37 trading partners, especially China. Bahmani-Oskooee and Fariditavana (2016) in their study of U.S. trade with 5 of its major trade partners, adopt the non-linear ARDL method and finds supportive evidence for the J-curve theory as well.

Interestingly, both exports and imports increase in response to the exchange rate depreciation shock. The increase in export is statistically significant and consistent with conventional theory. The increase in import is statistically significant, but only up to about 30 months. Higher imports after a depreciation shock indicate that the demand for imports is inelastic and the higher price of imports more than offsets the lower quantity (Levi, 2005). According to the Marshall-Lerner condition, exchange rate depreciation (devaluation) leads to improvement in trade balance only when the sum of the elasticities of export and import is greater than 1. Our results seem to suggest that this condition is not met for the U.S. trade in the short run but is met in the long run. Landon and Smith (2007) document an important finding; the authors differentiate exchange rate movements with respect to import source and those with respect to export destination countries, and find that a currency depreciation from the former has a negative (direct cost) effect while that from the latter has a positive (derived demand) effect on imports of machinery and equipment. They further find that the net effect on import is negative but insignificant. Since both U.S. exports and imports are heavily concentrated on capital goods and consumer durables (as in Erceg et al., 2008), our findings corroborate those of Landon and Smith (2007).

Import price and export price both increase over time in response to exchange rate depreciation shock. According to Polak and Chang (1950), export price can increase after exchange rate depreciation due to two reasons: 1) people make adjustment for the post-shock higher import prices and higher cost of living by demanding higher wages, eventually pushing up export prices; and 2) if foreign demand is inelastic and domestic supply is elastic for the exported goods, then export price will eventually go up after a depreciation shock. Our results are in general consistent with the consensus of partial and declining exchange rate pass-through to the U.S. import and export prices documented in the literature (Ganapolsky and Vilan, 2005; Marazzi and Sheets, 2007; Gopinath and Rigobon, 2008; Auer and Chaney, 2009; Bergin and Feenstra, 2009; and Bussiere et al., 2014).

(Figure 6 about here)

Production and Employment. Exchange rate depreciation shock appears expansionary to the U.S. economy. Industrial production, manufacturing (both durable and nondurable manufacturing), capacity utilization rate, and ISM purchasing manager's index all increase in response to the depreciation shock over time. Further, unemployment rate falls, employment especially nonagricultural employment and payroll, and the ISM manufacturing employment index all increase. All of the above results are statistically significant. Average weekly hours worked increase but the result is only marginally significant; average nominal hourly earnings increase and the result is statistically significant. Our findings are consistent with the existing literature. For example, Klein et al. (2003) find that a depreciation shock in the cyclical component of the U.S. dollar exchange rate tends to decrease job destruction but has little effect on job creation, thus it increases net employment growth. This view is shared by, among others, Burgess and Knetter (1998), Goldberg and Tracy (2001); the authors document that the U.S. dollar exchange rate movement is negatively related to aggregate employment growth and nominal wages in the U.S. In particular, our findings with employment match with Huang and Tang (2016), who document that a 1% real exchange rate depreciation has a positive 0.98% direct effect on manufacturing employment in U.S. cities and its indirect effect on the local nonmanufacturing employment increases with the size of the local manufacturing sector and can be up to 60% as large as the direct effect.

(Figure 7 about here)

Prices and Consumption It appears that an exchange rate depreciation shock is inflationary to the U.S. economy. Similar to the import price and export price discussed earlier, consumer price index, producer price index for both finished goods and all commodities, and the ISM manufacturing price index all increase over time to the exchange rate depreciation shock. With the rising prices, consumer confidence falls. All results are statistically significant. Real personal consumption exhibits a transitory rise but the result is statistically insignificant. Auer (2015) also finds that a U.S. dollar depreciation results in a pronounced increase in aggregate U.S. producer price inflation.

(Figure 8 about here)

Money and the Financial Sectors Monetary policy seems to be leaning against the wind. An exchange rate depreciation shock leads to a rise in the federal funds rate and a fall in the M2 money supply. 3-month T-bill rate first falls but later rises in about 10 months after the shock. All results are statistically significant. Long-term interest rate, the 10-year T-bond rate, and commercial and industrial loans also rises in the medium to long run, but the results are statistically insignificant. Our findings are consistent with Choudhri and Hakura (2006), who assert that the Fed tightens the money supply after depreciation to reduce the inflationary effects on the economy.

Exchange rate depreciation shock also appears to have positive effects on the stock market and the housing market. Both the S&P and the NASDAQ stock indices, as well as the housing start rise in response to the depreciation shock. All results are statistically significant. The literature documents mixed evidence of the effect of depreciation on stock market (Hsing, 2011; Ajayi and Mougoue, 1996). According to Ajayi and Mougoue (1996), currency depreciation can lead to a decline in stock prices in the short run since the movement of exchange rate can be followed by higher inflation in the future, which makes investors – especially foreign investors – skeptical about the economy. As a result, the stock prices can drop. Furthermore, investors tend to sell equity denominated in the depreciating currency as they are concerned about lower financial profits due to depreciation, which can cause additional negative impact on the economy. On the other hand, Gavin (1989) finds that a dollar depreciation boosts both profits from overseas operations of U.S. businesses and exporting companies in the U.S. and thus financial investors will be willing to purchase more stocks of those companies; this will lead to an increase in stock prices. Given the increasing financial linkages of the U.S. with the rest of the world as discussed at the beginning of the paper, we have reasons to believe that the latter force dominates.

