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JEL Classification: E31; Q43

Key Words: Pass-Through; Oil Prices; Gasoline Prices; Consumer Prices; Weekly Data

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Abstract

Using U.S. data from Monday of each week, this paper estimates oil price pass-through into consumer prices (PC) and oil price pass-through into gasoline retail prices (PG) in a continuous way. The results show that PC (PG) is about 0.5% (13%) after a week, 1.5% (37%) after three months, and 4.2% (50%) in the long run. The estimated PC is further decomposed into direct PC (representing oil price effects on consumer prices through gasoline retail prices) versus indirect PC (representing oil price effects on consumer prices through ex-gasoline prices), suggesting that long-run oil price effects on consumer prices are mostly through ex-gasoline consumer prices. Despite having distinct pass-through estimates, about three-fourths of weekly volatility in both gasoline retail and consumer prices are explained by oil price shocks in the long run.

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1 Introduction

Optimal monetary policy depends on the accurate prediction of domestic inflation that requires consideration of international shocks in an open economy. Since oil is a basic raw material at many production levels and its price is determined in global markets, changes in oil prices constitute a big portion of such international shocks (e.g., see Chen (2009), Castro and Jiménez-Rodríguez (2017), Lòpez-Villavicencio and Pourroy (2019) or Nusair (2019)). Accordingly, policy makers are interested in measuring the effects of an oil price shock on inflation, which can be achieved by estimating the oil price pass through into consumer prices (henceforth PC).

Oil price shocks can affect consumer prices through direct and indirect channels. The direct channel (that we consider in this paper) works through gasoline retail prices, because gasoline is the form of oil that is consumed the most as a final product by consumers (about 4% of overall expenditure), and thus developments in gasoline prices are salient to consumers as suggested by studies such as by Georganas, Healy, and Li (2014), Binder (2018) or Geiger and Scharler (2019).[1] The indirect channel works through prices of products other than gasoline (i.e., ex-gasoline prices) in the consumption basket, since oil is used in the production and/or transportation of almost all products (e.g., see Meyler (2009), Álvarez, Hurtado, Sánchez, and Thomas (2011) or Akçelik and Öğünç (2016)). Within this picture, oil price pass-through into gasoline prices (henceforth PG) represents the direct channel, while oil price pass through into ex-gasoline prices (henceforth PE) represents the indirect channel, both subject to the corresponding expenditure weights in the consumption basket.

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[1] Gasoline expenditure share data have been obtained from Consumer Expenditure Survey of the U.S. Bureau of Labor Statistics for the year of 2015.

By taking into account these direct and indirect channels, this paper estimates PC and PG by using U.S. data from Monday of each week on oil, gasoline retail, and consumer prices, where the estimation is achieved by a structural vector autoregression (SVAR) model. Using data based on Monday of each week is important to capture the dynamics of the oil market, since taking averages within a month, quarter or year as in the literature may suppress valuable information on weekly dynamics. The estimation by SVAR is also essential to identify weekly oil price shocks that are independent of weekly gasoline or weekly consumer price shocks. Following studies such as by Shambaugh (2008) or Forbes, Hjortsoe, and Nenova (2018) in the context of exchange rate pass-through measures, PC (PG) is measured as the cumulative impulse response of consumer (gasoline retail) prices divided by the cumulative impulse response of oil prices, both following an oil price shock. Such a strategy not only results in having oil price pass-through estimates in a continuous way but also makes them robust to any endogeneity problem, since the response of oil prices following an oil price shock is also taken into account. When the estimated measures of PC and PG are combined with the implications of an economic model introduced in the Appendix, measures of PE are also obtained. When *pre-shock* expenditure share of gasoline for consumers w_0^g is also considered, PC is finally decomposed into *direct* oil price pass-through into consumer prices ($DPC = w_0^g \times PG$) versus *indirect* oil price pass-through into consumer prices as ($IPC = (1 - w_0^g) \times PE$).

Overall, compared to earlier studies, the methodological contributions of this paper can be listed as follows: (i) weekly *consumer* prices are used for the estimation of pass-through measures, (ii) oil price pass-through estimates are obtained in a continuous way, (iii) effects of oil prices on ex-gasoline prices (PE) are obtained by using the implications of an economic model, (iv) PC is decomposed into DPC and IPC, which results in important policy and welfare implications, and (v) estimation strategy is robust to the consideration of any endogeneity problem due to considering the response of oil prices to their own shocks.

The empirical results show that PC (PG) is about 0.5% (13%) after a week, 1.5% (37%) after three months, 3.3% (50%) after one year, and 4.2% (50%) in the long run. These estimates are consistent with several studies in the literature, including Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018) who have estimated PC as 1% after one month and 4% after one year for several countries, Lòpez-Villavicencio and Pourroy (2019) who have estimated PC as 1.3% after three months for several countries, and Meyler (2009) who have estimated PG as 53% for the euro area in the long run. While it takes about a year for PG to reach its long-run value, it takes more than two years for PC, consistent with studies such as by Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018). The main contribution of this paper comes into picture when continuous PC estimates are decomposed into those through direct channels (DPC) versus indirect channels (IPC). The corresponding results show that DPC (IPC) is about 0.5% (0%) after a week, 1.5% (0.1%) after three months, 1.8% (1.5%) after one year, and 1.9% (2.3%) in the long run.

The corresponding literature provides evidence mostly for incomplete PC. Studies such as by Hooker (2002) justify this by showing that the effects of oil prices are mostly on energy products. LeBlanc and Chinn (2004) show that oil price shocks have a modest role on headline inflation for the main global economies. De Gregorio, Landerretche, Neilson, Broda, and Rigobon (2007), together with Blanchard and Gali (2007), show evidence for decreasing oil price pass-through into consumer prices over time; Moshiri and Banihashem (2012) show that oil price shocks affect domestic inflation only in the short run. Nasir, Al-Emadi, Shahbaz, and Hammoudeh (2019) provide evidence for heterogeneity across countries regarding the effects oil prices on domestic inflation. Similarly, Gelos and Ustyugova (2017) provide evidence for commodity price shocks having stronger effects on domestic inflation of developing countries compared to advanced countries.

