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Pass-Through of Shocks into Different U.S. Prices[1]

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Abstract

This paper estimates the pass-through of different shocks into different U.S. prices that are important for policy makers. The investigation is based on a structural vector autoregression model, where quarterly data are used. The empirical results depict oil price pass-through, exchange rate pass-through, import-price pass-through, and producer price pass-through into import prices, producer prices, and consumer prices for the U.S. economy. Policy implications suggest that achieving and sustaining consumer price stability highly depend on monitoring the developments in oil prices, followed by import prices and producer prices.

JEL Classification: E31, F31, Q43

Keywords: Pass-Through; Oil Prices; Exchange Rates; Import Prices; Producer Prices; Consumer Prices

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1. Introduction

The prices in the U.S. economy are affected by several international shocks as well as domestic shocks. Understanding the effects of these shocks for different U.S. prices is essential for understanding the transmission channel of these shocks and thus for conducting optimal monetary policy. Specifically, oil prices and exchange rates can affect consumer prices not only directly but also through producer and import prices (e.g., see Sek and Kapsalyamova, 2008; Yüncüler, 2011). Similarly, import prices can affect consumer prices not only directly but also through producer prices (e.g., see Auer, 2015; Çiftçi and Yilmaz, 2018; Saygili and Saygili, 2021).

It is implied that understanding the channels through which different shocks affect consumer prices requires an investigation that takes into account the endogeneity of all prices due to their continuous interaction. Within this context, this paper estimates the oil price pass-through and exchange rate pass-through into import prices, producer prices and consumer prices. The pass-through of import prices into producer prices and consumer prices as well as the pass-through of producer prices into consumer prices are also estimated. The estimation is based on the implications of a structural vector autoregression model, which takes into account the endogeneity of all U.S. prices.

Quarterly data on global oil prices, U.S. import prices, U.S. real gross domestic product (GDP), U.S. real imports, U.S. producer price index, U.S. consumer price index, the (shadow) federal funds rate, and the U.S. nominal effective exchange rate are used. Following earlier studies such as Forbes et al. (2018), Ha et al. (2020), and Yilmazkuday (2021), the pass-through measures are estimated by using the cumulative impulse response (CIR) of U.S. prices following specific shocks, which are divided by CIR of the shock variable to consider the developments (and the corresponding endogeneity) in that variable over time.

The results are first used to identify the nature of shocks. Specifically, oil price shocks are consistent with a higher aggregate demand (i.e., a demand-pull inflation) and a higher import demand, whereas positive currency (depreciation) shocks are consistent with negative supply shocks. Oil price pass-through into import prices and producer prices is about 16%, whereas oil price pass-through into consumer prices is about 7%. Exchange rate pass-through into import prices is about 36%, while exchange rate pass-through into producer prices is about 34%. Exchange rate pass-through into consumer prices is about 2%, although this is the only pass-through estimate that is statistically insignificant.

Import price pass-through into producer prices is about 72%, whereas import price pass-through into consumer prices is about 25%. Producer price pass-through into consumer prices is about 58%, which is the highest pass-through measure into consumer prices. These results are shown to be robust to the consideration of asymmetric (positive or negative) changes in oil prices and exchange rates, alternative ordering of the variables, and alternative lags of variables used in estimations.

It is implied that the pass-through measures are highly diverse for different U.S. prices, where relatively lower pass-through measures for consumer prices are consistent with the concept of distribution costs smoothing out the pass-through of shocks into U.S. consumer prices as in studies such as by Burstein et al. (2003), Goldberg and Campa (2010), Crucini and Yilmazkuday (2014), and Francois and Manchin (2019). When we further investigate the importance of each pass-through measure based on the estimated forecast error variance decomposition measures, oil price shocks explain the lion's share of changes in U.S. consumer prices, followed by import prices and producer prices.

There are several policy implications based on the empirical results. First, policy makers should watch oil prices, import prices and producer prices closely to understand the channels of pass-through and conduct optimal monetary policy. Second, policy makers should closely follow the transmission of exchange rate changes, first into import and producer prices, and then into consumer prices. Third, policy makers should follow both direct and indirect effects of import prices on consumer prices for a better forecast of inflation in alternative horizons. Fourth, policy makers should closely follow the drivers of producer prices, namely oil prices and exchange rates, if they would like to keep consumer prices under control.

Overall, the paper mainly contributes to the literature along the following two lines, although further details regarding the contribution of this paper are discussed in the next section. First, this paper estimates the pass-through of different shocks into different prices in the U.S., which is convenient to have pass-through estimates that are consistent with each other. In contrast, existing studies in the literature mostly focus on one or two shocks, which makes a comparison across different pass-through measures (across studies) relatively difficult. Second, having different pass-through measures provides the full picture for policy makers, where direct and indirect effects of international and domestic shocks can be identified.

The rest of the paper is organized as follows. The next section motivates the rest of the paper, where the contribution of the paper is discussed with respect to existing studies. Section 3 introduces the estimation methodology, whereas Section 4 introduces the data set used in estimations. Section 5 introduces the methodology for measuring pass-through estimates. Section 6 depicts the estimation results. Section 7 achieves several robustness checks. Section 8 concludes with several policy suggestions.

2. Motivation and Contribution

As this paper estimates pass-through of shocks in oil prices, exchange rates, import prices and producer prices into each other and the U.S. consumer prices, it is connected to several strands of the literature. This section reviews the corresponding studies in a brief way to motivate the reader regarding the contribution of this paper.

As oil is used as a major input in the production process of many goods and services, changes in oil prices are reflected as changes in different prices. When a closed economy is considered for motivation purposes, changes in oil prices are first passed into producer prices and then into consumer prices. Depending on how much oil is used in the production process, oil price pass-through into producer prices is determined. However, when oil price pass-through into consumer prices is considered, as consumer prices are subject to distribution costs (e.g., retail wages) as shown in studies such as by Burstein et al. (2003), Goldberg and Campa (2010), or Crucini and Yilmazkuday (2014), these distribution costs can smooth out the pass-through of oil prices into consumer prices as discussed by Francois and Manchin (2019). This is also consistent with studies such as by Jiménez-Rodríguez and Morales-Zumaquero (2021) who have estimated the long-run oil price pass-through into the producer prices of advanced countries as about 9%, whereas they have estimated the long-run oil price pass-through into the consumer prices of advanced countries as about 3%. The latter estimate is also consistent with other studies such as by Sekine (2020) who has estimated oil price pass-through to the U.S. consumer prices between 1% and 3% or studies such as by Yilmazkuday (2021) who has estimated it as about 4%. By considering oil price pass-through into both producer and consumer prices, this paper contributes to these studies by testing the corresponding difference using the U.S. data.

When an open economy is considered, changes in oil prices are also passed through import prices, because production and transportation of imports are subject to using oil as one of main inputs as well. As imports are used in the production of goods and services through input-output linkages (e.g., see Auer, Levchenko, and Sauré, 2019), changes in oil prices are reflected in not only import prices but also in producer and consumer prices. Accordingly, having an investigation including all of these prices is essential for the identification of different channels in the oil price pass-through measures (e.g., see Dedeoglu and Kaya, 2014), as we achieve in this paper.

Another strand of the literature has focused on the asymmetric effects of oil prices (e.g., Hooker, 2002; Zhu and Chen, 2019; Lòpez-Villavicencio and Pourroy, 2019). According to these studies, positive changes in oil prices may have different effects compared to negative changes in oil prices. Based on this motivation, as a robustness check, this paper also considers positive versus negative changes in oil prices (by following the seminal work of Mork, 1989) while investigating the pass-through of oil prices into import prices, producer prices and consumer prices.

As oil and other imports can be used either for production or consumption purposes, any change in exchange rates affecting oil prices or import prices can also have an impact on producer and consumer prices. Similar to the discussion that we had above regarding distribution costs potentially smoothing out the pass-through of oil prices into consumer prices (compared to producer prices), the exchange rate pass-through into different prices depends on the share of inputs in the production processes of imported goods, final goods and retail goods (e.g., see Nakamura, 2008). This is potentially the reason behind studies such as by Obstfeld and Rogoff (2000) or Burstein, Eichenbaum, and Rebelo (2005), for example, showing that exchange rate pass-through into import prices is higher than that into consumer prices. Accordingly, having an investigation including all of these prices is essential for the identification of different channels in the exchange rate pass-through measures, as we achieve in this paper.

Since several studies in the literature have considered asymmetric effects of exchange rates (e.g., Delatte and López-Villavicencio, 2012; Bussiere, 2013), as a robustness check, this paper also considers positive versus negative changes in exchange rates (as in Mork, 1989) while investigating the pass-through of exchange rates into import prices, producer prices and consumer prices.