In summary, impulse response results of key macroeconomic variables support the view that exchange rate depreciation shock is expansionary and inflationary to the U.S. economy. First, exchange rate depreciation shock decreases unemployment rate, increases industrial production, manufacturing, employment, nonagricultural payroll, capacity utilization, export, nominal earnings, hours worked, housing start, and stock market prices. Second, the depreciation shock improves the U.S. current account and boosts trade (both imports and exports). Our results also support the J-curve theory. Third, the depreciation shock leads to a rise in all prices – import price, export price, consumer price, producer price, and the ISM manufacturing price index. Finally, monetary policy in the U.S. appears to be leaning against the wind; the Fed follows a contractionary monetary policy to stabilize the economy post the exchange rate depreciation shock. Our results are consistent with the existing literature.

C. Variance Decompositions

Table 2 presents the proportion of forecast error variance of a selected variable that can be explained for by the exchange rate shock and all factors (including the exchange rate) over 60 month horizon.

(Table 2 about here)

The fourth column in Table 3 shows the contribution of the exchange rate shock to the forecast error variance of a selected variable. As can be seen, the exchange rate shock accounts for 7-28% of the forecast error variance of the "production, employment and earnings" variables, 6-13% of the "prices and consumption" variables, 4-70% of the "monetary and financial sectors" variables, and 7-32% of the "trade" variables. Clearly the foreign exchange market breeds their own shocks, and these shocks appear to play a nontrivial role in accounting for fluctuations in the U.S. economy over the study period.

Finally, the R^2 column shows that our model has pretty good explanatory power comparable to many similar studies in the literature. At the 60^{th} month horizon, the model (all factors and exchange rate) successfully explains a substantial proportion of the forecast error variances for variables like industrial production (89%), manufacturing (96%), durable manufacturing (88%), nondurable manufacturing (58%), capacity utilization (95%), nonagricultural payroll (94%), manufacturing payroll (88%), service payroll (80%), real average hourly earnings (62%), consumer price (92%), producer prices (61% and 64%), federal funds rate (77%), import price (54%); and a significant proportion for other variables like import (32%), export price (27%), unemployment rate (44%), employment (36%), and so on.

IV. ROBUSTNESS ANALYSIS

To check for robustness of our results, we conduct the following alternative exercises: 1) use M2 instead of the federal funds rate as the main monetary policy instrument when extracting factor 3; 2) use 4 factors or 5 factors instead of 3; 3) use 13 lags instead of 7; 4) use two alternative measures of real exchange rate, RERB or REER; 5) estimate two specific time periods to check for the consistency of the results, i.e. the Great Moderation period from 1984:01 to 2007:06 and the post Bretton Woods period up to 2007; 6) re-estimate the model using the nominal broad trade-weighted U.S. dollar index; 7) use the federal funds rate as an observable variable (rather than in a factor) in the FAVAR model as well as the real exchange rate; and 8) re-estimate the model using the two-step principal component analysis.[19]

All results from 1) through 6) are qualitatively similar to those obtained from the baseline model. The sub-period analysis provides overall consistent results but exhibits slight difference from the baseline estimation. For example, for the period up to the financial crisis (2007), we note that stock prices increase only marginally for about 6 months post the depreciation shock and then start to fall. During the Great Moderation period (1984-2007), the current account declines in response to a depreciation shock and takes a much longer time to stabilize, and the results are not statistically significant. We further find, that stock prices and CPI both record an increase, but again the results are not statistically significant. In sum, our results for the Great Moderation period support the stability of the U.S. economy during that period. All other results stay qualitatively the same.

Below, we elaborate more on two of the major robustness checks: using the observable federal funds rate (over a latent factor) as an indicator of monetary policy; and using the alternative method

[19] To save space, all results for the robustness analysis is presented in the online Appendix section.

of the two-step principal component analysis of FAVAR estimation. The impulse response results are presented in the online Appendix AE10-AE12.

A. Federal Funds Rate as an Observable Variable

In Bernanke et al. (2005), the monetary policy is represented by the observable federal funds rate (FFR), while in our baseline model, monetary policy is represented by a latent factor from a group of related interest rate and monetary aggregate variables. Our main focus is to examine the effects of exchange rate shock, therefore, we use the real exchange rate as the observable variable. Since in modern times monetary policy in practice could be conventional or unconventional, depending on what the economic situation warrants, we are leaned towards using a monetary policy factor to identify the monetary policy shock rather than simply the short term federal funds rate.[20] However, in this section we do check if using the observable federal funds rate as an indicator of monetary policy potentially introduces any major changes to our results or not. To do so we re-estimate our baseline model with three factors – economic activity, the price level, and monetary aggregate – and two observable variables - the federal funds rate and the real exchange rate. It is necessary to include the monetary aggregate factor (extracted from variables such as M1, M2, and other quantitative measures of money) in our FAVA in order to correctly identify the monetary policy shock.[21] The results are fairly consistent (See Figure AE10). In response to an exchange rate depreciation shock, industrial production increases, current account exhibits the J-curve pattern– first worsening then improving, unemployment falls, monetary policy is leaning against the wind – the federal funds rate rises. However, we do witness the 'price puzzle' (Sims, 1992) but the results are statistically insignificant.

[20] Read footnote 2.

[21] A pure monetary policy shock is a results of disturbances to the Fed's reaction function and not a reaction to changes in money demand (refer to Kim, 2002 for details on the distinction between monetary policy and traditional money demand eq.).

B. Two-Step Principal Component Analysis

For comparison purpose, in this section we re-estimate the FAVAR model using the two-step principal component analysis of Stock and Watson (2011), Bahadir and Lastrapes (2015), and others, in which the latent factors are first estimated by principal component approach prior to estimation of the FAVAR model.