The literature also suggests mixed evidence for the magnitude of PC. Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018) estimate PC as 1% after one month and 4% after one year for several countries. Lòpez-Villavicencio and Pourroy (2019) estimate PC as 1.3% after three months for several countries. LeBlanc and Chinn (2004) estimate PC as 8% after one year for the U.S., whereas Chen (2009) estimate PC as 0.4% after three months and 16.9% for the U.S. in the long run. By considering oil price pass-through estimates in a continuos way and using weekly consumer-price data, this paper sheds light to this mixed evidence in the literature.

Compared to the earlier studies, the main contribution of this paper comes into picture when continuous PC estimates are decomposed into DPC versus IPC. According to the estimation results summarized above, short-run effects of oil prices on consumer prices are through gasoline prices, while their long-run effects are more through ex-gasoline consumer prices. It is implied that gasoline prices should have higher weights in the short run, whereas ex-gasoline prices should have higher weights in the long run while conducting optimal policy through forming forward-looking monetary policy reaction functions. When consumer income is fixed, PC can also be used as a measure of welfare loss following an oil price shock (e.g., see implications of an economic model in the Appendix). Accordingly, following an oil price shock, consumers lose welfare in the short run more due to the direct effects of oil price shocks on gasoline prices, while their welfare loss in the long run is more due to the indirect effects of oil price shocks on ex-gasoline consumer prices.

The rest of the paper is organized as follows. The next section introduces the data set and methodology used. Section 3 introduces the implications of the estimation methodology for oil price pass-through measures. Section 4 depicts empirical results, while Section 5 reveals oil price pass-through estimates. Section 6 concludes. The Appendix provides details of an economic model that is useful in the decomposition of PC measures into those through direct versus indirect effects of oil price shocks.

2 Data and Estimation Methodology

Our objective is to measure the effects of oil price shocks on prices that consumers face. While the effects of oil price shocks on gasoline retail prices are considered as direct effects (subject to the expenditure share of gasoline), those on overall consumer prices (including gasoline prices) are considered as total effects. These effects are measured by using implications of the SVAR model of $z_t = (\Delta o_t, \Delta g_t, \Delta p_t)'$ based on U.S. weekly data, where Δo_t is the percentage change in oil prices, Δg_t is the percentage change in gasoline retail prices, Δp_t is the percentage change in overall consumer prices.

2.1 Data Set

For weekly U.S. gasoline prices g_t, series of "Weekly U.S. All Grades All Formulations Retail Gasoline Prices (Dollars per Gallon)" obtained from U.S. Energy Information Administration (EIA) have been used. Every Monday, these weekly gasoline retail prices are collected by telephone from a sample of approximately 800 retail gasoline outlets, and they include all taxes paid by consumers at the pump. For weekly U.S. oil prices o_t, to have consistency across series, Monday data for daily series of "Cushing, OK West Texas Intermediate (WTI) Spot Price FOB (Dollars per Barrel)" have been used, which have also been obtained from EIA.

For weekly U.S. consumer prices p_t (including gasoline prices), again to have consistency across series, Monday data for daily series of "Price Index Computed by PriceStats" obtained from The Billion Prices Project Dataverse of Harvard University have been used. This daily data set has been constructed by collecting online prices on a large scale by using a technology called "web scraping." The goods entering into the calculation of the daily price index (including gasoline) have been carefully selected to represent retail transactions of consumers. Further details of the series can be found in Cavallo and Rigobon (2016), where monthly averages of the daily price index are shown to be highly correlated with the monthly U.S. consumer price index (CPI) obtained from the U.S. Bureau of Labor Statistics.

The weekly sample period between Monday, July 6th, 2008 and Monday, July 27th, 2015 has been chosen to be consistent with data availability; unfortunately, the corresponding data are not available for any other period. In the estimation, all variables are represented as demeaned annual percentage changes measured by weekly year-on-year (52-weeks) log changes that are robust to any seasonality concern by construction. The corresponding series that enter the estimation are given in Figure 1. When the series are compared in terms of their scales, annual percentage changes in gasoline prices are similar in magnitude with those in oil prices, while those in consumer prices are much lower in magnitude. As is also evident, the series are highly correlated with each other, suggesting that their volatilities over time may potentially be explained by a common shock, especially in the long run. For sure, a formal investigation is required to justify this claim, of which details are given next.

2.2 SVAR Model

The formal investigation is based on a SVAR model given by:

$$A_o z_t = a + \sum_{k=1}^{4} A_k z_{t-k} + u_t$$

where u_t is the vector of serially and mutually uncorrelated structural innovations.[2] For estimation purposes, the model is expressed in reduced form as follows:

$$z_t = b + \sum_{k=1}^{4} B_k z_{t-k} + e_t$$

where $b = A_o^{-1} a$, $B_k = A_o^{-1} A_k$ for all k, and 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 (i.e., the identification is by triangular factorization).

The recursive structure imposed on A_o^{-1} requires an ordering of the variables used in the estimation for which we use the ordering already given in z_t above. In particular, (i) oil prices that are mainly determined in the world market do not initially respond to shocks in gasoline prices or consumer prices; (ii) gasoline prices do not initially respond to shocks in consumer prices, although they respond to shocks in oil prices due to replacement costs; and (iii) consumer prices initially correspond to shocks in both oil and gasoline prices, since oil (or products produced by using it) and gasoline prices constitute a part of consumer prices.

The motivation behind ordering oil prices first comes from Kilian and Vega (2011) who have formally tested and proved that there is no immediate feedback from U.S. macroeco-

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[2] The number of lags has been determined by comparing log-10 marginal likelihood measures across alternative models. The model variables are confirmed to be stable and no root lies outside the unit circle.

nomic aggregates to innovations in energy prices, especially in high-frequency data sets (such as the weekly one used in this paper). This identification strategy is also supported by several other studies such as by Kilian (2008), Gao, Kim, and Saba (2014) and Conflitti and Luciani (2019). Ordering gasoline prices after oil prices is motivated by Bachmeier (2013) who provides evidence that oil prices do not respond contemporaneously to the shocks in the U.S. gasoline market. This identification strategy is also supported by other studies such as by Radchenko and Shapiro (2011). Ordering consumer prices after oil prices is supported by Kilian and Vega (2011), Gao, Kim, and Saba (2014) and Wong (2015), whereas ordering consumer prices after gasoline prices is supported by Kilian and Zhou (2021) who show that consumer prices respond more slowly than gasoline prices.