As imports are used in the production of goods and services through input-output linkages (e.g., see Auer et al., 2019), changes in import prices can affect both producer and consumer prices. However, as in the case of oil price pass-through and exchange rate pass-through, retail/wholesale distribution costs as discussed by Burstein et al. (2003), Goldberg and Campa (2010), or Francois and Manchin (2019) can smooth out the pass-through of import prices into consumer prices (compared to producer prices). Within this context, the pass-through of producer prices into consumer prices is also affected by the share of the corresponding distribution costs in consumer prices as in Crucini and Yilmazkuday (2014). By considering all of these prices, this paper again controls for alternative channels that are effective in explaining different pass-through measures.

3. Estimation Methodology

The investigation based on the U.S. quarterly data is achieved by the SVAR model of $z_t = (\Delta op_t, \Delta ip_t, \Delta y_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t, \Delta e_t)'$, where Δop_t represents percentage changes in global oil prices, Δip_t represents percentage changes in import prices, Δy_t represents percentage changes in output, Δm_t represents percentage changes in real imports, Δpp_t represents percentage changes in producer price index, Δcp_t represents percentage changes in consumer price index, Δr_t represents changes in the federal funds rate, and Δe_t represents percentage changes in the nominal effective exchange rate (measured as depreciation). The formal investigation is based on the following SVAR model:

$$A_o z_t = a + \sum_{k=1}^{2} A_k z_{t-k} + u_t \quad (1)$$

where u_t is the vector of serially and mutually uncorrelated structural innovations. For estimation purposes, the model is expressed in reduced form as follows:

$$z_t = b + \sum_{k=1}^{2} B_k z_{t-k} + e_t \quad (2)$$

where $b = A_o^{-1}a$ and $B_k = A_o^{-1}A_k$ for all k. The number of lags (of 2) has been determined by minimizing the Deviance Information Criterion across alternative lags (between 1 and 8). It is postulated that the structural impact multiplier matrix A_o^{-1} has a recursive structure such that the reduced form errors e_t can be decomposed according to $e_t = A_o^{-1}u_t$, where the sizes of shocks are standardized to unity.[3]

The recursive structure imposed on A_o^{-1} requires an ordering of the variables used in the estimation for which we utilize the ordering in $z_t = (\Delta op_t, \Delta ip_t, \Delta y_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t, \Delta e_t)'$, although the results are very similar when alternative ordering of variables are considered.[4] Oil prices Δop_t are ordered first as they are mostly determined globally, but they can still react to the developments in the U.S. economy in later periods as it is the largest economy. Import prices Δip_t are affected by global oil prices, but as they are also determined outside of the U.S. economy, they are ordered before the U.S. variables. Developments in the U.S. economic activity captured by Δy_t can have an immediate impact on imports Δm_t that can have immediate impacts on both producer prices Δpp_t and consumer prices Δpp_t. The federal funds rate Δr_t immediately reacts to the changes in the U.S. economy, whereas the exchange rates Δe_t

[3] When the impulse responses are used to identify the nature of shocks (e.g., identifying demand or supply shocks based on the responses of prices and output), considering a recursive structure is superior to alternative identification strategies (such as sign restrictions), because we don't have any sign or value restrictions on the reaction of variables other than their ranking in the estimation (that is based on contemporaneous zero impacts).

[4] The results of such robustness checks are available upon request.

immediately adjust based on all developments.

The estimation is achieved by a Bayesian approach with independent normal-Wishart priors.[5] This corresponds to generating posterior draws for the structural model parameters by transforming each reduced-form posterior draw. In particular, for each draw of the covariance matrix from its posterior distribution, the corresponding posterior draw for A_o^{-1} is constructed by using by triangular factorization so that the sizes of shocks are standardized to unity. In the Bayesian framework, a total of 2,000 samples are drawn, where a burn-in sample of 1,000 draws is discarded. The remaining 1,000 draws are used to determine the structural impulse responses to be further used for estimating the pass-through and forecast error variance decomposition measures.[6] While the median of each distribution is considered as the Bayesian estimator, the 16th and 84th quantiles of distributions are used to construct the 68% credible intervals (which is the standard measure considered in the Bayesian literature).

4. Data and Descriptive Statistics

All quarterly data for the period between 1994:Q1 and 2023:Q3 have been obtained from Federal Reserve Economic Data (2023), except for the Wu-Xia shadow federal funds rate

[5] Regarding the hyperparameters, following studies such as by Dieppe, Legrand and van Roye (2016) and Ordóñez, Monfort and Cuestas (2019), the overall tightness is set to 0.1, the cross-variable specific variance parameter is set to 0.5, and the scaling coefficient controlling the convergence is set to 1.

[6] For robustness, we also considered a total of 20,000 samples drawn, where a burn-in sample of 10,000 draws is discarded. The corresponding results, which are available upon request, are virtually the same.

that has been constructed by combining data from Wu and Xia (2016) and Federal Reserve Economic Data (2023). The latter variable is used instead of the federal funds rate as the U.S. has experienced zero lower bound environments as suggested in studies such as by Kim and Singleton (2012), Krippner (2013), or Bauer and Rudebusch (2016).

Regarding the connection with the SVAR model, to ensure stationarity, percentage changes in global oil prices Δop_t are obtained as the year-on-year log changes in the "Global price of WTI Crude, U.S. Dollars per Barrel, Quarterly, Not Seasonally Adjusted." Percentage changes in import prices Δip_t are obtained as the year-on-year log changes in the "Import Price Index (End Use): All Commodities, Index 2000=100, Quarterly, Not Seasonally Adjusted." Percentage changes in output Δy_t are obtained as the year-on-year log changes in the "Real Gross Domestic Product, Billions of Chained 2017 Dollars, Quarterly, Seasonally Adjusted Annual Rate." Percentage changes in real imports Δm_t are obtained as the year-on-year log changes in the "Real imports of goods and services, Billions of Chained 2017 Dollars, Quarterly, Seasonally Adjusted Annual Rate." Percentage changes in producer prices Δpp_t are obtained as the year-on-year log changes in the "Producer Price Index by Commodity: All Commodities, Index 1982=100, Quarterly, Not Seasonally Adjusted." Percentage changes in consumer prices Δcp_t are obtained as the year-on-year log changes in the "Personal Consumption Expenditures: Chain-type Price Index, Index 2017=100, Quarterly, Seasonally Adjusted" as it is the main price measure used by the Federal Reserve System. Changes in the federal funds rate Δr_t are obtained as the year-on-year changes in the Wu-Xia shadow federal funds rate. Percentage changes in the nominal effective exchange rate (measured as depreciation) are obtained as the year-on-year log changes in the "Broad Effective Exchange Rate for United States, Index 2020=100, Quarterly, Not Seasonally Adjusted." The quarterly data series used in the SVAR model of $z_t = (\Delta op_t, \Delta ip_t, \Delta y_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t, \Delta e_t)'$ are also depicted over time in Figure 1.

5. Pass-Through Estimates

Similar to earlier studies such as by Forbes et al. (2018), Ha et al. (2020), or Yilmazkuday (2021), pass-through measures are estimated by using the cumulative impulse responses (CIR) of U.S. prices to different shocks, where the developments in the shock variable over time are also considered. This is achieved by using the ratio between CIR of U.S. prices to a shock and CIR of the shock variable to its own shock.

Formally, the pass-through is estimated according to the following expression:

$$\text{Pass} - \text{Through} = \frac{\text{CIR of US Prices to the Shock}}{\text{CIR of the Shock Variable to the Shock}} \qquad (3)$$

which is independent of the scale of the variables/shocks considered, and it can be estimated for different U.S. prices, different shocks and alternative horizons.

According to Equation 3, different pass-through measures are estimated. Oil price pass-through into import prices, producer prices and consumer prices are estimated by using the CIR of these variables in the numerator, and using the CIR of oil prices to oil price shocks in the denominator. Exchange rate pass-through into import prices, producer prices and consumer prices are estimated by using the CIR of these variables in the numerator, and using the CIR of exchange rates to exchange rate (currency) shocks in the denominator. Import price pass-through into producer prices and consumer prices are estimated by using the CIR of these variables in the numerator, and using the CIR of import prices to import price shocks in the denominator. Finally, producer price pass-through into consumer prices is estimated by using the CIR of consumer prices in the numerator, and using the CIR of producer prices to producer price shocks in the denominator.

While estimating the pass-through measures, Equation 3 is calculated for each 1,000 draw, where the median is considered as the Bayesian estimator, and the 16th and 84th quantiles of the distribution are used to construct the 68% credible intervals (that is standard in the Bayesian literature). For robustness, in the tables representing the results, we also consider the 95% credible intervals. As year-on-year percentage changes of variables are used in the estimation of the SVAR model, the pass-through measures should be interpreted on a year-on-year basis as well.

6. Estimation Results

The SVAR model of $z_t = (\Delta op_t, \Delta ip_t, \Delta y_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t, \Delta e_t)'$ is estimated, and the corresponding CIR of variables are calculated. Before moving to the estimates of the pass-through measures, we would like to investigate the nature of shocks that are used in such measures, namely oil price shocks, import price shocks, and currency shocks. We focus on the CIR of the real output, consumer prices (that we call inflation), real imports and import prices to understand the nature of these shocks.