In the first step (step I), we estimate the latent factors using the principal component approach and record the factor loadings. For example, economic activity factor is estimated from 95 variables reflecting production, employment, housing, consumption, and trade variables; the price level factor from 23 consumer and producer price variables, the interest rate factor from 8 different types of short term and long term interest rates, and monetary aggregate factor from 7 quantitative measures of money variables. The real exchange rate is used as the observable variable. We use a broad measure of interest rate in the form of a latent factor, over the federal funds rate as a single observable (as in Bernanke et al., 2005). Given the time period of study, our understanding is that, just inclusion of a short term interest rate, i.e., the FFR as an observable in the FAVAR may not be a sufficient or accurate measure/indicator of the monetary policy reaction function, due to the zero lower bound problem during the crisis period. In 2008, for example the Fed resorted to unconventional monetary policy and lowered the interest rates on long-term assets (rather than lowering short-term interest rates as with conventional easing). Therefore, in order to ensure that the policy rate in our model correctly measures/represents the monetary policy reaction function, we estimate the policy rate as a latent factor from a broad group of short-term and long-term interest rates. In particular, we load eight different indicators of the interest rate, and then we estimate the first principal component as a measure of the policy rate.

In the second step (step II), we estimate the FAVAR model using the following recursive ordering of the factors/observable – real economic activity factor, price level factor, interest rate factor, nominal money factor, and the observable real exchange rate.[22] We identify the exchange rate shock using Cholesky decomposition, and compute the impulse responses of the estimated factors to the exchange rate depreciation shock (See Figure AE11). We then use the factor loadings from step I to compute the impulse responses of the full set of observable variables to the exchange rate depreciation shock (See Figure AE12).[23] The results from the two-step approach are highly consistent with the baseline results (from one-step approach). Our main finding still holds, that is, the exchange rate shock is expansionary and inflationary to the U.S. economy. In response to an exchange rate depreciation shock, economic activity expands, prices increase, interest rates increase, and money supply falls, indicating that monetary policy is leaning against the wind. We find the J-curve effect of the exchange rate depreciation shock on the current account balance, which first worsens and later improves. Industrial production, employment, nonagricultural payroll, stock price, and CPI all increase in response to the depreciation shock, and unemployment falls.[24]

In sum, our results from the baseline model are highly reliable and robust all changes in model parameters, model specifications, and estimation procedures.

[22] This recursive structure has been widely used by previous researchers, for example, Sims and Zha (2006); Kim (1999); Christiano et al. (1996); Gordon and Leeper (1994); Kim and Roubini (2000); Kim (2002). Kim (2002) for example argues that firms do not change their output and price unexpectedly in response to unexpected changes in financial signals or monetary policy within a month due to adjustment costs and planning delays.

[23] Complete details of the model specification, identification, and estimation of the FAVAR model using the 2-step principal component approach are provided in Appendix D. For the complete algorithm, refer to Stock and Watson (2011) and Bahadir and Lastrapes (2015).

[24] PCA results are only shown for selected variables, to be consistent with all other robustness check analysis. Full set of results from PCA (similar to those shown for the baseline model) will be made available upon request.

V. CONCLUSION

In this paper, we extend the FAVAR framework of Bernanke et al. (2005) to study the effects of exchange rate depreciation shock on the U.S. economy using a large dataset of 148 monthly time series observations for the post-Bretton Woods period ranging from 1973:02 to 2017:03. We extract three factors using the one-step Bayesian likelihood method and the Gibbs sampling approach to represent, respectively, economic activity, price level, and monetary policy. Real exchange rate is the observable variable. We define the exchange rate shock as exogenous disturbances originating from the foreign exchange market, and movements in exchange rate that are not accounted for by changes in the U.S. monetary policy, in the spirit of Artis and Erhman (2006). We identify the exchange rate shock following a recursive identification scheme and Cholesky decomposition. We then examine the effects of this exchange rate shock to the broad U.S. economy in trade, production and employment, prices and consumption, and money and financial sectors. To our best knowledge, this is the first attempt of applying such state-of-the-art method in studying effects of exchange rate depreciation shock for the broad U.S. economy in one integrated model.

Our impulse response and variance decomposition results support the following conclusions: 1) we find that an exchange rate depreciation shock does help improve the U.S. current account balance and increase trade; both import and export rise in response to the depreciation shock, and the results conform to the J-curve theory; 2) the exchange rate depreciation shock appears expansionary to the U.S. economy as industrial production, manufacturing, employment, nonagricultural payroll, capacity utilization, export, hours worked, housing start, and stock market price all increase; and 3) exchange rate depreciation seems inflationary to the economy as consumer price, producer price, import price, export price, ISM manufacturing price index, and nominal earnings all increase in response to the depreciation shock. Further, in the long run, the exchange rate shock explains 7-20+% of the forecast error variance of key macroeconomic indicators, suggesting that the effects of exchange rate shock to the U.S. economy are nontrivial and warrant more consistent considerations in policy and decision makings. Our results imply that monetary policy alone is not enough to stabilize the effects of exchange rate shocks to the U.S. economy. Other measures are called for to mitigate the potential nontrivial effects of exchange rate shocks arising from external and foreign exchange markets to the U.S. economy. Our results are consistent with the literature and robust to various estimation modifications, including the two-step principal component analysis.