The estimation is achieved by a Bayesian approach with independent normal-Wishart priors. 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 that are necessary for the estimation of pass-through measures (which are introduced next) as well as the historical decompositions (HDs) and forecast error variance decompositions (FEVDs).

3 Implications for Oil Price Pass-Through

3.1 Measurement of Pass-Through

The pass-through of oil price shocks to gasoline prices are measured by PG that is defined as the ratio of the cumulative impulse of gasoline prices divided by the cumulative response of oil prices, both following a one-time oil price shock:

$$PG = \frac{\text{Cumulative Response of Gasoline Prices}}{\text{Cumulative Response of Oil Prices}} \tag{1}$$

which can be calculated for any period after the shock; hence, pass-through measures can be estimated in a continuous way. Similarly, the pass-through of oil prices to consumer prices are measured by PC that is defined as the ratio of the cumulative impulse of consumer prices divided by the cumulative response of oil prices, both following a one-time oil price shock:

$$PC = \frac{\text{Cumulative Response of Consumer Prices}}{\text{Cumulative Response of Oil Prices}} \tag{2}$$

This approach (of using ratios of cumulative responses) is similar to those in studies such as by Shambaugh (2008) or Forbes, Hjortsoe, and Nenova (2018) who estimate exchange rate pass-through by dividing the cumulative response of prices by the cumulative response of the exchange rate, both following a common shock.

3.2 Direct versus Indirect PC

As shown in details in the Appendix, by using the implications of an economic model, PC can be written as a weighted average of PG and oil price pass-through into other (ex-gasoline) consumer prices (PE) as follows:

$$PC = w_0^g \times PG + (1 - w_0^g) \times PE \tag{3}$$

where w_0^g is the *pre-shock* (initial) expenditure share of gasoline for consumers at the time of the oil price shock (i.e., $t = 0$), although it is important to emphasize that this expression already takes into account potential changes in the expenditure share of gasoline following an oil price shock as shown in the Appendix. The U.S. data on gasoline expenditure share (obtained from BLS) suggest that $w_0^g = 3.73\%$ for the year of 2015 (which is the final year in our sample, representing the *pre-shock* environment). Accordingly, PE can be calculated as follows:

$$PE = \frac{PC - w_0^g \times PG}{1 - w_0^g} \tag{4}$$

for which we already estimate PC and PG in a continuous way as introduced above.

By further defining direct oil price pass-through into consumer prices as $DPC = w_0^g \times PG$ and indirect oil price pass-through into consumer prices as $IPC = (1 - w_0^g) \times PE$, Equation 3 can be rewritten as follows:

$$PC = DPC + IPC \tag{5}$$

which decomposes PC into DPC and IPC.

4 Estimation Results

In the Bayesian estimation, the right hand sides of Equations 1, 2 and 4 are calculated for each of the 1,000 draws. While the median of each distribution is considered as the Bayesian estimator of oil price pass-through, the 16th and 84th quantiles of distributions are used to construct the 68% credible interval (which is the standard credible interval considered in the Bayesian literature).[3]

4.1 Structural Impulse Responses

The estimation of the model results in the structural impulse responses given in Figure 2. As is evident, a positive oil shock increases both gasoline and consumer prices for more than a year, whereas oil prices are not affected by gasoline price shocks. Effects of an oil price shock are much higher in magnitude for gasoline prices compared to consumer prices, suggesting a higher PG compared to PC as we discuss in details below. Finally, a positive consumer price shock has reducing effects on both gasoline and oil prices for a certain number of weeks, consistent with the effects of a negative aggregate supply shock that would increase consumer prices but reduce gasoline and oil prices due to lower demand for them.

4.2 Historical and Forecast-Error Variance Decompositions

Which shocks (among those considered in this paper) are more responsible for the weekly volatility of gasoline and consumer prices? The answer to this question, which is important for an accurate prediction of inflation, is given in Figure 3 for gasoline prices and in Figure 4 for consumer prices, where both HDs and FEVDs in percentage terms are given. According

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[3] The 90% credible intervals provide very similar results regarding the significance of pass-through estimates. Such alternative figures are available upon request.

to HD estimates, oil price shocks have historically contributed the most to both gasoline and consumer prices, consistent with studies such as by Chouinard and Perloff (2007). For example, decline in gasoline prices and consumer prices through the end of the sample period is explained the most by the decline in oil prices during the same period.

Similarly, when FEVDs are considered, the contribution of oil prices dominates others in the long run (defined as the period after which FEVDs converge to a stable value), especially after six months for gasoline prices and after one year for consumer prices. It implied that oil price shocks can be used to forecast about three-fourths of both gasoline and consumer prices in the long run, whereas they are useful to forecast up to only about one-fourth of the same variables for horizons less than a year.

Since optimal monetary policy depends on the prediction of both short-run and long-run inflation rates, it is implied that considering inflation measures independent of oil prices (e.g., core inflation) would be more useful for forecasting inflation in the short run, while consideration of oil prices would be more useful in the long run. Therefore, there is evidence for the effects of oil prices on consumer prices increasing over time, as we investigate in details next.

5 Oil Price Pass-Through Estimates

Based the impulse response functions given in Figure 2, oil price pass-through estimates are given in Table 1 as point estimates and Figure 5 as continuous estimates.

5.1 Oil Price Pass-Through into Gasoline Prices

As is evident, PG is about 13% (meaning that doubling oil prices results in about 13% of an increase in gasoline prices) only one week after an oil price shock, increasing to 24% after one month, and 37% after three months. PG has a long-run estimate of about 50% (measured after five years), which is in line with the share of oil in the retail price of gasoline (paid at the pump, according to EIA). About 26% of this long-run estimate is achieved only one week after the oil price shock, about 47% of it is achieved after one month, and about 99% of it is achieved after about a year, suggesting that the effects of oil prices are reflected in gasoline prices in a relatively small amount of time. The 68% credible intervals highly support these estimates.