The results are given in Figure 2. As is evident, positive oil price shocks increase output, inflation, real imports and import prices, which suggest that they are consistent with a higher aggregate demand (i.e., a demand-pull inflation) and a higher import demand. This result is in contrast to positive oil price shocks reflecting negative oil supply shocks, which would rather result in lower output due to lower production of oil and higher production costs (e.g., see Hamilton, 1996).

Positive import price shocks decrease output and real imports, whereas they increase inflation and import prices, suggesting that they are consistent with a lower aggregate supply (i.e., a cost-push inflation) and a lower import supply. Finally, positive currency (depreciation) shocks only increase import prices in a statistically significant way (based on the 68% credible intervals), suggesting that they are consistent with negative supply shocks.

These shocks are further used to calculate the pass-through measures based on Equation 3. The estimated pass-through measures over time are given in Figure 3, whereas they are summarized in Table 1 in the long run (i.e., after five years) that we accept as our summary pass-through measures.

As is evident, oil price pass-through into import prices is about 16% (14%), meaning that 100% of a shock in oil prices results in about 16% (14%) of an increase in import prices (producer prices), after controlling for the developments in oil prices over time according to Equation 3. This result is consistent with earlier studies such as by Jiménez-Rodríguez and Morales-Zumaquero (2021). Oil price pass-through into consumer prices is about 7% , similar to earlier studies such as by Sekine (2020) and Yilmazkuday(2021).

Exchange rate pass-through into import prices is about 36% (consistent with earlier studies such as by Campa and Goldberg, 2005), while exchange rate pass-through into producer prices is about 34%. Exchange rate pass-through into consumer prices is about 2%, although this is the only pass-through estimate that is statistically insignificant in Table 1. Import price pass-through into producer prices is about 72% (which is in line with complete pass-through based on the 95% credible intervals), whereas import price pass-through into consumer prices is about 25%.

Finally, producer price pass-through into consumer prices is about 57%. It is implied that the pass-through measures are highly diverse for different U.S. prices, where relatively lower pass-through measures for consumer prices are consistent with the concept of distribution costs (e.g., transportation, wholesale or retail costs as in studies such as by Crucini and Yilmazkuday, 2014) smoothing out the pass-through of shocks into U.S. consumer prices.

When we further investigate the importance of each pass-through measure based on the estimated forecast error variance decomposition measures in Table 2, the volatility of import prices is mostly explained by oil prices with a contribution of about 62%, followed by exchange rates with a contribution of about 5%. The volatility of producer prices is mostly explained by oil prices with a contribution of about 60%, followed by import prices with a contribution of about 15%, and exchange rates with a contribution of about 4%. The volatility of consumer prices is mostly explained by oil prices with a contribution of about 59%, followed by import prices with a contribution of about 13%, producer prices with a contribution of about 9%, and exchange rates with a contribution of about 0.4%. Therefore, although oil price pass-through into consumer prices is only about 7%, most of the consumer price volatility is explained by oil price shocks, implying that the effects of oil price shocks on consumer prices are through their volatility. Consistent with earlier studies such as by Ha, Kose, Ohnsorge, and Yilmazkuday (2019), it is implied that oil price shocks explain the lion's share of changes in U.S. prices.

Regarding policy suggestions, as the consumer price stability in the U.S. highly depends on oil prices, followed by import prices and producer prices, monetary policy makers should watch them closely, especially as they are effective in the long run. We provide further policy suggestions at the end of the paper, but before that, we consider several robustness checks in the next section.

7. Robustness Checks

This section achieves several robustness checks, including the asymmetric pass-through measures, ordering of the variables, number of lags, and the pass-through measures when core prices are used instead of consumer prices.

7.1. Asymmetric Pass-Through Measures

As the SVAR model used so far investigates the pass-through of different shocks into different U.S. prices in a linear way, it cannot control for the asymmetric effects of (positive versus negative) changes in oil prices and exchange rates as in studies such as by Delatte and López-Villavicencio (2012), Bussiere (2013), Hooker (2002), Zhu and Chen (2019), or Lòpez-Villavicencio and Pourroy (2019). Therefore, for robustness, this section investigates these asymmetric effects.

The robustness check is achieved by splitting the percentage changes in both oil prices and exchange rates into two variables, one representing positive changes and the other representing negative changes as in the seminal work of Mork (1989); they are set equal to zero otherwise. In formal terms, $z_t = (\Delta op_t^+, \Delta op_t^-, \Delta ip_t, \Delta y_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t, \Delta e_t^+, \Delta e_t^-)'$ is estimated as the alternative SVAR model for robustness purposes, where Δop_t^+ (Δop_t^-) represents positive (negative) percentage changes in global oil prices, and Δe_t^+ (Δe_t^-) represents positive (negative) percentage changes in the nominal effective exchange rate that is measured as depreciation. As in the benchmark model, the corresponding CIR of variables are calculated, and they are further used in Equation 3 to obtain pass-through estimates.

When positive percentage changes in oil prices and exchange rates are considered, the estimated pass-through measures over time are given in the Online Appendix Figure A.1, and they are summarized in the Online Appendix Table A.1 in the long run (i.e., after five years) that we accept as our summary pass-through measures. Similarly, when negative percentage changes in oil prices and exchange rates are considered, the estimated pass-through measures over time are given in the Online Appendix Figure A.2, and they are summarized in the Online Appendix Table A.2 in the long run.

As is evident, the pass-through measures are very similar to those obtained by the benchmark model. When the 68% credible intervals are considered (which is standard in the Bayesian literature), the results are not statistically different from each other. It is implied that there is no statistically significant evidence for asymmetric effects of (positive versus negative) changes in oil prices and exchange rates on pass-through measures.

7.2. Ordering of the Variables

As the oil prices and import prices may be affected by contemporaneous changes in exchange rates and the developments in the U.S. economy, two alternative orderings of the variables in the SVAR model are considered as robustness checks. The first robustness check orders the percentage changes in the nominal effective exchange rate first by considering the SVAR model of $z_t = (\Delta e_t, \Delta op_t, \Delta ip_t, \Delta y_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t)'$, whereas the second robustness check orders the percentage changes in the U.S. real output first by considering the SVAR model of $z_t = (\Delta y_t, \Delta op_t, \Delta ip_t, \Delta m_t, \Delta pp_t, \Delta cp_t, \Delta r_t, \Delta e_t)'$.

When exchange rates are ordered first, the estimated pass-through measures over time are given in the Online Appendix Figure A.3, and they are summarized in the Online Appendix Table A.3 in the long run. Similarly, when the U.S. output is ordered first, the estimated pass-through measures over time are given in the Online Appendix Figure A.4, and they are summarized in the Online Appendix Table A.4 in the long run.

As is evident, when the 68% credible intervals are considered, the results of the first robustness check (when exchange rates are ordered first) are not statistically different from the benchmark results, except for the exchange rate pass-through measures that are relatively higher, whereas the results of the second robustness check (when the U.S. output is ordered first) are very similar to the benchmark results. It is implied that the benchmark results are mostly robust to the consideration of alternative ordering of the variables.

7.3. Number of Lags

Although the benchmark SVAR model is estimated with 2 lags determined by minimizing the Deviance Information Criterion across alternative lags (between 1 and 8), an alternative SVAR model is estimated with 4 lags as an additional robustness check. The corresponding pass-through measures over time are given in the Online Appendix Figure A.5, and they are summarized in the Online Appendix Table A.5 in the long run. As is evident, these results based on 4 lags are highly consistent with the benchmark results, which further support the main findings of this paper.

7.4. Core Prices

In order to check whether oil price shocks are effective on consumer prices through food and energy prices included in consumer prices or they are effective through other prices (excluding food and energy prices), the benchmark estimation is replicated by replacing consumer prices with core prices ("Personal Consumption Expenditures Excluding Food and Energy (Chain-Type Price Index), Index 2017=100, Quarterly, Seasonally Adjusted" obtained from Federal Reserve Economic Data, 2023). The corresponding pass-through measures over time are given in the Online Appendix Figure A.6, and they are summarized in the Online Appendix Table A.6 in the long run. As is evident, although oil price pass-through measures into import and producer prices are positive and statistically significant, oil price pass-through into core prices is statistically insignificant. The latter result is similar to earlier studies such as by Hooker (2002), Kilian (2008), Clark and Terry (2010), and Conflitti and Luciani (2019). It is implied that the effects of oil price shocks on consumer prices are through food and energy prices rather than the prices of other goods and services.

8. Concluding Remarks and Policy Suggestions

This paper has estimated the pass-through of different shocks into different U.S. prices that are important for policy makers. It has been shown that oil price pass-through and exchange rate pass-through are higher for import prices and producer prices compared to consumer prices. There is evidence for complete pass-through of import prices into producer prices, although the import price pass-through into consumer prices is much less. It has also been shown that more than half of producer price shocks are reflected into consumer prices. These results have been shown to be robust to the consideration of asymmetric (positive or negative) changes in oil prices and exchange rates, alternative ordering of the variables, and alternative lags used in estimations.