Some caveats remain. One major issue is that our model is linear and symmetric, that is, it treats exchange rate depreciation and appreciation shocks symmetrically, and therefore cannot draw inferences for how exchange rate appreciation and depreciation may affect the U.S. economy in asymmetric ways. There has been a growing interest along this line of research and evidence of nonlinearity of exchange rates have been documented (Bahmani-Oskooee and Saha, 2016; Bahmani-Oskooee et al., 2016; Bussiere, 2013; and Ignatieva and Ponomareva, 2017). Second, the post-Bretton Woods period spans a long time and the U.S. economy has gone through the sub-periods of Great Inflation, Great Moderation, and Post Great Recession. Further research can be pursued with time-varying FAVAR models to detect whether regime changes could matter a great deal for the way exchange rate shocks may affect the U.S. economy. It is in the authors' intention to continue the current research along these directions.

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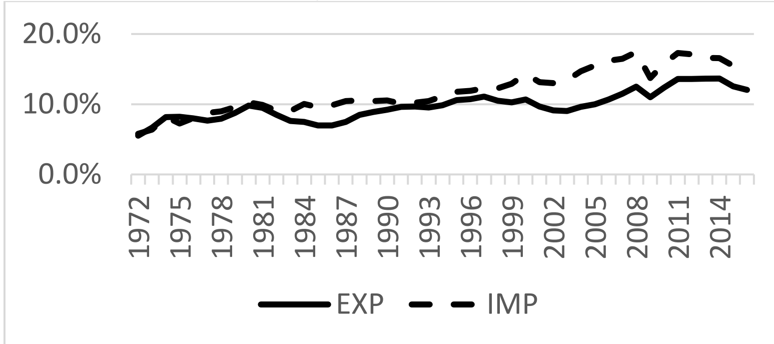
FIGURE 1

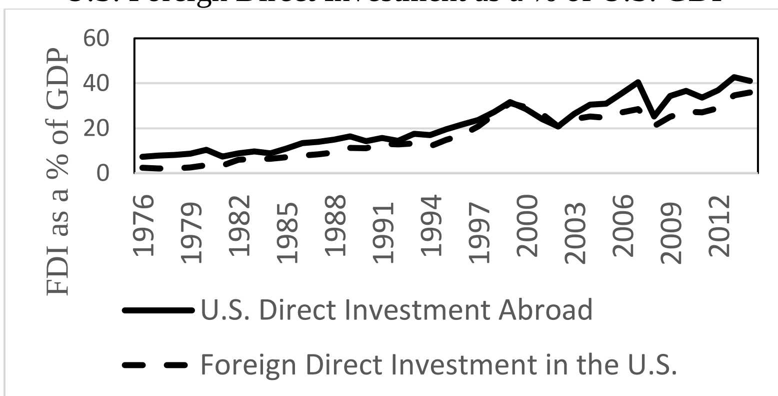
Openness of the U.S. Economy – Export and Import as a % of U.S. GDP



Source: Bureau of Economic Analysis and author's calculation.

FIGURE 2

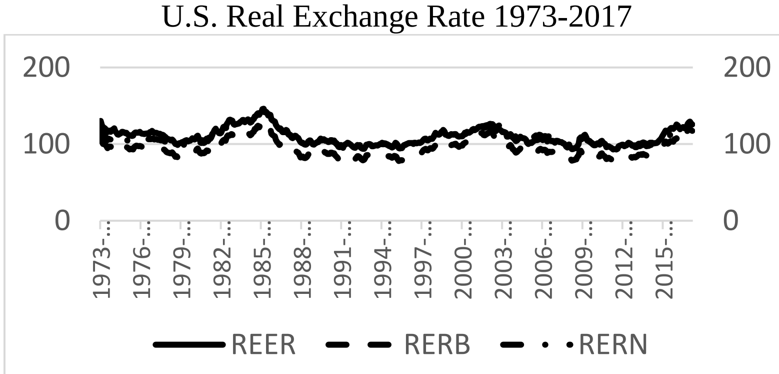
U.S. Foreign Direct Investment as a % of U.S. GDP



Source: Bureau of Economic Analysis and author's calculation.