These estimates are highly consistent with several studies in the literature, including Meyler (2009) who have estimated PG as 53% for the euro area in the long run; nevertheless, they deviate from studies such as by Blair, Campbell, and Mixon (2017) who have estimated PG as 75% for the U.S. in the long run.[4]

5.2 Oil Price Pass-Through into Consumer Prices

Estimates of PC are much lower, taking a value of about 0.5% (meaning that doubling oil prices results in only about 0.5% of an increase in consumer prices) one week after an oil price shock, 0.8% after one month, 1.5% after three months, and 4.2% in the long run (measured after five years). It takes more than two years for PC to reach its long-run value (consistent with studies such as by Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro

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[4] The latter difference can be attributed to Blair, Campbell, and Mixon (2017) not considering the response of oil prices to their own shocks as we achieve in Equations 1 and 2.

(2018)), suggesting that oil prices are gradually reflected in consumer prices in a slower pace compared to gasoline prices. The 68% credible intervals highly support these estimates.

These estimates are also consistent with several recent studies in the literature, including Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018) who have estimated PC as 1% after one month and 4% after one year for several countries, and Lòpez-Villavicencio and Pourroy (2019) who have estimated PC as 1.3% after three months for several countries; nevertheless, they deviate from studies such as by LeBlanc and Chinn (2004) who have estimated PC as 8% after one year for the U.S., or by Chen (2009) who have estimated PC as 0.4% after three months and 16.9% for the U.S. in the long run.[5]

5.3 Direct versus Indirect Oil Price Pass-Through into Consumer Prices

When PC is decomposed into direct effects through DPC and indirect effects through IPC, it is only DPC that contributes to PC in the short run (for about five months), while IPC is not significant during this period. Hence, short-run effects of oil prices on consumer prices are through gasoline prices. However, when long-run effects are considered, IPC estimates are about 2.3% (corresponding to about 55% of PC), while DPC estimates are about 1.9% (corresponding to about 45% of PC). Therefore, long-run effects of oil prices on consumer prices are through ex-gasoline consumer prices, for which PE estimates are about 2.4% in the long run.

When authorities would like to consider these direct and indirect effects of oil prices on future inflation to form their forward-looking monetary policy reaction function, it is implied

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[5] The latter difference can be attributed to declining pass-through measures over the years, as documented in studies such as by Chen and Wen (2011), Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018), or Lòpez-Villavicencio and Pourroy (2019).

that gasoline prices should have higher weights in the short run, whereas ex-gasoline prices should have higher weights in the long run. Moreover, according to Figure 5, such weights should be considered in a continuos way.

Since percentage changes in consumer prices can also be used as a measure of consumer welfare loss (as detailed in the Appendix), these results also have implications on welfare. In particular, following an oil price shock, consumers lose welfare in the short run due to the direct effects of oil price shocks on gasoline prices, while their welfare loss in the long run is due to the indirect effects of oil price shocks on ex-gasoline consumer prices.

6 Conclusion and Policy Implications

Oil price pass-through measures are important not only to conduct optimal monetary policy but also to evaluate welfare effects on consumers following an oil price shock. Since estimation of these pass-through measures requires the identification of oil price shocks, this paper has used an SVAR model together with U.S. data from Monday of each week on oil prices, gasoline prices, and consumer prices. The results show that PC (PG) is about 0.5% (13%) after a week, 1.5% (37%) after three months, and 4.2% (50%) in the long run. While it takes about a year for PG to reach its long-run value, it takes more than two years for PC. Despite having distinct pass-through estimates, about three-fourths of weekly volatility in both gasoline retail and consumer prices are explained by oil price shocks in the long run.

When continuous PC estimates are further decomposed into those through direct versus indirect channels, it is shown that short-run effects of oil prices on consumer prices are through gasoline prices, while their long-run effects are through ex-gasoline consumer prices. It is implied that gasoline prices should have higher weights in the short run, whereas ex-gasoline prices should have higher weights in the long run while conducting optimal policy through forming forward-looking monetary policy reaction functions. When consumer income is fixed, it is also implied that consumers lose welfare in the short run due to the direct effects of oil price shocks on gasoline prices, while their welfare loss in the long run is due to the indirect effects of oil price shocks on ex-gasoline consumer prices.

7 Appendix: Economic Model

Consumers get utility C_t out of consuming gasoline and other (ex-gasoline) products according to the following constant elasticity of substitution (CES) function:

$$C_t = \left((\beta_t)^{\frac{1}{\sigma}} \left(C_t^g \right)^{\frac{\sigma-1}{\sigma}} + (1-\beta_t)^{\frac{1}{\sigma}} \left(C_t^e \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{6}$$

where C_t^g is the utility out of consuming gasoline, C_t^e is the utility out of consuming other (ex-gasoline) products, σ is the elasticity of substitution across gasoline and ex-gasoline products, and β_t is a taste parameter. The optimization based on the budget constraint of $Y_t = G_t C_t^g + E_t C_t^e$ (with Y_t representing income, while P_t, G_t and E_t representing prices per unit of C_t, C_t^g and C_t^e) results in the following demand functions:

$$C_t^g = \beta_t \left(\frac{G_t}{P_t} \right)^{-\sigma} C_t \tag{7}$$

and

$$C_t^e = \beta_t \left(\frac{E_t}{P_t} \right)^{-\sigma} C_t \tag{8}$$

where

$$P_t \equiv \left(\beta_t \left(G_t\right)^{1-\sigma} + \left(1-\beta_t\right)\left(E_t\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{9}$$

which implies that:

$$Y_t = P_t C_t \tag{10}$$

When income Y_t is fixed, this expression suggests that log changes in consumer prices P_t can be used as a measure of consumer welfare/utility loss as follows:

$$\begin{aligned} \Delta c_t^{t+k} &= \Delta y_t^{t+k} - \Delta p_t^{t+k} \qquad (11) \\ &= -\Delta p_t^{t+k} \qquad\qquad \text{when } \Delta y_t^{t+k} = 0 \end{aligned}$$

where Δx_t^{t+k} represents log changes (i.e., percentage changes) in any variable X_t between periods t and $t+k$.