The results of this paper are consistent with the concept of distribution costs as in studies such as by Burstein et al. (2003), Goldberg and Campa (2010) or Crucini and Yilmazkuday (2014), where distribution costs (e.g., transportation, wholesale or retail costs) can smooth out the pass-through of shocks into U.S. consumer prices as discussed by Francois and Manchin (2019).

Several policy implications follow. First, the consumer price stability in the U.S. highly depends on oil prices, followed by import prices and producer prices, suggesting that monetary policy makers should watch them closely, especially as they are effective in the long run. Second, the effects of exchange rates are mostly through import and producer prices, suggesting that their effects on consumer prices would be evident when changes in import and producer prices are passed onto consumer prices; accordingly, policy makers should closely follow the transmission of exchange rate changes, first into import and producer prices, and then into consumer prices, if they would like to have a better forecast for the price stability. Third, import prices contribute to producer prices as much as they do to consumer prices, suggesting that their indirect effects on consumer prices (through producer prices) would show up in a longer horizon compared to their direct effects; therefore, policy makers should follow both direct and indirect effects of import prices on consumer prices for a better forecast of inflation in alternative horizons. Fourth, as more than half of producer price shocks are passed onto consumer prices, policy makers should closely follow the drivers of producer prices, especially oil prices and exchange rates, if they would like to keep consumer prices under control.

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Table 1 - Long-Run Pass-Through of Shocks into U.S. Prices

	Import Prices	Producer Prices	Consumer Prices
Oil Price	0.163**	0.144**	0.066**
Pass-Through	[0.123,0.200]	[0.108,0.182]	[0.052,0.088]
	{0.085,0.246}	{0.071,0.240}	{0.040,0.121}
Exchange Rate	0.355**	0.335**	0.015
Pass-Through	[0.249,0.459]	[0.242,0.436]	[-0.025,0.054]
	{0.112,0.561}	{0.125,0.533}	{-0.073,0.098}
Import Price		0.715**	0.245**
Pass-Through		[0.544,0.902]	[0.171,0.339]
		{0.380,1.207}	{0.096,0.509}
Producer Price			0.571**
Pass-Through			[0.384,0.912]
			{0.235,3.051}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

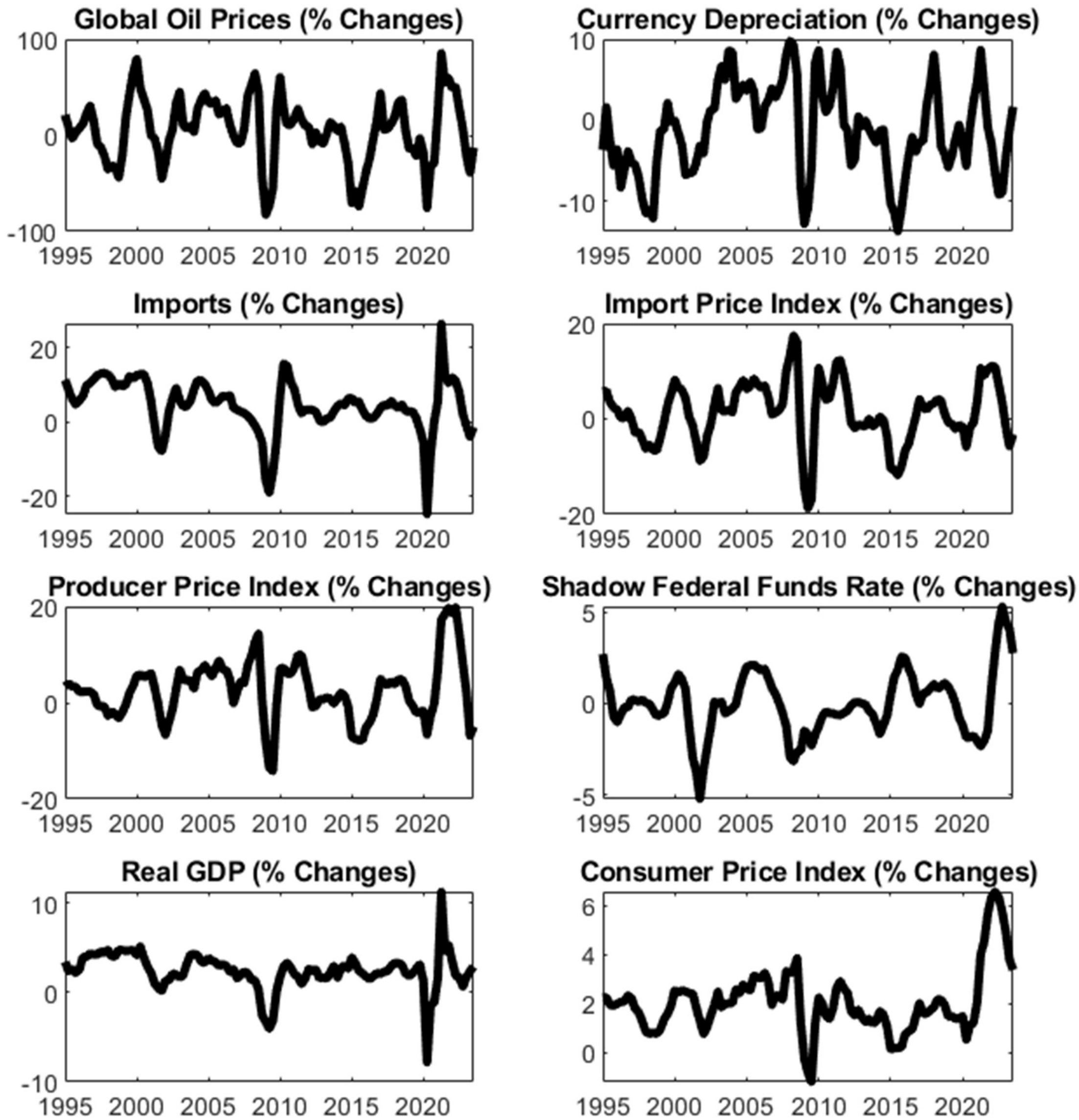
Table 2 - Long-Run Contribution of Selected Shocks to U.S. Prices

Contribution of:	Import Prices	Producer Prices	Consumer Prices
Oil Price	61.7%	60.4%	58.7%
Shocks	[53.9%,68.9%]	[53.9%,66.6%]	[50.8%,66.1%]
	{46.5%,74.2%}	{47.8%,72.2%}	{42.5%,71.4%}
Exchange Rate	4.7%	3.6%	0.4%
Shocks	[2.3%,8.1%]	[1.8%,6.5%]	[0.1%,1.3%]
	{0.8%,12.7%}	{0.4%,10.1%}	{0.0%,3.7%}
Import Price		14.5%	13.2%
Shocks		[11.0%,18.9%]	[9.0%,18.2%]
		{8.2%,23.3%}	{5.4%,24.3%}
Producer Price			9.2%
Shocks			[6.1%,13.2%]
			{4.0%,18.1%}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to the forecast error variance decomposition measures calculated after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas those in braces represent the 95% credible intervals.