FIGURE 3

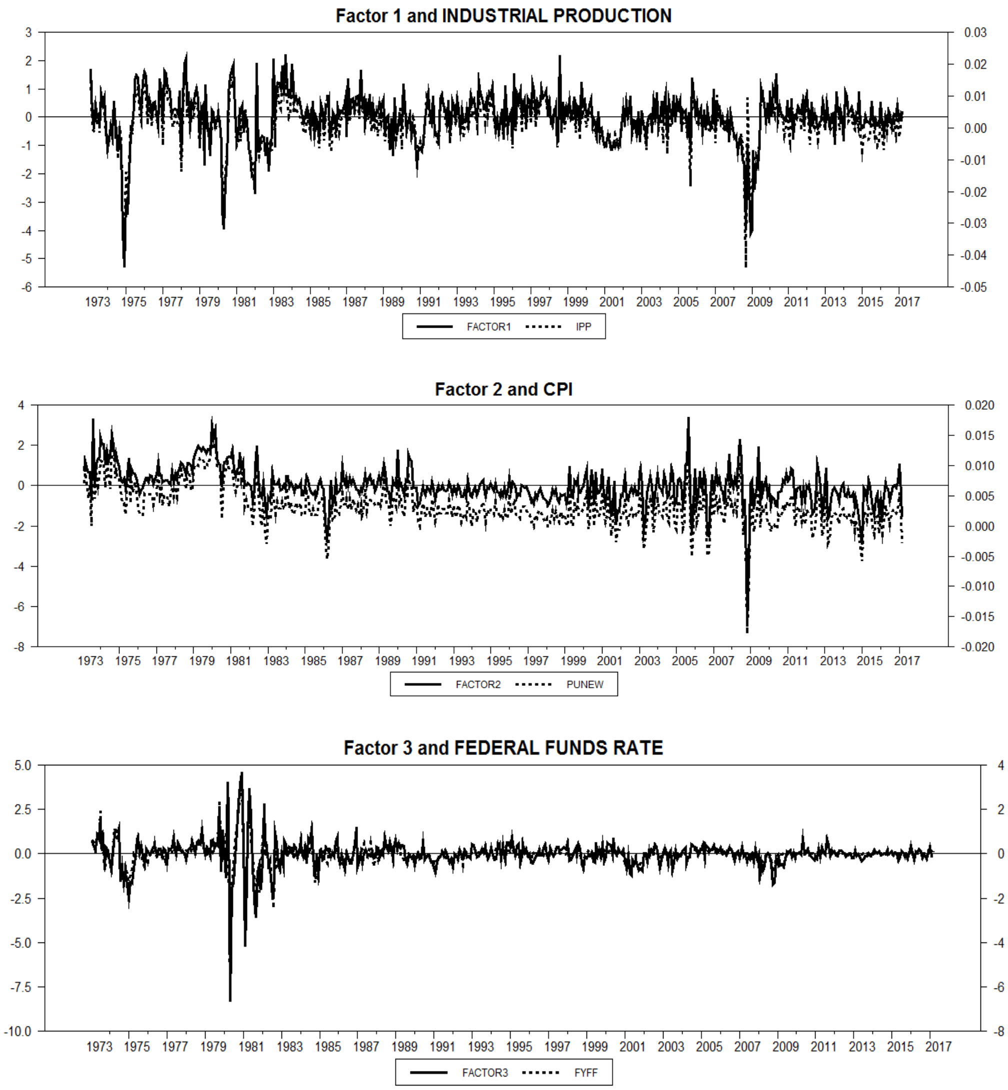
U.S. Real Exchange Rate 1973-2017



Note: REER is the real narrow effective exchange rate from the Bank for International Settlement, FRED label is RNUSBIS, 2010=100; RERN is the real trade weighted U.S. dollar index against major currencies from the Board of Governors of the Federal Reserve System (Fed), FRED label is TWEXMPA, Mar 1973=100; RERB is the real trade weighted U.S. dollar index against a broad basket of foreign currencies from the Fed, FRED label is TWEXBPA, Mar 1973=100.

FIGURE 4

Estimated Factors and Their Corresponding Economic Variables



Note: Estimation is done with RERN as the measure of real exchange rate. The left y-axis represents the movements of factors, while the right y-axis represents the growth rate of corresponding economic indicators. The x-axis is the time period. Factor 1 represents the “economic activity” factor, factor 2 the “price level factor, and factor 3 the “monetary policy” factor.

FIGURE 5

Impulse Responses of Trade Variables to an Exchange Rate Depreciation Shock (RERN)