The expenditure shares of gasoline w_t^g and ex-gasoline products w_t^e are implied as follows:

$$w_t^g = \frac{G_t C_t^g}{Y_t} = \beta_t \left(\frac{G_t}{P_t}\right)^{1-\sigma} \tag{12}$$

and

$$w_t^e = \frac{E_t C_t^e}{Y_t} = \left(1-\beta_t\right)\left(\frac{E_t}{P_t}\right)^{1-\sigma} = 1 - w_t^g \tag{13}$$

We are interested in the effects of oil prices on overall consumer prices of P_t. Such effects can be measured by the elasticity of P_t with respect to oil prices O_t, which can be written as follows:

$$\begin{aligned}\frac{\partial P_t}{\partial O_t}\frac{O_t}{P_t} &= \frac{O_t}{P_t}\frac{\frac{1}{1-\sigma}\left(\beta_t\left(G_t\right)^{1-\sigma}+\left(1-\beta_t\right)\left(E_t\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}{\left(\beta_t\left(G_t\right)^{1-\sigma}+\left(1-\beta_t\right)\left(E_t\right)^{1-\sigma}\right)} \\ &\times\left(\frac{(1-\sigma)}{G_t}\beta_t\left(G_t\right)^{1-\sigma}\left(\frac{\partial G_t}{\partial O_t}\right)+\frac{(1-\sigma)}{E_t}\left(1-\beta\right)\left(E_t\right)^{1-\sigma}\left(\frac{\partial E_t}{\partial O_t}\right)\right)\end{aligned} \tag{14}$$

which can be simplified as follows:

$$\frac{\partial P_t}{\partial O_t}\frac{O_t}{P_t}=\frac{\beta_t\left(G_t\right)^{1-\sigma}\left(\frac{\partial G_t}{\partial O_t}\frac{O_t}{G_t}\right)+\left(1-\beta_t\right)\left(E_t\right)^{1-\sigma}\left(\frac{\partial E_t}{\partial O_t}\frac{O_t}{E_t}\right)}{\beta_g\left(P_g\right)^{1-\sigma}+\beta_e\left(P_e\right)^{1-\sigma}} \tag{15}$$

Using Equations 12 and 13, this can be rewritten as follows:

$$\frac{\partial P_t}{\partial O_t}\frac{O_t}{P_t}=w_t^g\left(\frac{\partial G_t}{\partial O_t}\frac{O_t}{G_t}\right)+\left(1-w_t^g\right)\left(\frac{\partial E_t}{\partial O_t}\frac{O_t}{E_t}\right) \tag{16}$$

where w_t^g corresponds to pre-shock (initial) gasoline expenditure weight. In terms of log changes, this expression can further be written as follows:

$$\frac{\Delta p_t^{t+k}}{\Delta o_t^{t+k}}=w_t^g\frac{\Delta g_t^{t+k}}{\Delta o_t^{t+k}}+\left(1-w_t^g\right)\frac{\Delta e_t^{t+k}}{\Delta o_t^{t+k}} \tag{17}$$

where Δx_t^{t+k} again represents log changes (i.e., percentage changes) in any variable X_t between periods t and $t+k$. When these changes are measured in a cumulative way as in Equations 1 and 2 following an oil price shock at time $t=0$, we can write the same expression in terms of oil price pass-through measures as follows:

$$PC=w_0^g\times PG+\left(1-w_0^g\right)\times PE \tag{18}$$

where $PC = \frac{\Delta p_0^k}{\Delta o_0^k}$ is the oil price pass-through into consumer prices, w_0^g is the pre-shock (initial) gasoline expenditure weight (at $t = 0$), $PG = \frac{\Delta g_0^k}{\Delta o_0^k}$ is the oil price pass-through into gasoline prices, and $PE = \frac{\Delta e_0^k}{\Delta o_0^k}$ is the oil price pass-through into ex-gasoline prices.

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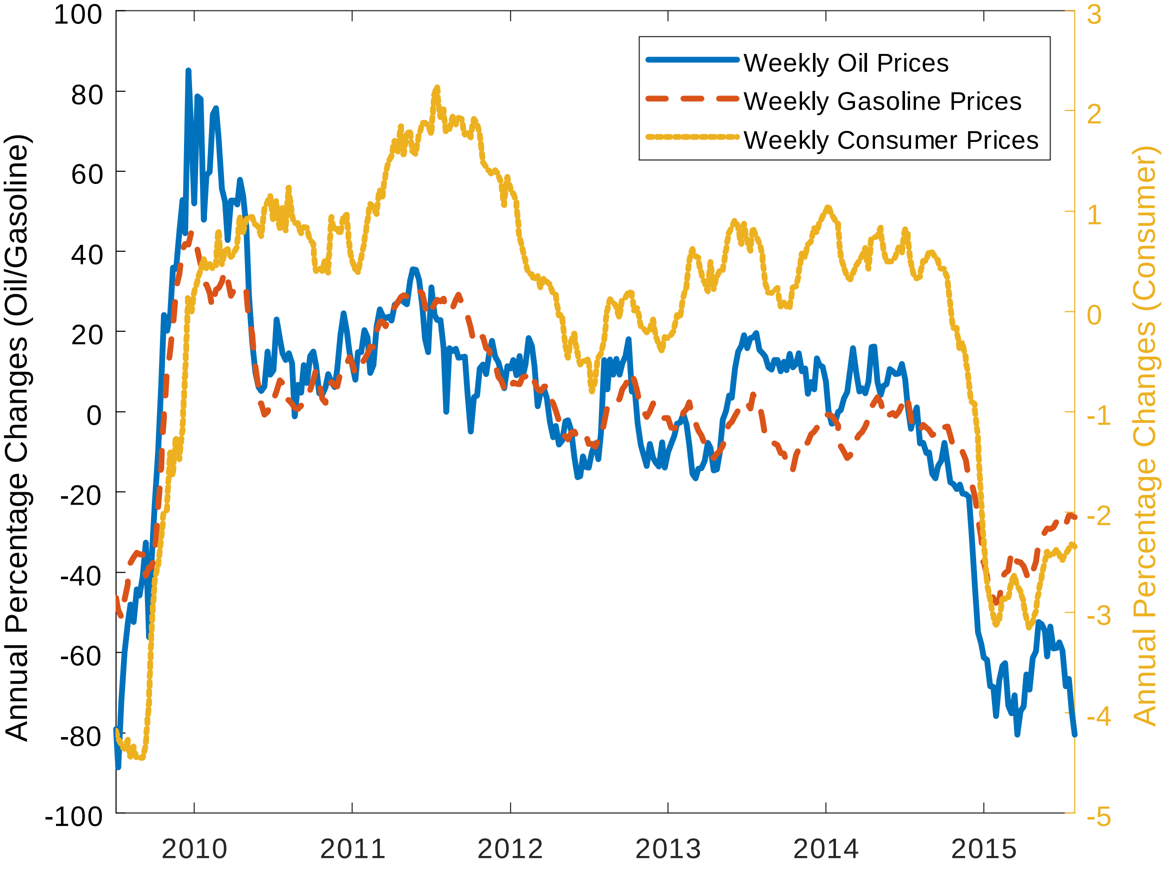
Table 1 - Oil Price Pass-Through Estimates (%)