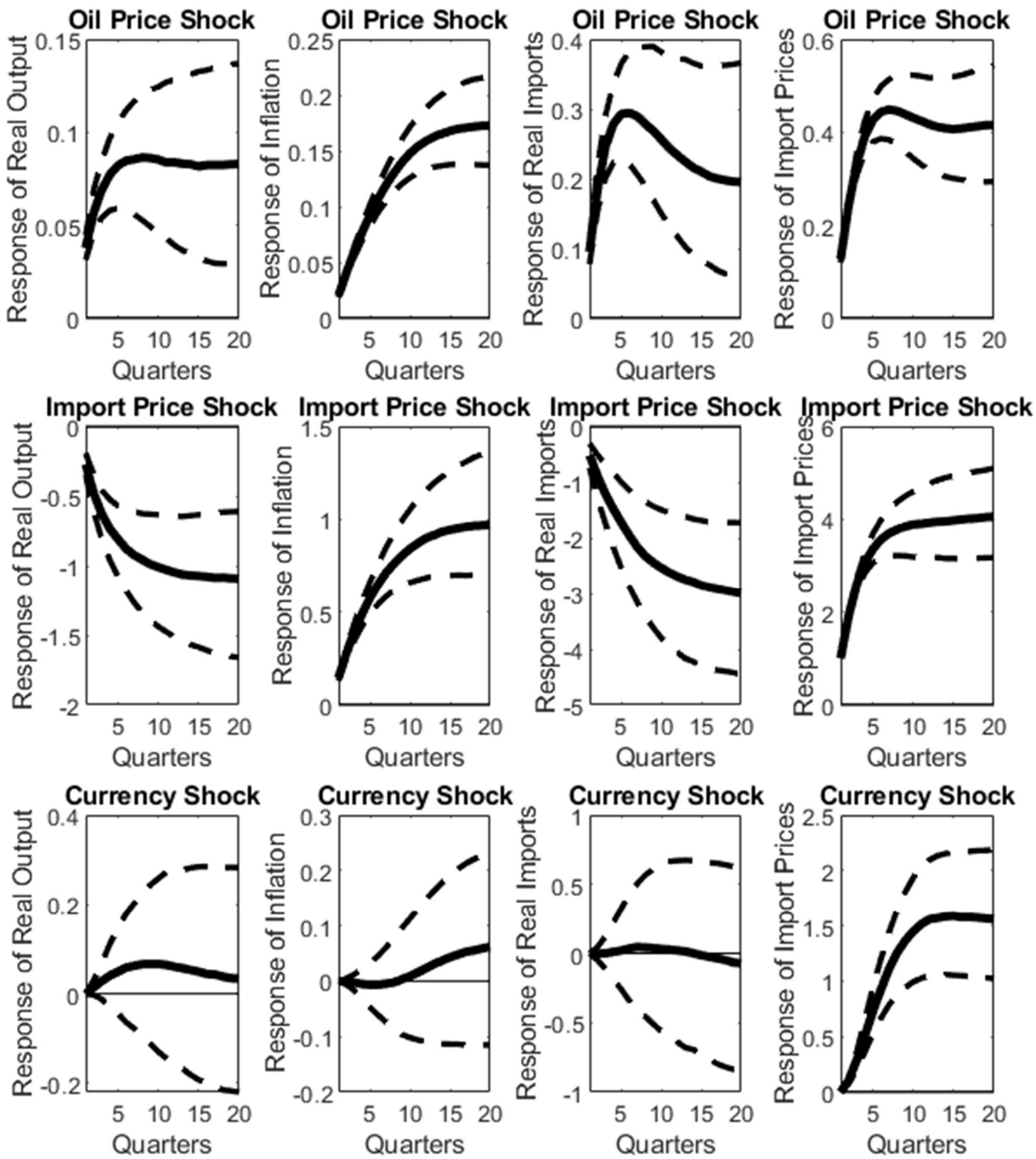
Figure 1 - Descriptive Statistics



Source: All quarterly data for the period between 1994:Q1 and 2023:Q3 have been obtained from Federal Reserve Economic Data (2023), except for the Wu-Xia shadow federal funds rate that has been obtained from Wu and Xia (2016).

Notes: Series represent those used in the estimation.

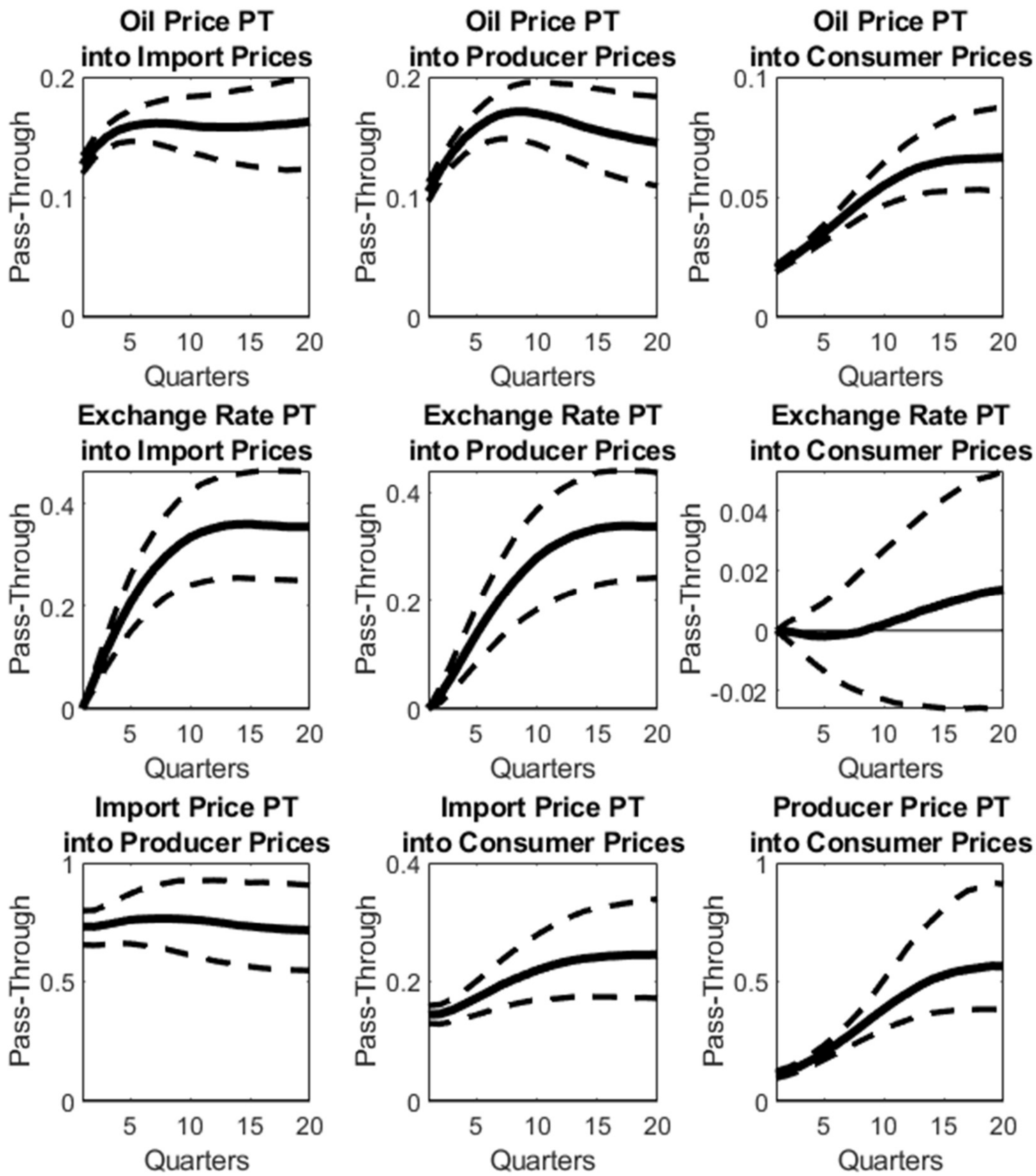
Figure 2 - Understanding the Nature of Shocks



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

Figure 3 - Pass-Through of Shocks into U.S. Prices



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

Table A.1 - Long-Run Pass-Through of Shocks into U.S. Prices with Positive Changes in Oil Prices and Exchange Rates

	Import Prices	Producer Prices	Consumer Prices
Oil Price	0.197**	0.148**	0.080**
Pass-Through	[0.129,0.266]	[0.092,0.210]	[0.058,0.109]
	{0.062,0.355}	{0.034,0.295}	{0.042,0.149}
Exchange Rate	0.360*	0.296*	0.040
Pass-Through	[0.104,0.593]	[0.090,0.484]	[-0.032,0.114]
	{-0.156,0.817}	{-0.149,0.676}	{-0.114,0.191}
Import Price		0.705**	0.239**
Pass-Through		[0.549,0.896]	[0.169,0.326]
		{0.410,1.164}	{0.106,0.487}
Producer Price			0.551**
Pass-Through			[0.394,0.920]
			{0.232,1.962}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

Table A.2 - Long-Run Pass-Through of Shocks into U.S. Prices with Negative Changes in Oil Prices and Exchange Rates

	Import Prices	Producer Prices	Consumer Prices
Oil Price	0.146**	0.139**	0.052**
Pass-Through	[0.099,0.190]	[0.106,0.181]	[0.038,0.071]
	{0.045,0.242}	{0.064,0.228}	{0.025,0.099}
Exchange Rate	0.399**	0.482**	0.029
Pass-Through	[0.204,0.570]	[0.333,0.637]	[-0.033,0.089]
	{0.029,0.734}	{0.199,0.825}	{-0.094,0.154}
Import Price		0.705**	0.239**
Pass-Through		[0.549,0.896]	[0.169,0.326]
		{0.410,1.164}	{0.106,0.487}
Producer Price			0.551**
Pass-Through			[0.394,0.920]
			{0.232,1.962}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

Table A.3 - Long-Run Pass-Through of Shocks into U.S. Prices when Exchange Rates are Ordered First

	Import Prices	Producer Prices	Consumer Prices
Oil Price	0.123**	0.116**	0.070**
Pass-Through	[0.077,0.163]	[0.078,0.161]	[0.052,0.098]
	{0.010,0.217}	{0.032,0.224}	{0.038,0.159}
Exchange Rate	0.880**	0.695**	0.179**
Pass-Through	[0.711,1.072]	[0.546,0.890]	[0.111,0.263]
	{0.569,1.302}	{0.398,1.137}	{0.45,0.373}
Import Price		0.673**	0.333**
Pass-Through		[0.468,0.935]	[0.229,0.485]
		{0.239,1.396}	{0.139,0.929}
Producer Price			0.456**
Pass-Through			[0.339,0.650]
			{0.234,1.077}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