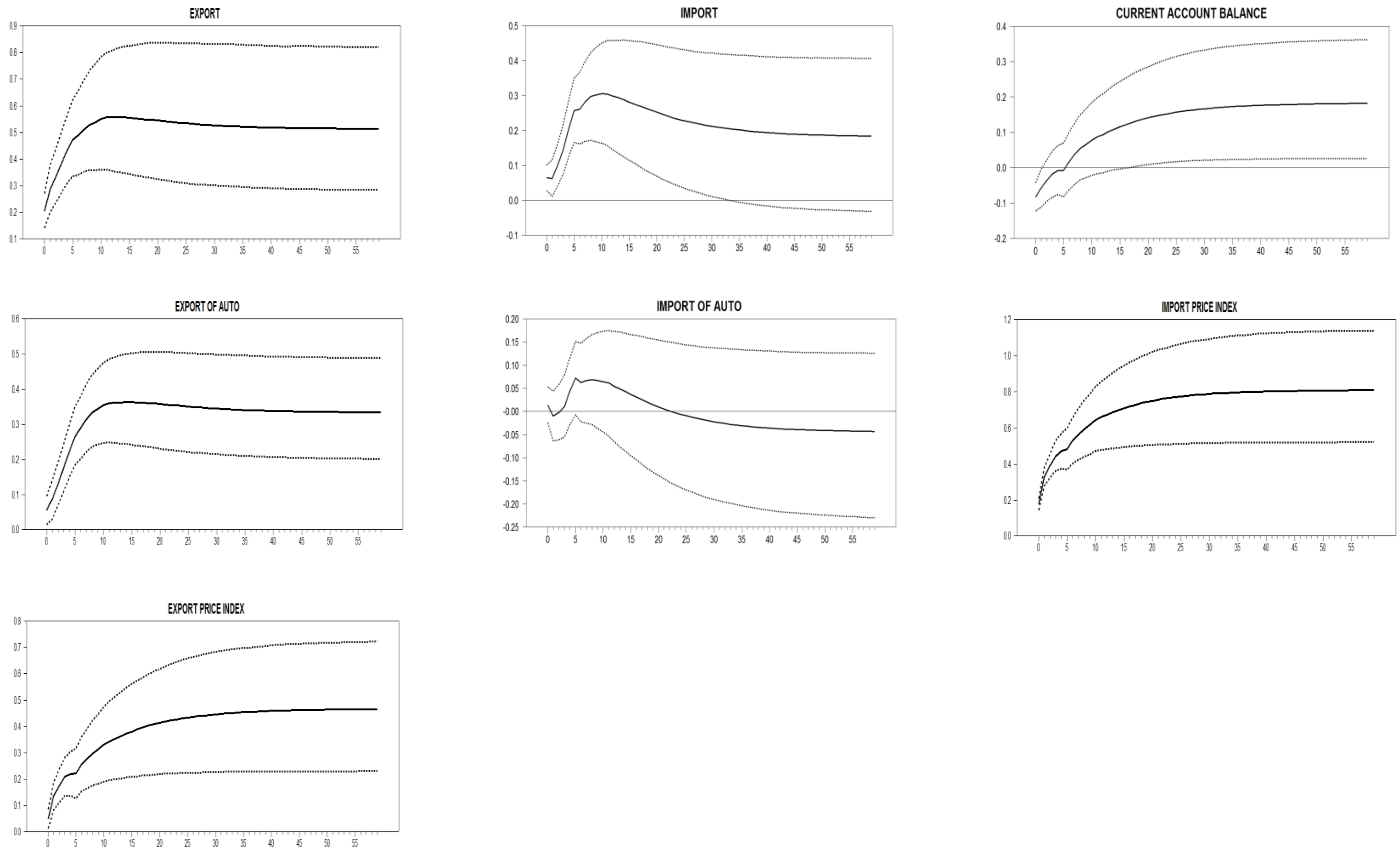


FIGURE 6

Impulse Responses of Production, Employment, and Earnings to an Exchange Rate Depreciation Shock (RERN)

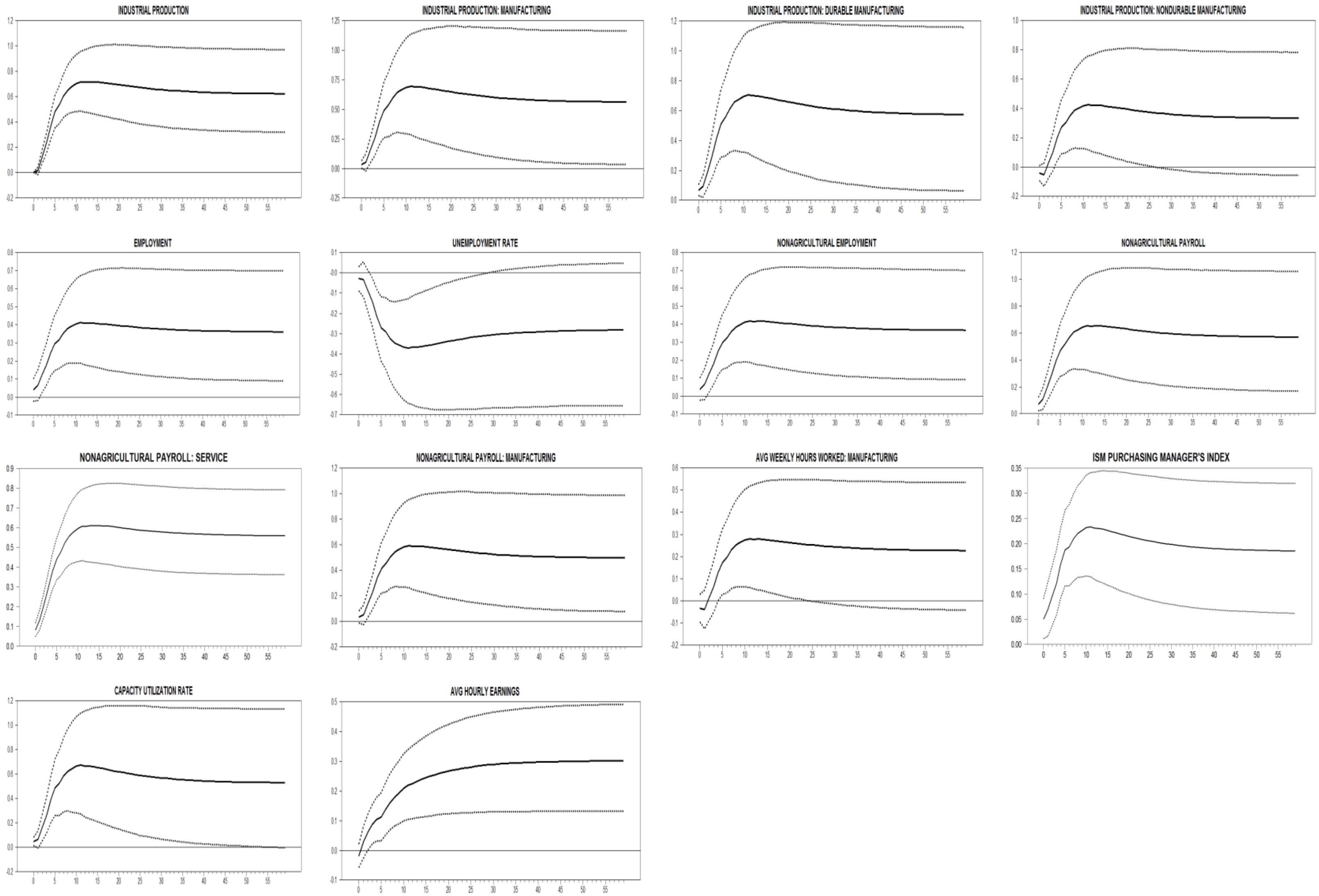


FIGURE 7

Impulse Responses of Money and Financial Sectors to an Exchange Rate Depreciation Shock (RERN)