	1 Week	1 Month	3 Months	1 Year	5 Years
PG	13.04	23.64	37.49	49.57	50.00
	$[11.29, 14.83]$	$[21.20, 26.16]$	$[34.16, 40.92]$	$[44.53, 54.46]$	$[43.94, 55.75]$
PC	0.48	0.80	1.48	3.32	4.19
	$[0.33, 0.62]$	$[0.61, 0.97]$	$[1.22, 1.74]$	$[2.77, 3.88]$	$[3.51, 4.90]$
DPC	0.49	0.88	1.40	1.85	1.86
	$[0.42, 0.55]$	$[0.79, 0.98]$	$[1.27, 1.53]$	$[1.66, 2.03]$	$[1.64, 2.08]$
IPC	-0.01	-0.09	0.08	1.47	2.32
	$[-0.16, 0.14]$	$[-0.27, 0.09]$	$[-0.16, 0.33]$	$[0.95, 2.02]$	$[1.68, 3.02]$
PE	-0.01	-0.10	0.08	1.52	2.42
	$[-0.17, 0.15]$	$[-0.28, 0.09]$	$[-0.17, 0.34]$	$[0.99, 2.10]$	$[1.74, 3.13]$

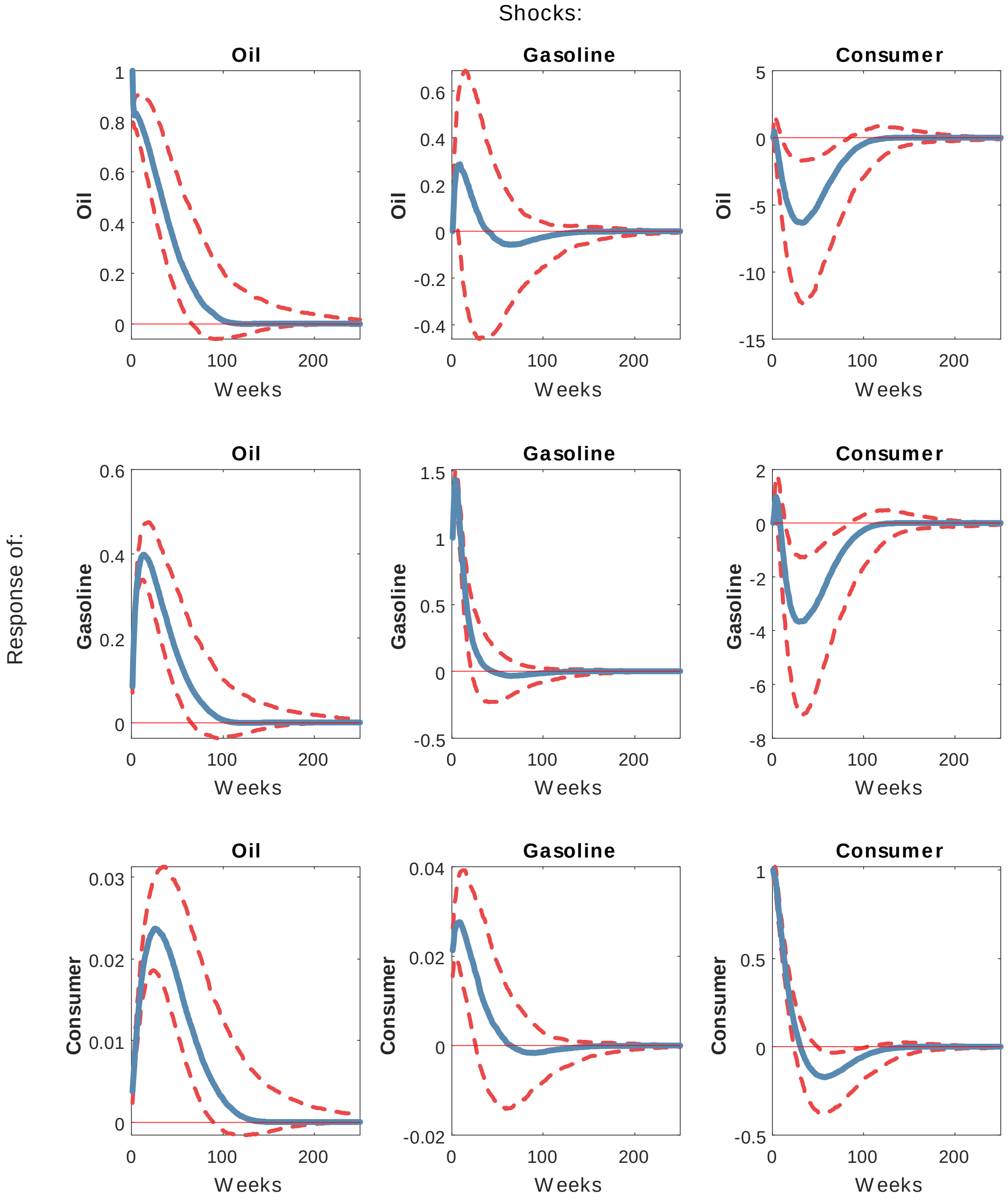
Notes: PG is the oil price pass-through into gasoline prices, PC is the oil price pass-through into consumer prices, DPC is the direct oil price pass-through into consumer prices, IPC is the indirect oil price pass-through into consumer prices, PE is the oil price pass-through into ex-gasoline consumer prices. The estimates represent the median across 1,000 draws. Lower and upper bounds in brackets represent the 68% credible intervals.