Table A.4 - Long-Run Pass-Through of Shocks into U.S. Prices when U.S. Output is Ordered First

	Import Prices	Producer Prices	Consumer Prices
Oil Price	0.177**	0.152**	0.059**
Pass-Through	[0.140,0.215]	[0.121,0.188]	[0.046,0.077]
	{0.109,0.266}	{0.92,0.247}	{0.035,0.107}
Exchange Rate	0.359**	0.335**	0.018
Pass-Through	[0.247,0.470]	[0.237,0.428]	[-0.025,0.058]
	{0.125,0.573}	{0.142,0.543}	{-0.075,0.101}
Import Price		0.700**	0.295**
Pass-Through		[0.536,1.891]	[0.211,0.413]
		{0.361,1.192}	{0.143,0.588}
Producer Price			0.561**
Pass-Through			[0.406,0.980]
			{0.255,2.721}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

Table A.5 - Long-Run Pass-Through of Shocks into U.S. Prices with Four Lags

	Import Prices	Producer Prices	Consumer Prices
Oil Price	0.149**	0.156**	0.060**
Pass-Through	[0.122,0.178]	[0.190,0.127]	[0.047,0.078]
	{0.088,0.209}	{0.097,0.231}	{0.037,0.110}
Exchange Rate	0.381**	0.269**	-0.005
Pass-Through	[0286,0.467]	[0.172,0.350]	[-0.047,0.032]
	{0.173,0.542}	{0.073,0.449}	{-0.102,0.071}
Import Price		0.859**	0.256**
Pass-Through		[0.722,1.029]	[0.181,0.358]
		{0.608,1.233}	{0.112,0.507}
Producer Price			0.555**
Pass-Through			[0.417,0.871]
			{0.317,1.866}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

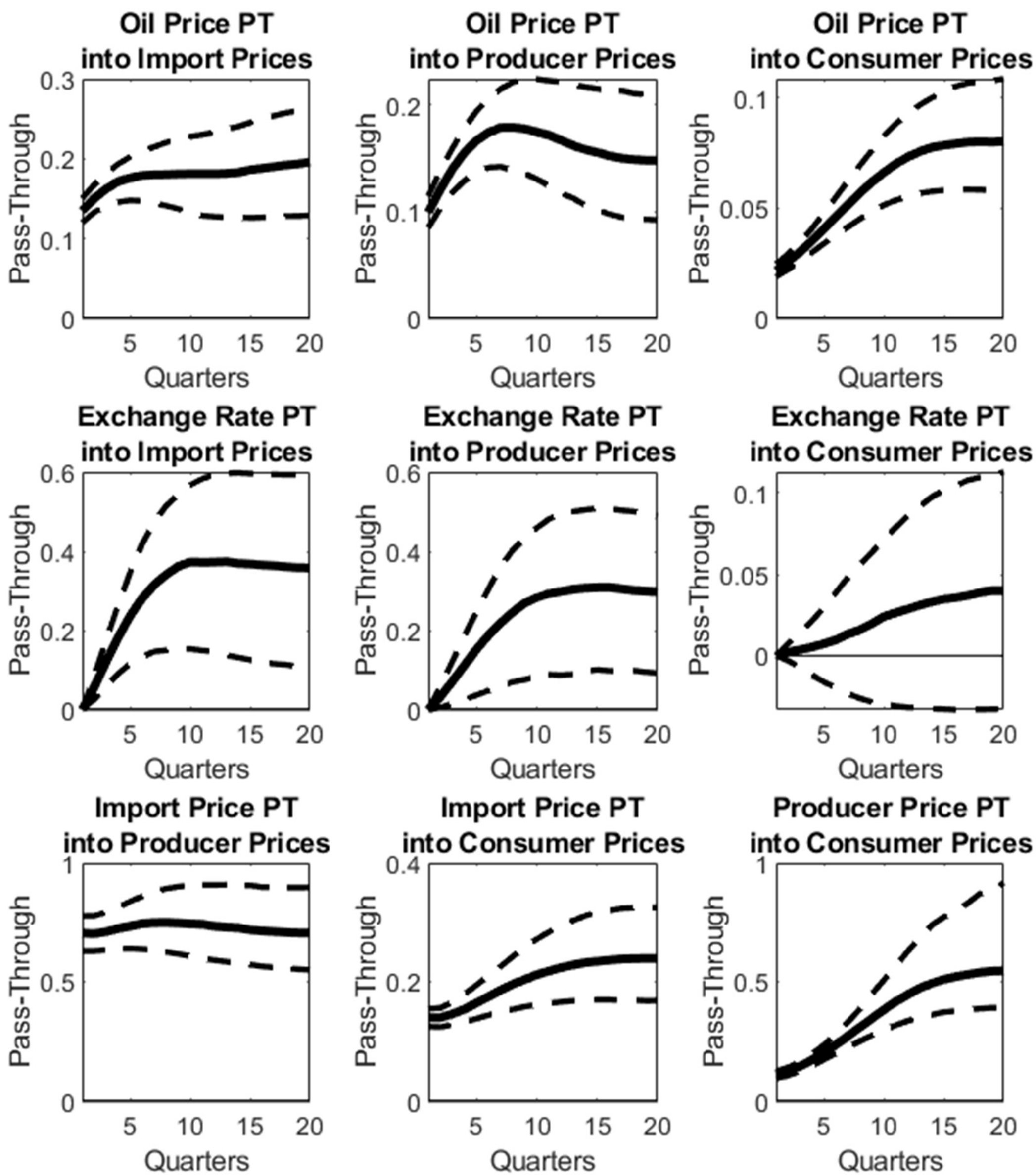
Table A.6 - Long-Run Pass-Through of Shocks into U.S. Prices with Core Prices

	Import Prices	Producer Prices	Core Prices
Oil Price	0.171**	0.171**	-0.003
Pass-Through	[0.140,0.202]	[0.138,0.207]	[-0.039,0.044]
	{0.109,0.239}	{0.103,0.260}	{-0.071,0.104}
Exchange Rate	0.195	0.210*	0.087
Pass-Through	[-0.022,0.394]	[0.024,0.398]	[-0.136,0.424]
	{-0.283,0.614}	{-0.205,0.573}	{-0.310,1.083}
Import Price		0.809**	-0.590**
Pass-Through		[0.628,1.012]	[-0.806, -0.388]
		{0.488,1.250}	{-1.064, -0.181}
Producer Price			0.640**
Pass-Through			[0.289,1.245]
			{0.014,2.787}

Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The estimates represent the median across 1,000 draws. Long-run estimates correspond to those measured after five years following a shock. Lower and upper bounds in brackets represent the 68% credible intervals, whereas * represents significance based on these intervals. Lower and upper bounds in braces represent the 95% credible intervals, whereas ** represents significance based on these intervals.

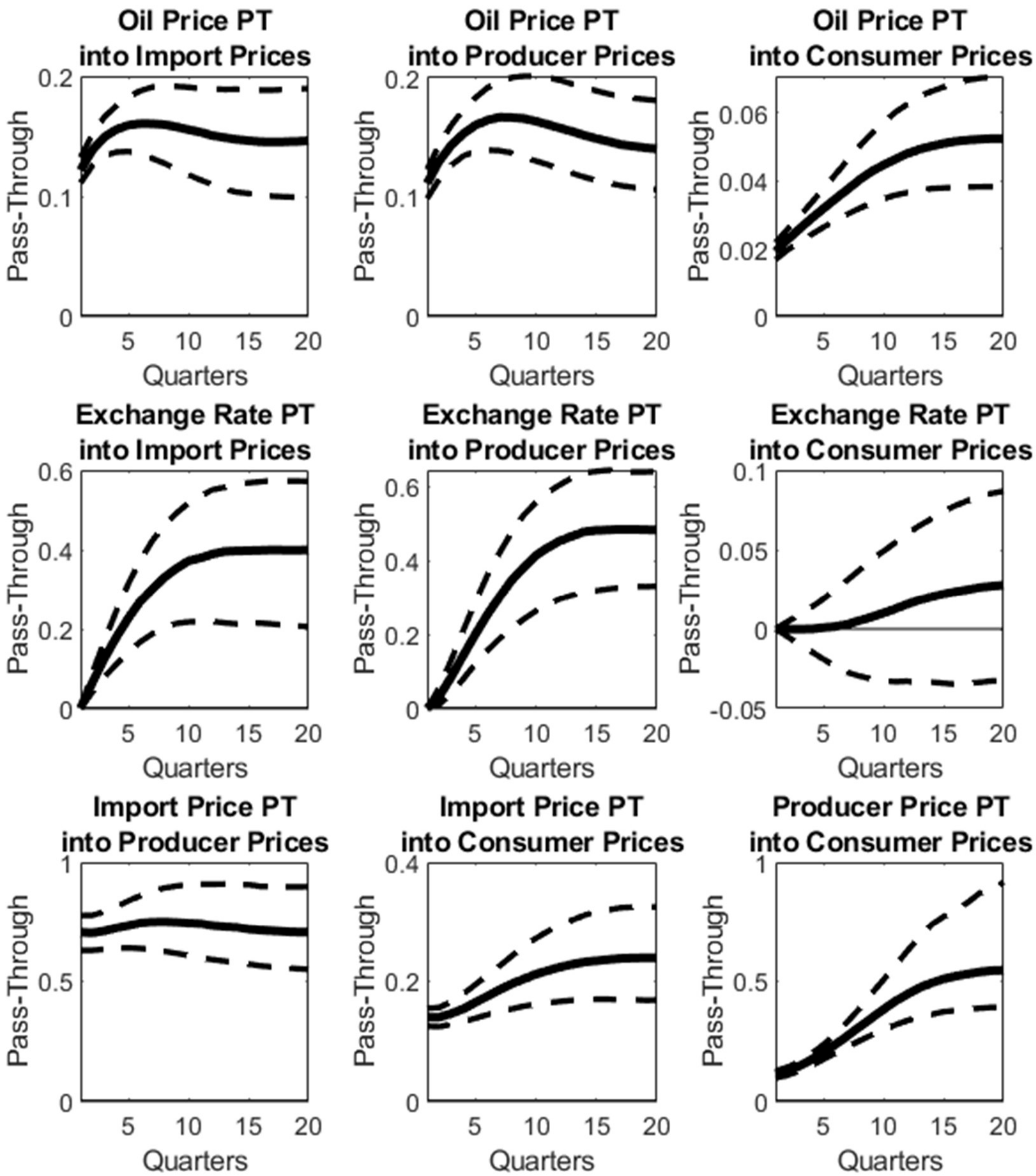
Figure A.1 - Pass-Through of Shocks into U.S. Prices with Positive Changes in Oil Prices and Exchange Rates