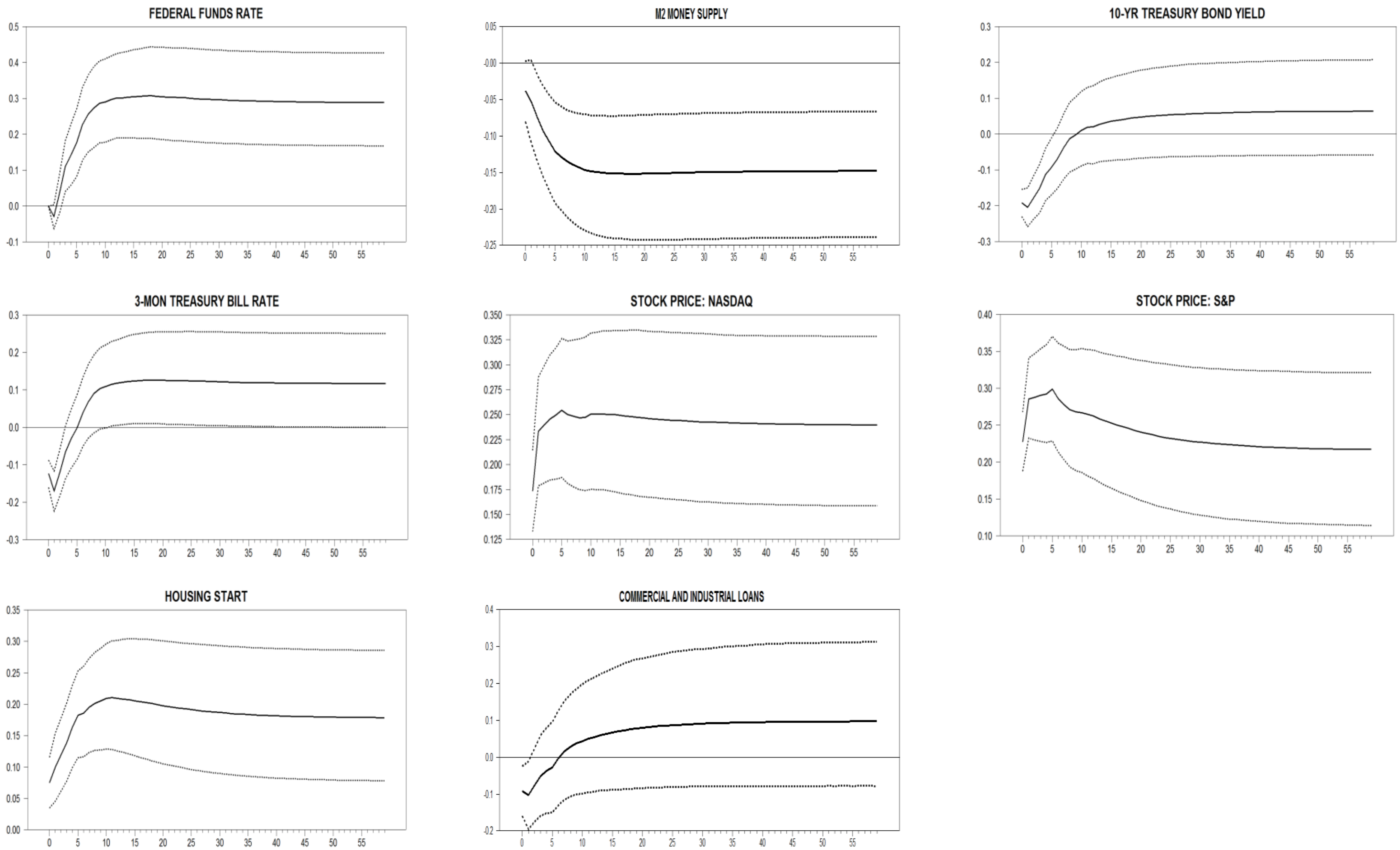
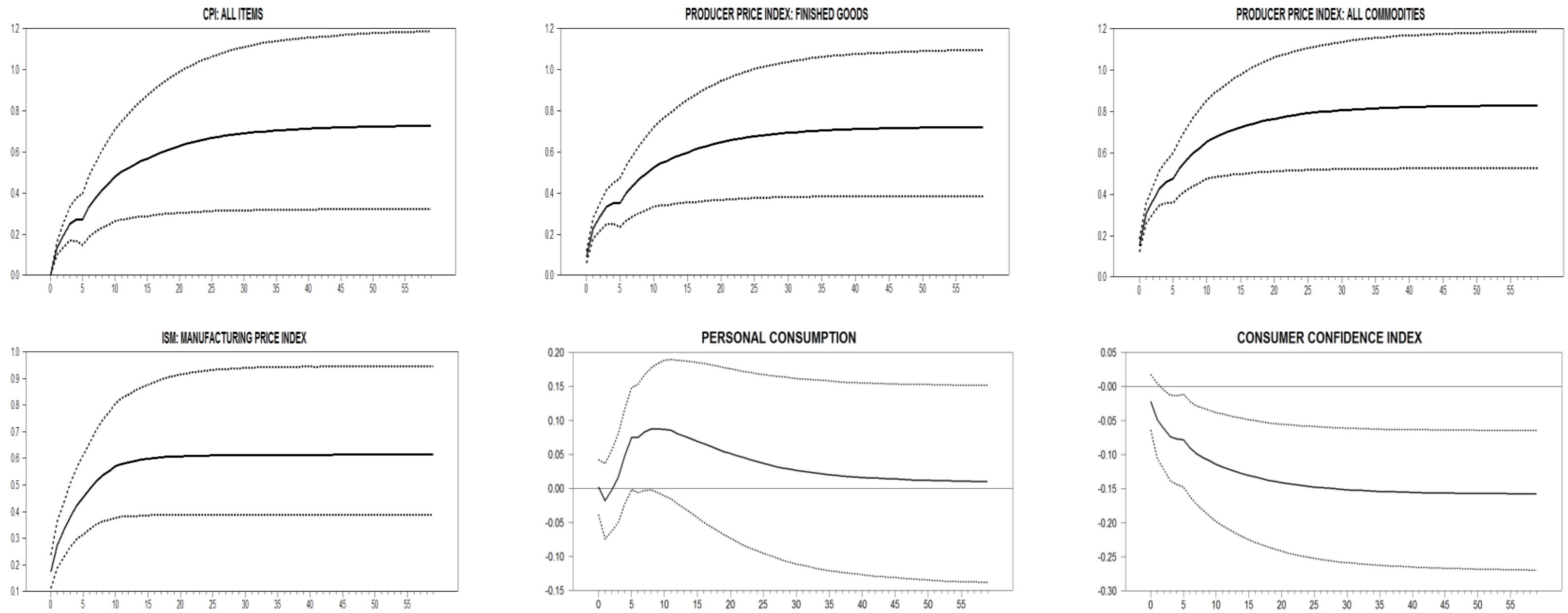