Figure 1 - Percentage Changes in Weekly Oil, Gasoline and Consumer Prices



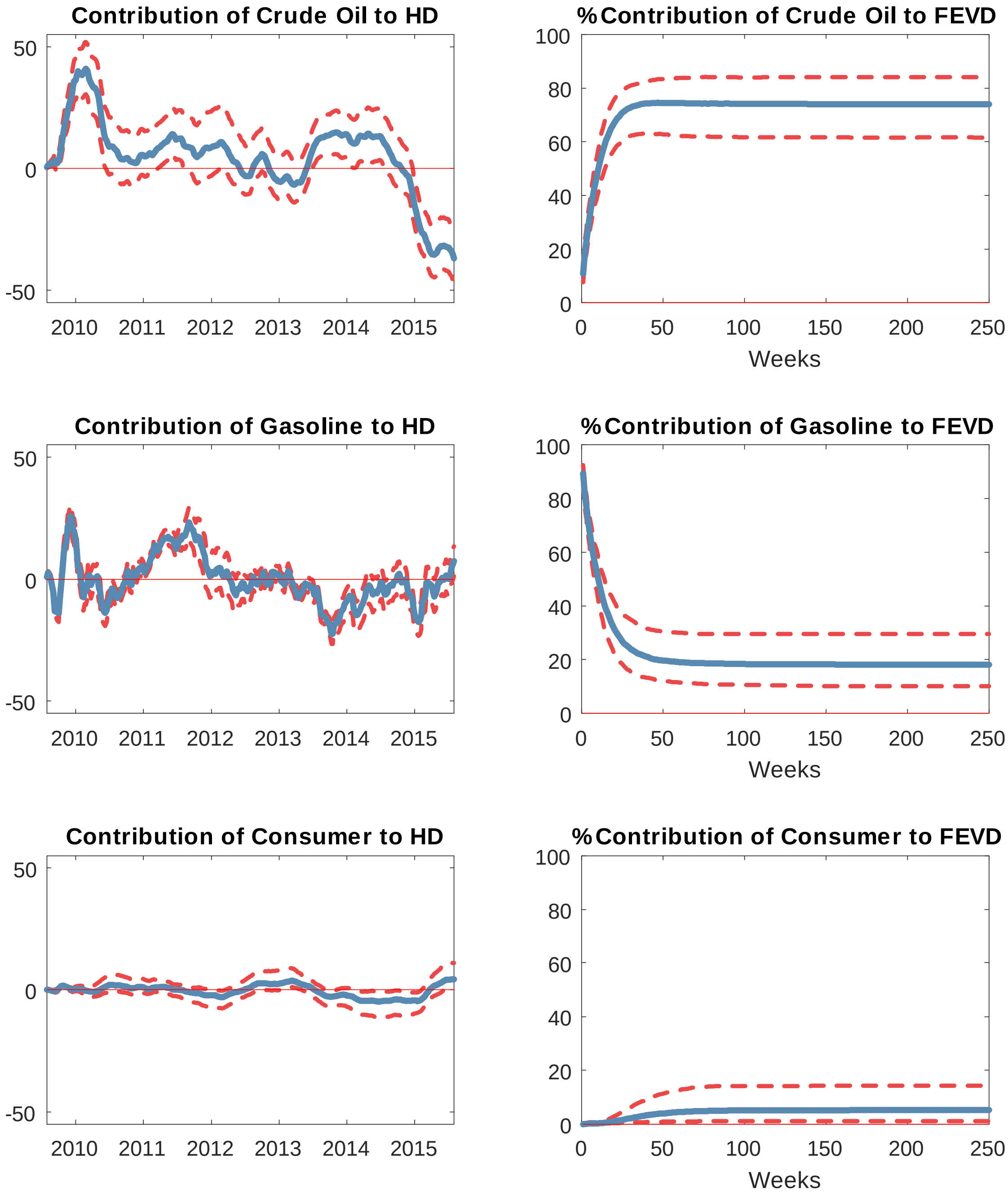
Notes: Oil and gasoline prices are represented by the left vertical axis, while consumer prices are represented by the right vertical axis.

Figure 2 - Structural Impulse Responses



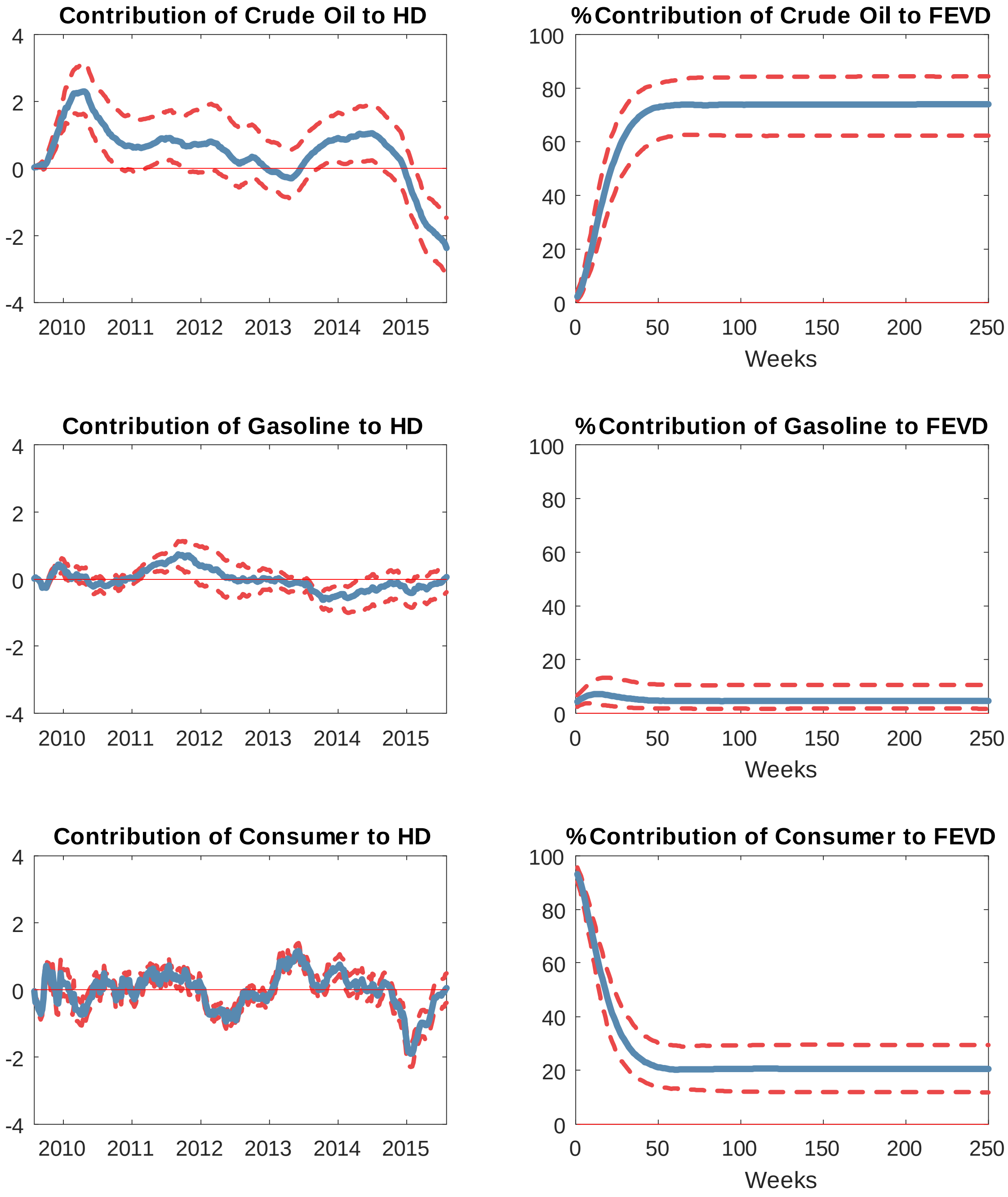
Notes: The solid lines represent the estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