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

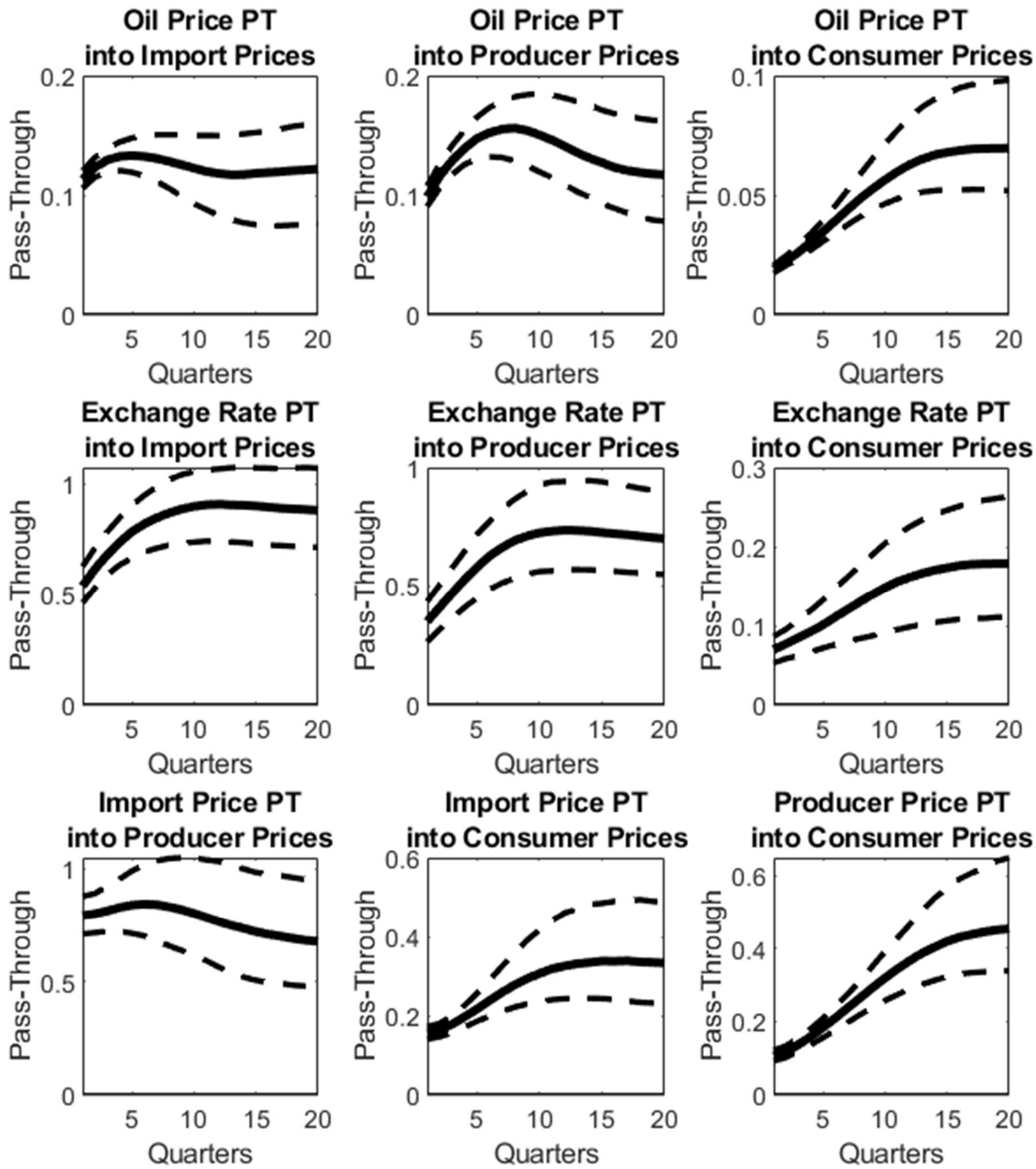
Figure A.2 - Pass-Through of Shocks into U.S. Prices with Negative Changes in Oil Prices and Exchange Rates



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

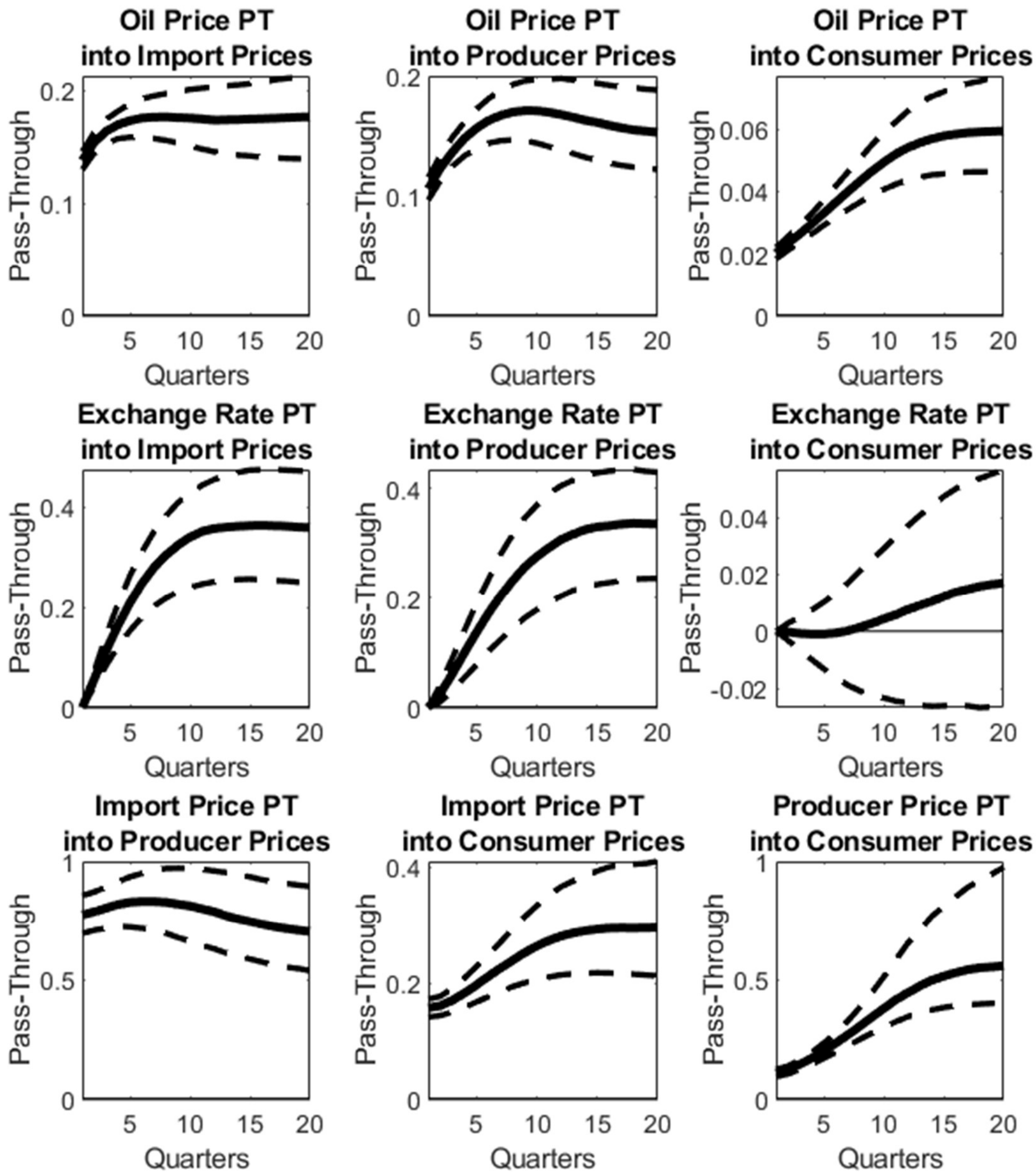
Figure A.3 - Pass-Through of Shocks into U.S. Prices when Exchange Rates are Ordered First