FIGURE 8

Impulse Responses of Prices and Consumption to an Exchange Rate Depreciation Shock (RERN)



Note: Figures 5 through 8, estimation is done with RERN as the measure of real exchange rate. The plots show the impulse responses to a one standard deviation negative shock to the real exchange rate (depreciation) with 7 lags. The three lines are 16% quantile, the median and the 84% quantile of the posterior distribution.

TABLE 1

Granger Causality Test between Estimated Factors and the Real Exchange Rate

F-Test Statistic	Causality from Real Exchange Rate to	Causality from Factors to Real Exchange Rate
Factor 1	2.648*(0.007)	0.671(0.717)
Factor 2	2.400*(0.015)	0.942 (0.481)
Factor 3	1.144(0.332) 3.964*(0.000)	0.608(0.772) 2.045*(0.040)

Note: The null hypothesis is that X does not Granger cause Y. (*) indicates that we can reject the null hypothesis at the <5% level of significance. Estimation is done with RERN as the measure of real exchange rate. The underlined test statistics are obtained using the nominal exchange rate to separate the price effect from the real exchange rate.

TABLE 2

Variance Decomposition at the 60th Month with RERN

	Factor 1	Factor 2	Factor 3	ER	R^2
Industrial Production	0.79	0.07	0.08	0.07	0.89
Manufacturing	0.78	0.07	0.08	0.07	0.96
Durable Manufacturing	0.78	0.07	0.08	0.08	0.88
Nondurable Manufacturing	0.79	0.07	0.07	0.07	0.58
Capacity Utilization	0.78	0.07	0.08	0.07	0.95
ISM Purchasing Manager Index	0.64	0.09	0.17	0.10	0.16
ISM Manufacturing Employment Index	0.66	0.09	0.10	0.15	0.14
M Manufacturing Price Index	0.29	0.39	0.04	0.28	0.30
Employment	0.75	0.08	0.08	0.09	0.36
Unemployment Rate	0.76	0.08	0.09	0.07	0.44
Agricultural Employment	0.23	0.25	0.25	0.27	0.03
Nonagricultural Employment	0.75	0.08	0.08	0.09	0.36
Nonagricultural Payroll	0.76	0.07	0.08	0.09	0.94
Nonagricultural Payroll: Manufacturing	0.77	0.07	0.08	0.08	0.82
Nonagricultural Payroll: Service	0.72	0.11	0.07	0.11	0.80
Avg. Wkly Hrs Worked: Manufacturing	0.77	0.07	0.08	0.08	0.33
Real Avg. Hourly Earnings	0.06	0.84	0.04	0.07	0.62
Consumer Price	0.06	0.85	0.03	0.06	0.92
Producer Price: All Commodities	0.08	0.77	0.03	0.13	0.61
Producer Price: Finished Goods	0.06	0.82	0.03	0.09	0.64
Personal Consumption	0.57	0.26	0.11	0.06	0.10
Consumer Confidence	0.12	0.63	0.12	0.14	0.04
Federal Funds Rate	0.20	0.04	0.73	0.04	0.77
3-month T-bill Rate	0.32	0.07	0.51	0.10	0.34
10-year T-bond Rate	0.27	0.32	0.19	0.22	0.21
M2 money supply	0.28	0.12	0.37	0.22	0.19
Commercial and Indus. Loans	0.17	0.37	0.31	0.15	0.25
Housing Start	0.54	0.11	0.14	0.21	0.07
Stock Price: S&P	0.05	0.23	0.08	0.64	0.11
Stock Price: Nasdaq	0.07	0.08	0.15	0.70	0.07
Import	0.66	0.17	0.10	0.07	0.32
Export	0.50	0.08	0.10	0.32	0.19
Import of Petroleum	0.24	0.57	0.03	0.16	0.24
Import of Auto	0.45	0.38	0.13	0.05	0.16
Export of Auto	0.72	0.08	0.09	0.11	0.14
Current Account Balance	0.06	0.77	0.06	0.10	0.38
Import Price	0.07	0.75	0.03	0.16	0.54
Export Price	0.06	0.80	0.05	0.09	0.27

Note: Estimation is done with RERN as the measure of real exchange rate. The columns present the fractions of the forecast error variance of a variable that are explained by shocks to each of the three factors, the exchange rate, and all of $(F_t^{'}, Y_t^{'})$ jointly, respectively.