Figure 3 - Decomposition of Gasoline Prices



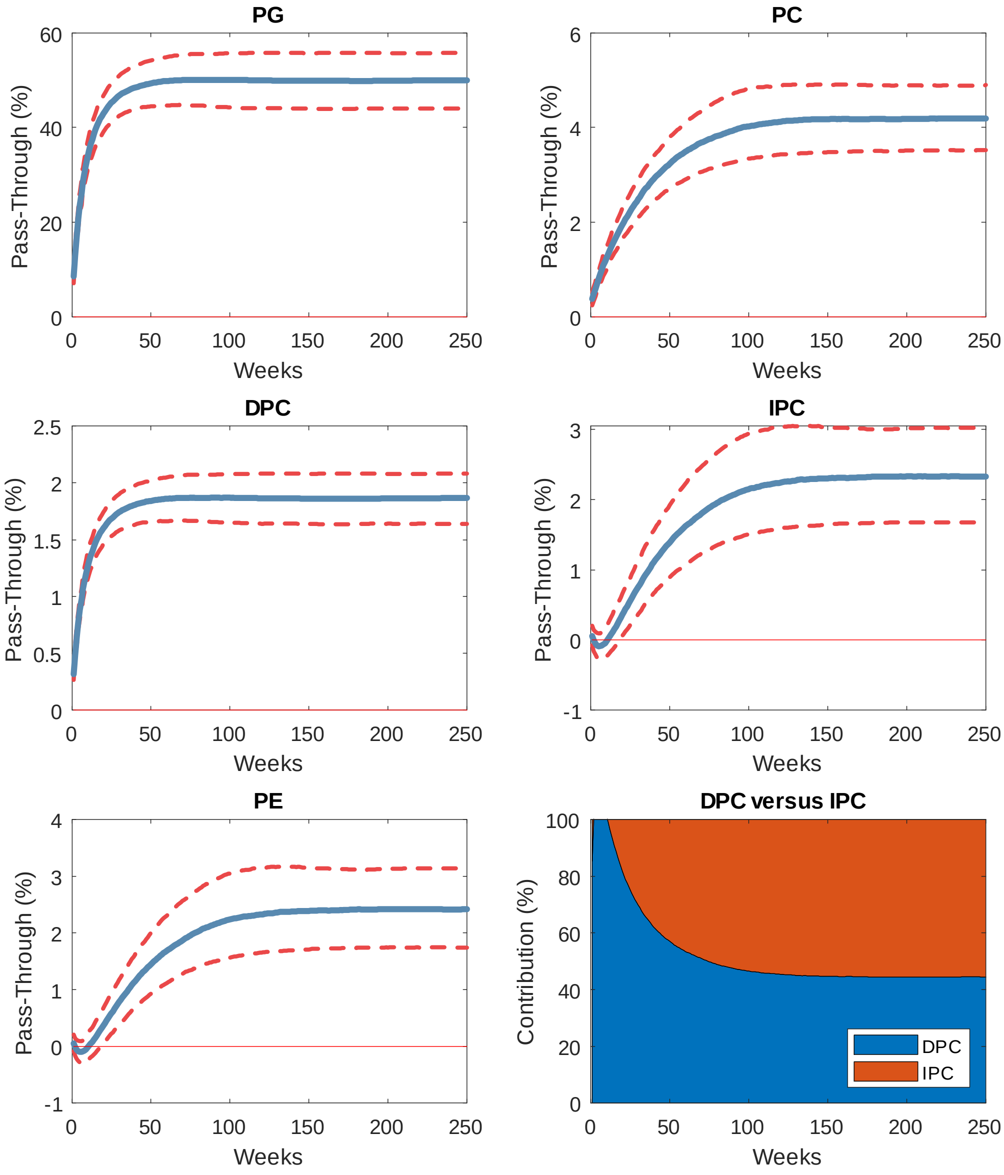
Notes: The solid lines represent the pass-through estimates, while dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.

Figure 4 - Decomposition of Consumer Prices



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

Figure 5 - Oil Price Pass-Through Estimates



Notes: PG is the oil price pass-through into gasoline prices, PC is the oil price pass-through into consumer prices, DPC is the direct oil price pass-through into consumer prices, IPC is the indirect oil price pass-through into consumer prices, PE is the oil price pass-through into ex-gasoline consumer prices. The solid lines represent the estimates. Dashed lines represent lower and upper bounds that correspond to the 68% credible intervals.