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

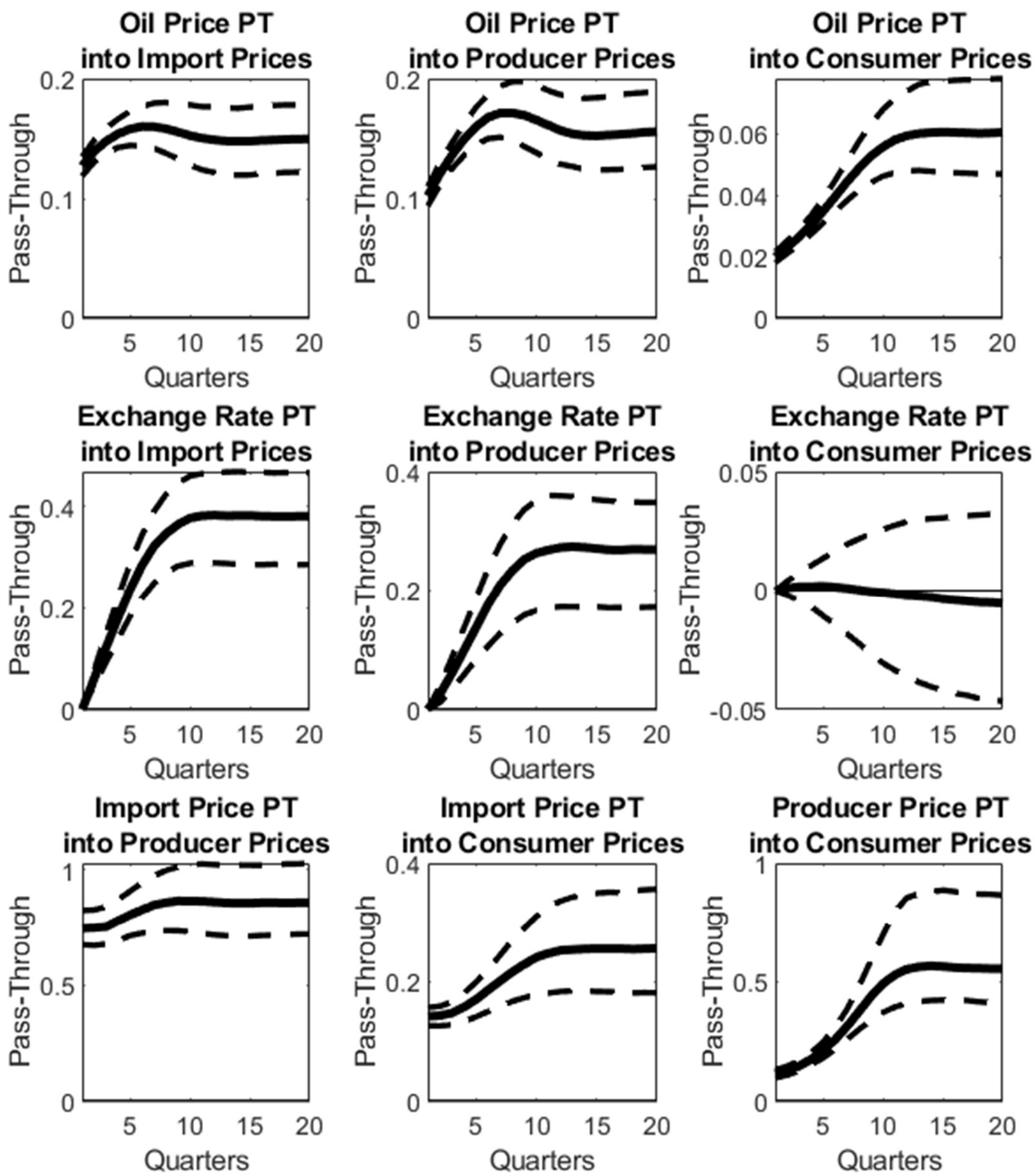
Figure A.4 - Pass-Through of Shocks into U.S. Prices when U.S. Output is Ordered First



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

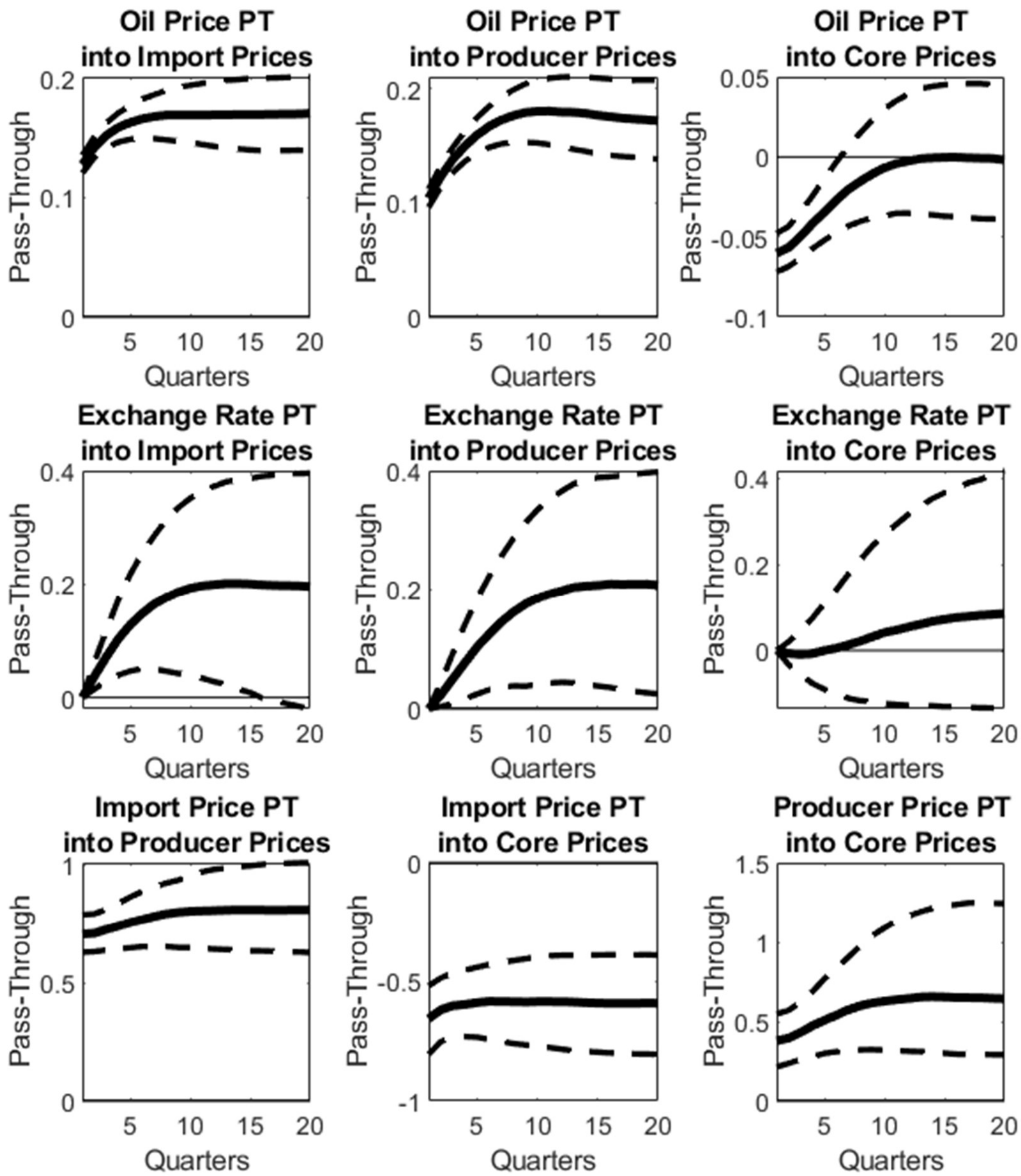
Figure A.5 - Pass-Through of Shocks into U.S. Prices with Four Lags



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

Figure A.6 - Pass-Through of Shocks into U.S. Prices with Core Prices



Source: Own calculations using data from Wu and Xia (2016) and Federal Reserve Economic Data (2023) for the quarterly period between 1994:Q1 and 2023:Q3.

Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.